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#PL1

OPPORTUNITIES AND CHALLENGES IN MAGNETIZED LINER INERTIAL FUSION

KEYNOTE SPEAKER

AMPLEFORD David

Sandia National Laboratories, Albuquerque, USA

ABSTRACT

Magnetized Liner Inertial Fusion (MagLIF) provides a promising path to multi-MJ fusion yields in the laboratory. MagLIF is a magneto-inertial fusion scheme that relies on magnetic field coils to pre-magnetize a fusion fuel, a high-power laser pulse to pre-heat the fuel, and a pulsed-power driven current to compress the pre-conditioned fuel to reach fusion conditions. In recent years MagLIF has been the principal pulsed-power driven fusion scheme investigated on the 26-MA Z-Machine at Sandia National Laboratories. While the Z machine does not provide sufficient current to achieve multi-MJ yields, it allows us to test the key attributes of magneto-inertial fusion, and to address many of the risks associated with scaling to future machines. In this talk we will review recent progress on MagLIF. We will discuss how focused physics experiments, along with improved diagnostics and magneto-hydrodynamic simulations, have led to advanced understanding of preheat, implosion stability, and stagnation conditions in MagLIF. We describe how this improved understanding, along with recent improvements in available laser coupling, current coupling and magnetic field coils, have led to record fusion yields from MagLIF. Finally, we will outline scaling arguments used to define the applied field, laser preheat, and pulsed power driver required to achieve MJ yields.

SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525

#PL2

PULSED POWER AND ELECTROMAGNETIC LAUNCH DEVELOPMENTS AT FIRST LIGHT FUSION: AN OVERVIEW

KEYNOTE SPEAKER

CABALLERO BENDIXSEN Luis Sebastian

First Light Fusion, Oxford, United Kingdom

ABSTRACT

First Light Fusion Ltd is a privately funded company researching energy generation using inertial confinement fusion. Efforts are centered around developing both simulation and experimental capabilities. For this, First Light Fusion (FLF) currently operates a pair of two-stage light gas guns with projectile velocities exceeding 7 km/s. Our electromagnetic launch capabilities include two low inductance capacitor bank pulsed power generators delivering 3.5 MA in 600 ns and 14 MA in 2 us. Experimental campaigns are focused on validation of Hytrac (multi-material hydro with front tracking and AMR) and B (parallel multi-material resistive MHD) codes, two simulation tools developed by FLF. This improves our understanding of target physics and electro-magnetic launch for projectile driven fusion experiments. Supporting our experimental facilities, world class diagnostic capabilities have been established at FLF. These include ultra-high-speed (~ 3 ns exposure) and streaked optical imaging, spectroscopy, VISAR and x-ray radiography. Rapid feedback enables iteration within experimental campaigns and continuous improvement of the designs

During this talk an overview of the pulsed power capabilities that FLF has developed over the last 5 years will be presented, with emphasis on the design and development of M3 (14 MA in 2 us). This driver was commissioned at the end of 2018 with science experiments starting January 2019. It was designed primarily as an electromagnetic launch driver and has delivered measured projectile velocities around 12 km/s, with impact timing analysis suggesting speeds approaching 20 km/s. Plate flyer experiments will be discussed in detail showing FLF electromagnetic launch capabilities, diagnostic suite, and analysis.

#PL3

THE LASER MÉGAJOULE (LMJ) FACILITY STATUS

KEYNOTE SPEAKER

CAILLAUD Tony

(1) CEA/DAM Centre du CESTA, Le Barp, France

ABSTRACT

The Laser MégaJoule (LMJ) program ([1], [2]) aims at providing an experimental facility dedicated to the simulation program that is a keystone to guarantee the French nuclear deterrence. As advanced physics data and models are used to compute numerical simulation, the LMJ offers unique capabilities for the simulation program in High Energy Density Physics (HEDP) by validating the advanced theoretical models, the basic science (by determination of equation of state, atomic and nuclear physics). A large panel of experiments can be done on LMJ to study physical processes at temperatures from 100 eV to 100 keV, and pressures from 1 Mbar to 100 Gbar. Inertial Confinement Fusion (ICF) is also an exciting challenge, since ICF experiments set the most stringent specifications on LMJ's features. The LMJ building is a huge monument of 300 m length, 150 m width and 40 m height, composed of 4 laser bays containing 5 or 7 laser bundles each (1 bundle is 8 beams). The laser pulses duration go from 0.7 ns to 25 ns. At the end, 176 beams will be available to heat the millimetric targets. The whole laser energy will be about 1.5 MJ (UV light on target). At the building center, a large cylindrical target bay of 30 m diameter contains a 10 m diameter target chamber made of 10 cm thick aluminum covered with 40 cm thick borated concrete. Around the target chamber, a complete set of equipment allows target positioning, laser-matter interaction characterization, and laser focusing on target. An extra multi-PW beam, PETAL [3], coupled to LMJ, offers the opportunity to study matter in extreme conditions. We will introduce and describe the LMJ-PETAL facility status and provide the necessary technical performances consistently with the theoretical models constraints. We will also explain how this program relies on and feeds the industrial network from the Nouvelle Aquitaine area.

[1] A. Michel, "The French megajoule laser project (LMJ)," Fusion Engineering and Design 44 (1), 43-49 (1999).
[2] C. Lion, "The LMJ program: an overview," Journal of Physics 244 (1), 012003 (2010).
[3] N. Blanchot et al, Plasma Phys. Control. Fusion 50, 124045 (2008).

#PL4

PRIMARY IMPACTS OF PULSED ELECTRIC FIELDS ON ORGANISMS AND THEIR INDUSTRIAL APPLICATIONS

KEYNOTE SPEAKER

KATSUKI Sunao

Kumamoto University, Kumamoto, Japan

ABSTRACT

Pulsed electric field (PEF) primarily impacts phospholipid membranes which are regarded as dielectric films, and giant biomolecules such as nucleic acids and proteins which have electrical charge distribution in them. PEF accumulates electrical charges on the membrane in a conductive liquid so that the trans-membrane field is enhanced to the order of 1 MV/cm. Such an extremely large field breaks down and permeabilizes the membrane. After that the transport of ions and bio molecules take places through the permeabilized membrane. We have been investigating the morphological and functional changes of membrane exposed to PEFs and the subsequent transmembrane ion transport using various kinds of cells including mammalian cells, plant cells, bacteria and artificial cells. Also, an extremely large PEF causes intra- and inter-molecular stresses in giant biomolecules, which eventually result in their structural and functional changes. Membrane proteins, which interface intracellular to extracellular regions, are exposed to such an extremely large field exceeding 1 MV/cm during the exposure to even relatively low PEF. We have demonstrated that the structural and functional changes of several kinds of proteins and their aggregation using the 1 ns, 1.5 MV/cm PEF exposure chamber. These primary impacts of PEF have been widely applied for scientific and industrial fields including biotechnology, medical treatment, food processing, biorefinery, environment, etc. and discussed the further possibility.

This paper overviews the primary impacts of PEF and describes several attractive applications based on our study.

#O1-1

NEW APPROACH FOR AN ELECTROMAGNETICALLY DRIVEN ACTIVE ARMOUR SYSTEM

KEYNOTE SPEAKER

PINGUET Sylvain [1], SPAHN Emil [1], NUSSBAUMER Thomas [2], LOEFFLER Jan-Markus [3]

[1] PPS AG, Wallbach, Switzerland
[2] RUAG AG, Zweisimmen, Switzerland
[3] Loeffler Consulting, Coesfeld, Germany

ABSTRACT

For protecting objects, like infrastructure and vehicles, against incoming threats, active armour systems are well suited. In particular, electromagnetically launched systems distinguish themselves by rapid reaction times and an excellent acceleration of the payload.

The approach presented in the paper allows to control the direction of the payload. For realizing that, several inductive coil launchers are used and supplied by independent power sources. To control the direction of the payload the launchers are precisely provided with different amounts of electrical energy. For enabling that, pulsed power supplies have been developed and adapted to the load.

The paper describes the principle of the active armour system as well as the topology and the set-up of the power supply. For switching purposes only solid-state switches are used to ensure a high reliability and a good lifetime of the system. In a further step first experiments of the complete active armour system are presented. They show the direction controllability of the payload launch. In comparison to a conventional system, it has been demonstrated that the system has exceptionally low reaction times. So, countering of threats like shaped charges is feasible in real time

#O1-2

RAILGUN TESTS AT ASELSAN ELECTROMAGNETIC LAUNCH LABORATORY

KEYNOTE SPEAKER

KARAGOZ Mustafa[(1)], CIVIL Anil[(1)], ORUC Ahmet[(1)], BOLAT Bora[(1)], YILDIRIM Baran[(1)], YURDAKUL Burak[(1)], HIZIR Erinc[(1)], TAN Evren[(1)], YURDAKONAR Ferhat[(1)], OZTURK Gokhan[(1)], AKDEMIR Huseyin[(1)], DEMIRKOL Hakan[(1)], GUNGEN Ibrahim[(1)], ONUR Ibrahim[(1)], OZCEYLAN Mert[(1)], CAVBOZAR Ozgur[(1)], GOCMEN Ulas[(1)]

[(1)] ASELSAN Inc., ANKARA, Turkey

ABSTRACT

ASELSAN Inc. has been conducting experimental research on electromagnetic launchers since 2014. First generation 1 MJ and second generation 3.25 MJ Pulsed Power Supplies were built and tested with 25 mm x 25 mm square bore EMFY-1 electromagnetic launcher at open area test range. In 2018, ASELSAN constructed a laboratory to accelerate EML activities in Ankara. The first shot at the laboratory was with EMFY-2 electromagnetic launcher which has a 50 mm x 50 mm square bore and 3 m length. In this paper, results of the further experiments with EMFY-2 Electromagnetic Launcher and experiments with new EMFY-3 electromagnetic launcher are presented. EMFY-3 which is fed by 8 MJ Pulsed Power Supply, has a 50 mm x 75 mm rectangular bore and 6 m length. High speed cameras and flash x-ray system are used for projectile monitoring during experiments. Furthermore, a Doppler radar system and b-dot magnetic sensors are used for projectile in bore velocity measurement.

#O1-3

ADVANTAGES OF NANOSECOND PULSED POWER DRIVEN STREAMER PLASMA

KEYNOTE SPEAKER

PEMEN A.J.M., HUISKAMP T., HOEBEN W.F.L.M.

Eindhoven University of Technology, Eindhoven, Netherlands

ABSTRACT

Plasmas exhibit properties that make them useful in a wide range of applications, such as plasma medicine, future fuels, plasma agriculture and environmental applications. Within this large area, pulsed-power driven, streamers perform much better in energy efficiency and processing performance, and this paper provides an overview of the developments in this field in Eindhoven.
Rapid progress is being made in the field of nanosecond pulsed-power techniques, fast and heavy duty solid state switches, electrical diagnostics, multiscale modelling, optical and laser-based diagnostics and chemical characterization of streamers. Considerable progress has been made in pulsed-power levels for industrial applications. Detailed research on the electrical and chemical processes in pulsed-power driven transient plasmas resulted in a boost of efficiencies. Electrical efficiency was raised to above 90 %. Simultaneous improvement of plasma chemistry resulted in record high processing yields for plasma driven processes as ozone production and the abatement of nitrogen oxides.
The following examples will be discussed: processing of gas flows (pollution control), and plasma agriculture (e.g. plasma based nitrogen fixation, and plasma as a sustainable alternative for pesticides in horticulture).

#O1-4

MUZZLE VOLTAGE CHARACTERISTICS OF RAILGUNS

KEYNOTE SPEAKER

TOSUN Nail[(1)], KARAGÖZ Mustafa[(2)], YURDAKONAR Ferhat[(2)], GÜLLETUTAN Görkem[(1)], KEYSAN Ozan[(1)]

[(1)] Middle East Technical University, Ankara, Turkey
[(2)] ASELSAN, Ankara, Turkey

ABSTRACT

Muzzle voltage is an essential diagnostic tool used in both contact resistance modeling and transition determination. However, it is challenging to stem the necessary meanings from the collected measurements. In this study, EMFY-3 launch experiments are used to model muzzle voltage characteristics to understand the transition mechanism better. These experiments have muzzle energies in the range between 1.69-2.85 MJ in ASELSAN Electromagnetic Launcher Laboratory. Six different launch tests with various rail current waveforms that ranged between 1.5-2.1 MA are used to investigate different scenarios. Some parameters which affect muzzle voltage are calculated with the 3-D Finite Element Method (FEM), i.e. rail mutual inductance (). Muzzle voltages are decomposed into subsections; each subsection is calculated with proper models. Simulation results are coherent with experimental measurements. Findings are compared with previous studies, and differences are explained with possible reasons. Even though we could not conclusively resolve which physical quantity starts to transition, the study showed that transition does not start a specific muzzle velocity, armature action integral, or down-slope rail current ratio.

#O1-5

EFFECTS OF RESIDUAL SPACE CHARGES ON PROGRESSIVE STREAMER-TO-LEADER TRANSITION IN N2-SF6 MIXTURES UNDER POSITIVE AND NEGATIVE REPETITIVE NANOSECOND PULSES

KEYNOTE SPEAKER

ZHAO Zheng, DAI Zhifeng, SUN Anbang, LI Jiangtao

School of Electrical Engineering, Xi'an, China

ABSTRACT

Nanosecond repetitively pulsed power technologies have enabled many unique low-temperature plasma applications. Plasma reactivity is enhanced by the high amplitude and high frequency voltage pulses, which, nevertheless, impose significant difficulties to the insulation design of pulse generator. It has been demonstrated that the gas gap insulation strength nonlinearly decreases with increasing the voltage amplitude and pulse repetition frequency (PRF). Electronegative gases, such as SF_6, can increase the insulation strength by capturing free electrons and retarding channel propagation. The electron detachment under following voltage pulses and the spatial electric field distortion by residual heavy space charges are critical, however, largely unclear before the repetitively pulsed breakdown formation. This paper focuses on effects of residual space charges on a new progressive streamer-to-leader transition phenomenon in N_2-SF_6 mixtures under repetitive nanosecond pulses. A clear saturation tendency of the number of applied pulses before breakdown appeared with increasing PRF. Higher concentration of SF_6 was beneficial for improving the insulation strength under repetitive pulses. Discharge channel evolutions when SF_6 was introduced were totally different from those in pure N_2. Multi-peak structure of light intensity around the needle tip was observed with 1% SF_6. It was preliminarily inferred that a streamer (under the first voltage pulse)-to-leader (under following voltage pulses) transition occurred in a repetitive pulse train. Discharge mechanism transition was explained based on residual charge relaxation behavior and its effect on the spatial electric field distribution. A further understanding of repetitively pulsed gas breakdown mechanism could be obtained.

#O1-6

DEVELOPMENT OF A LOW VOLTAGE RAILGUN IN THE CONTEXT OF LIGHTNING RESTRIKE

KEYNOTE SPEAKER

ANDRAUD Vincent [1], SOUSA-MARTINS Rafael [1], ZAEPFFEL Clément [1], TESTE Philippe [2], LANDFRIED Romaric [2]

[1] DPHY, ONERA, Université Paris-Saclay, F-91123 Palaiseau, France
[2] Geeps, CentraleSupelec, 91190 Gif-Sur-Yvette, France

ABSTRACT

In the context of lightning strikes to aircraft, there is a relative motion between the static lightning channel and the airplane that flights at velocities faster than 100 m/s. Thus, the attachment point is displacing through the fuselage and is able to impact any part of the aircraft. The complex physical phenomenon that drives this displacement remains a high challenge for computational simulations, mainly because there is a lack of reliable experimental measurements.

To accurately reproduce this experiment in a laboratory and then obtain physical measurements based on reliable diagnostics, a low voltage Railgun is designed and realized. It aims to propel aeronautical material plates of few hundreds of grams up to 100 m/s within 2 meters, performing an acceleration of a hundred of g's before being hit by a lightning electric arc produced from an electric current generator.

Whereas common Railgun applications operate at thousands of Volts to provide current intensities up to the mega Amperes during a few milliseconds to reach thousands of g's of acceleration, the designed Railgun operates under 30 V for safety reasons and to smooth the acceleration profile. A maximum current of 25 kA is reached thanks to the use of a supercapacitor bank made of 144 supercapacitors for a total equivalent capacitance of 3000 F. The speed of the railgun is enhanced by Neodymium NdFeB magnets providing augmented magnetic field. As the gliding contact is the main problem in this kind of application since a bad electric contact might prevent the generator to provide power to the projectile, different configurations of projectile are tested as well as its geometry and its material.

#O2-1

REAL TIME AND POLARIMETRIC ANALYSIS OF INTENSE ELECTRIC FIELD USING ELECTRO-OPTIC PROBE

KEYNOTE SPEAKER

ALJAMMAL Farah[(1)], GABORIT Gwenael[(1,2)], BERNIER Maxime[(1)], ISENI Sylvain[(3)], REVILLOD Guillaume[(2)], DUVILLARET Lionel[(2)]

[(1)] IMEP-LAHC, Le Bourget-du-Lac, France
[(2)] Kapteos, St Hélène-du-Lac, France
[(3)] GREMI, Orléans, France

ABSTRACT

We present herein our latest results concerning the comprehensive characterization of the electric (E) field vector obtained thanks to high performances electro-optic (EO) technique. The EO probe, ensuring the absolute measurement of the E field, consists in a millimetre sized optical arrangement and involves only dielectric material. The disturbance of the field to be measured is thus minimized. This sensor is pigtailed and is linked to an optoelectronic unit delivering an analog electric signal directly proportional to one component of the E-field vector. The specifications of the whole setup are as follows:

- dynamic range greater than 120 dB, spreading from lower than 0.05 V/m up to more than 1 MV/m,
- frequency bandwidth covering instantaneously more than 9 decades up to > 60 GHz,
- rejection of the unwanted component of the field vector higher than 50 dB,
- transverse spatial resolution weaker than 1 mm

These performances are in a complete agreement with the real time and non-interfering E-field analysis and have been used for the characterization of intense pulsed fields, especially associated to dielectric barrier discharges and plasma jets. The real time and vectorial measurement allows to extract the polarimetric behaviour of the field vector which describes ellipses. These ellipses are driven by the ionizing field and by the temporal dynamics of the ionized particles. A mapping of these ellipses has been performed and the velocity of the ionization wave has been extracted. A lot of experimental results will be presented during the conference.

#O2-2

NON-LINEAR ABSORPTION OF HIGH-POWER MICROWAVE PULSES IN A PLASMA FILLED WAVEGUIDE

KEYNOTE SPEAKER

CAO Yang, LEOPOLD John, BLIOKH Yuri, LEIBOVITCH Guy, KRASIK Yakov

Technion, Haifa, Israel

ABSTRACT

We present the first observation of complete absorption of a K-band high-power microwave (HPM) pulse (1.2 GW, 0.5 ns, 25.6 GHz) propagating in a plasma-filled waveguide when the plasma density dependent waveguide cut-off frequency is near the pulse frequency. Electrons are ejected towards the waveguide walls due to the ponderomotive force, resulting in a positively charged plasma which forms a potential well in the waveguide where the remaining electrons oscillate in the pulse's field. Due to the decrease in the group velocity of the pulse at this density, these trapped electrons have sufficient time to collide with ions while their regular field-induced oscillatory motion becomes chaotic. The latter leads to almost complete HPM pulse energy transfer to the kinetic energy of electrons. This non-linear absorption phenomenon is absent when the pulse power is low, for which the plasma remains on average neutral and a potential well does not form. Particle-in-cell (PIC) simulations confirm the experimental results and reveal the dynamics involved.

#O2-3

A 3-D NUMERICAL ANALYSIS AND EXPERIMENTAL VALIDATION OF A BIPOLAR PULSE FORMING TRANSMISSION LINE FOR HPM APPLICATIONS

KEYNOTE SPEAKER

IBRAHIMI Njomza[(1)], ARIZTIA Laurent[(1)], SILVESTRE DE FERRON Antoine[(1)], RIVALETTO Marc[(1)], NOVAC Bucur M.[(1,2)], BERTRAND Valérie[(3)], PECASTAING Laurent[(1)]

[(1)] Universite de Pau et des Pays de l'Adour, E2S UPPA, Pau, France
[(2)] Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, Loughborough, Leicestershire LE11 3TU, United Kingdom
[(3)] CISTEME – 15 rue Daniel de Cosnac, 19100 Brive-La-Gaillarde, France

ABSTRACT

This article presents a bipolar pulse forming transmission line (bipolar PFL) which was designed following a thorough analytical calculation and by verification using 3-D numerical modeling in CST MICROWAVE STUDIO. Through detailed analysis and simulations, we come to a design capable to generate voltages of up to 500 kV peak-to-peak amplitude and a FWHM of around 1 ns when connected to a 50 Ω load. The traveling wave process was comprehensively analyzed first by determining the impedance and propagation time of each line of the bipolar PFL separately followed by a study considering the bipolar former as a whole. In addition, a preliminary approach for spark gap representation in the 3-D model is proposed. The localization of the SMA type V-dot probe at 600 mm from the peaking switch allowing to measure less distorted signals is optimized following a 3-D numerical parametric study. Finally, we present the experimental results of an arrangement composed of the bipolar PFL connected at the output of a Marx generator recently developed at SIAME laboratory capable to generate voltage impulses of an amplitude of 500 kV and a rise time of 20 ns. The tests performed in the described assembly give a good compromise between experimental and numerical data.

#O2-4

AN/TPQ-18 RADAR TRANSMITTER

KEYNOTE SPEAKER

CHIPMAN Christopher, GORDON Philip, JASHARI Luan, KINROSS-WRIGHT John, GAUDREAU Marcel, KEMPKES Michael, SIMPSON Rebecca

Diversified Technologies, Inc., Bedford, USA

ABSTRACT

Diversified Technologies, Inc. (DTI) has delivered a new transmitter for the U.S. Air Force (USAF) Western Range AN/TPQ-18 radar facility. This 3 MW C-Band radar transmitter energizes, controls, and protects a CPI VKC- 8313A (5.4 GHz to 5.9 GHz) Extended Interaction Klystron (EIK). RF output is to a space-fed Cassegrainian antenna.

At the system core is a modulator which uses a DTI advanced solid-state switch to drive a pulse transformer providing 135 kV pulsing capability. The system includes a DTI high voltage power supply (HVPS), high power RF driver amplifier, custom output waveguide, and control consoles. A 19" rack houses power supplies for the klystron filament heater, pulse transformer core reset, solenoids, and ion pump.

The cathode power is provided by a 40 kV, 100 kW switching power supply (HVPS). The HVPS high voltage output is supplied to the modulator capacitor. This high stability/low noise unit operates from a 480 VAC, 60 Hz three-phase input. The HVPS uses an advanced PWM inverter to provide voltage and current regulation over the full output range. Nominal output behavior is 0.1% ripple and voltage regulation, with fast response to transients. Internal filter components reduce the line disturbance to modest levels. The high voltage section is built into a small tank filled with transformer oil. A heavy-duty high voltage cable connects the power supply to the modulator. A front panel provides local controls, indicators, and voltage/current limits for the collector HVPS.

The control cabinet houses the main system controls and interface, as well as most of the power distribution. The cabinet is divided into separate compartments to accommodate AC power distribution, low voltage DC utility distribution, and a controls section which includes the Klystron Control board and the Programmable Logic Controller (PLC) for system sequencing and other functions. The cabinet front panel provides an E-Stop button, touchscreen, and BNC monitor panel which allows convenient monitoring of buffered signals from the control board.

The RF rack houses the Microwave Control Unit (MCU), RF drive amplifier, and I/O components. The MCU handles RF faults and communicates with the Klystron Control board for pulse timing and fault interlock initiation.

The Klystron's RF output is fed to a WR187 waveguide, pressurized with Sulfur Hexafluoride (SF6) gas to 30 psig (nominal) to prevent arcing. The waveguide includes an optical arc detector, directional couplers for signal monitoring, isolator for protection from reflected antenna power, and a switch which allows full power testing into a dummy load.

Installation of the transmitter has been completed, and acceptance testing at Vandenberg AFB is scheduled for mid-2021 to accommodate range operations. This design is applicable to a number of other range instrumentation radars operated by the USAF and US Navy.

This effort was performed under Contract FA8823-18-C- 0013.

#O2-5

DESIGN OF A VACUUM INTERFACE OF A MICROSECOND TIMESCALE HPM DIODE WITH GUIDING MAGNETIC FIELD

KEYNOTE SPEAKER

YANG Hanwu, XUN Tao, GAO Jingming, ZHANG Zicheng

College of Advanced Interdisciplinary Studies, National University of Defense Technology, Changsha, China

ABSTRACT

Vacuum interfaces are vital part of a vacuum diode which allows high voltage feedthrough and supports the cathode structure. One of the keys in designing a vacuum interface is to prohibit the surface flashover across the insulator. Flashover happens more easily if the pulse duration of the voltage is longer and there is magnetic field present. In the paper we report a design of a vacuum interface which works in the microsecond range and with guiding magnetic field present. Two metal screens are used: one screen is fixed on the cathode shaft to intercept any electrons coming from the cathode or the slow wave structures, and another screen is fixed on the inside of the vacuum envelop to decrease the triple point electric field of the vacuum insulator, where flashover usually initiates. The electric field distribution and the low current trajectories of the electrons are calculated and the vacuum interface structure is adjusted so that electric fields near the triple point are low and electrons cannot collide directly into the insulator. The designed vacuum interface has been verified in the long pulse high power microwave experimental research.

#02-6

MEASUREMENT AND ANALYSIS OF ELECTRON BEAM BEHAVIOR IN A VIRTUAL CATHODE OSCILLATOR

KEYNOTE SPEAKER

NAGAO Kazuki[(1)], OHTA Michihiro[(1)], INUI Kentaro[(1)], SUGAI Taichi [(1)], TOKUCHI Akira[(1,2)], JIANG Weihua[(1)]

[(1)] Nagaoka University of Technology, Nagaoka, Japan
[(2)] Pulsed Power Japan Laboratory Ltd., Kusatsu, Japan

ABSTRACT

The virtual cathode oscillators(vircators) are the high-power microwave oscillator devices that used space charge limited effect by the high current electron beam. Simplicity and high-power capability are advantages. However, the low efficiency and frequency stability are serious problems. The physics and operation of the vircators have not been uncovered clearly and are difficult to understand. To quantitatively clarify the oscillation physics and operation of the vircators, the measuring and analyses of electron beam flow were carried out by two types of electron beam detectors (Large detector and Small detector). The information about the amplitude of the transmitted and injected/reflected beam current in a vircator was obtained from these detectors.

#O3-1

BIOTECHNOLOGICAL VALORIZATION OF PLATELET RELEASATE BY SELECTIVE PULSED ELECTRIC FIELDS APPLICATION

KEYNOTE SPEAKER

SALVADOR Daniela [1,2], ALMEIDA Henrique [1,2], REGO Duarte [3], MENDONÇA Pedro [4], SOUSA Ana Paula [4], REDONDO Luis [5], SERRA Margarida [1,2]

[1] iBET, Instituto de Biologia Experimental e Tecnológica, Oeiras, Portugal
[2] ITQB-NOVA, Instituto de Tecnologia Química e Biológica António Xavier, Universidade Nova de Lisboa, Oeiras, Portugal
[3] EPS, Energy Pulse Systems, Lisboa, Portugal
[4] IPST, Instituto Português do Sangue e da Transplantação, Lisboa, Portugal
[5] ISEL, Instituto Superior de Engenharia de Lisboa, Lisboa, Portugal

ABSTRACT

Platelets contain a wide range of bioactive factors, which are released upon platelet activation. Therefore, Platelet Concentrates have attracted great attention to regenerative medicine as a milieu of human growth factors with therapeutic potential.

Our work aims to apply pulsed electric fields (PEF) technology to platelets with no therapeutic value, to identify a new biological product, with high therapeutic potential and commercial value. It was already demonstrated by our group and others that the application of PEF to platelet concentrates induces the release of endogenous proteins from platelet granules1,2, however no studies have identified a specific pulse to achieve certain final content. Thus, in this study, we assessed the impact of applying different PEF parameters, such as pulse width (2-5µs), pulse number (1-15) and electric field strength (5-15kV/cm), to selectively activate platelets and modulate platelet releaseate (PR) content.

Our data demonstrates a significant increase in platelet activation (CD62P positive platelets) with all PEF conditions applied, particularly for 7 and 15, 2µs pulses, with 10 and 12.5 kV/cm. We also observed that platelet activation levels and PDGF release upon PEF application were positively correlated, except for 15 kV/cm conditions. In these sample, PDGF concentration was lower when compared to the other conditions, which might be related to an increase in PR temperature during process.

This study demonstrates that PEF leads to selective platelet activation and release of key growth factors, such as PDGF. Detailed characterization of the composition and bioactivity of PR is ongoing, aiming to generate a novel biotechnological product.

[1] Hargrave, B., and Li F.,, Nanosecond pulse electric field activated-platelet rich plasma enhances the return of blood flow to a large and ischemic wounds in rabbit model. Physiological Reports. 3, 1-9 (2015)
[2] Rego, Duarte, et al., Application of pulsed electric fields for the valorization of platelets with no therapeutic value for transfusion medicine, Technology. 07, 40-45 (2019)

#O3-2

PULSED ELECTRON BEAM: MECHANISMS INVOLVED IN BACTERIA ERADICATION

KEYNOTE SPEAKER

LAMARCHE Camille[(1)], DA SILVA Charlotte[(2)], PILLET Flavien[(2)], DEMOL Gauthier[(1)], ROLS Marie-Pierre[(2)]

[(1)] ITHPP, Thégra, France
[(2)] IPBS, Toulouse, France

ABSTRACT

The efficiency of bacteria eradication by electron beam has been proven for many years. Nevertheless, the mechanisms responsible for bacterial inactivation after their treatment with an electron beam are still unknown. The goal of this study was to find an explanation for this observation.
Different technologies can be used to produce electron beam. The one used in this study allows to generate a pulsed electron beam (PEB). A 250 keV PEB at a pulse repetition frequency of 100 Hz and with a pulse duration (FWHM) of 10 ns was used. The strain chosen was Bacillus pumilus ATCC 27142 because it is the reference for ionizing treatment. Experiments were lead on vegetative and spore forms of this bacteria. Spores have a specific organization with different layers (proteins, lipids, peptidoglycans,…) and a dehydrated core, which allow them to be very resistive in an inauspicious environment.

To answer this issue, different approaches were applied. First, cutting-edge microscopies (Scanning Electron Microscopy, Transmission Electron Microscopy, Atomic Force Microscopy) at the nanoscale allow to observe cell integrity or internal organization of bacteria but also to evaluate physicochemical modifications. Pulsed-Field Gel Electrophoresis (PFGE) was used in order to observe the integrity of genomic DNA.

The results of these experiments allow to find an explanation to bacteria inactivation after their treatment with PEB. Indeed, AFM revealed a modification of Bacillus pumilus hydrophobicity, which suggested a degradation of cell wall molecules. Moreover, PFGE highlighted genomic DNA damage. In particular, it showed single or double-strand breaks.

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#O3-3

INFLUENCE OF ELECTRIC FIELD AND GAP LENGTH ON OH RADICAL PRODUCTION BY PULSED ELECTRIC DISCHARGE IN WATER

KEYNOTE SPEAKER

SUGAI Taichi[(1)], TOKUCHI Akira[(2)], JIANG Weihua[(1)]

[(1)] Nagaoka University of Technology, Nagaoka, Japan
[(2)] Pulsed Power Japan Laboratory Ltd., Kusatsu, Japan

ABSTRACT

As one of the industrial applications by pulsed power, water purification by pulsed electric discharge with water has been investigated. For the water purification, OH radicals are produced by irradiation of discharged electrons to water and decompose harmful substances which cannot be decomposed by general methods such as biological and chemical treatments. This study focuses on phenomena of electrical discharge in point-to-plate electrode in water, that is the most basic reactor. Discharge mechanism and plasma state in water change depending on the strength and polarity of electric field and the gap length of an electrode, affecting OH radical production. We observed discharge plasma and measured the amount of OH radical in cases of various field and gap length to investigate those influence. OH radical was measured by fluorescence method using disodium salt of terephthalic acid (NaTA) as a probe. High electric field was applied by a pulsed power source of type of SOS or LTD, was changed by voltage value and gap distance, and was expected from simulation of the COMSOL Multiphysics. In this presentation, the experiment results are shown, and discussed from the relation between the amount of OH radical and discharge state changed according to field and gap length.

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#O3-4

USING SUBNASECOND PULSED ELECTRIC FIELDS TO ELECTROPORATE BACTERIA

KEYNOTE SPEAKER

VALLET Leslie [1], IBRAHIMI Njomza [2], ARIZTIA Laurent [2], ANDRE Franck [1], RIVALETTO Marc [2], SILVESTRE DE FERRON Antoine [2], RANCHOU-PEYRUSE Anthony [3], PECASTAING Laurent [2], M. MIR Lluis [1]

[1] Université Paris-Saclay, Institut Gustave Roussy, CNRS, Metabolic and systemic aspects of oncogenesis (METSY), 94805, Villejuif, France
[2] Université de Pau et des pays de l'Adour/E2S UPPA, SIAME, Pau, France
[3] Université de Pau et des pays de l'Adour/E2S UPPA, IPREM, UMR5254, 64000, Pau, France

ABSTRACT

Ability of microsecond and nanosecond Pulsed Electric Fields (µsPEFs and nsPEFs, respectively) to electroporate (reversibly and irreversibly) bacteria and eukaryotic cells has been extensively studied for decades [1, 2]. Conversely, up to now, reports on the ability of subnanosecond pulsed electric fields to electroporate bacteria or eukaryotic cells are relatively scarce, mainly as a consequence of the lack of reliable subnanosecond exposure systems [3]. However, trypan blue exclusion experiments have already shown electroporation and membrane resealing in B16 melanoma cells treated with 800 ps duration pulses of 55 MV/m (from 1 to 2000 pulses applied) [4]. Also, significant changes in membrane conductance have been reported in RHN, NG108 and CHO cells treated with burst of twenty-five 500 ps duration pulses of 19 MV/m at 1 kHz [5]. Here, our study focuses on the effect of 800 ps duration PEFs on the level of electroporation of bacteria (E.coli DH5α strain), examining the influence of various parameters such as the number of pulses applied, the pulse repetition frequency, or the amplitude of the electric field. The latter was supported by CST simulations.

The work aimed at finding conditions in which bacteria can be reversibly and irreversibly electroporated by 800 ps duration PEFs in the perspective of ulterior applications in medicine and food processing.

This study was performed using a Marx generator combined with a pulse forming line with the following characteristics: maximum output voltage 25 kV, rise time of 340 ps, pulse duration of approximately 800 ps at half maximum, maximum pulse repetition frequency of 200 Hz. The selected biological model was E.coli DH5α strain. Immediate electroporation and reversibility of the electropermeabilization were assessed by the double staining method using YO-PRO-1 iodide and SYTO-17, two DNA binding dyes, on bacteria subsequently analyzed by flow cytometry. Culturability of the bacteria submitted to subnanosecond pulses was assessed by Colony Forming Unit assays.

We followed the evolution in the percentage of immediately electroporated bacteria, in the reversibility of the electropermeabilization 30 min post exposure, as well as in the culturability of the bacteria 20 hours post exposure, with respect to the number of pulses applied and to the pulse repetition frequency. Our results show that bacteria can be electroporated by 800 ps pulses at electric fields around 1 MV/m, and that the percentage of immediate permeabilization, the permeabilization state 30 min post exposure and the culturability 20h post exposure strongly depend on the number of pulses applied (ranging from 1 to 20 000) and only slightly on the pulse repetition frequency (ranging from 0,1 to 200 Hz).

This work is a first step in finding conditions of reversible and irreversible electroporation of bacteria for ulterior applications in medicine and in food processing.

We would like to thank ANR Astrid ESCAPADE (ANR-18-ASTR-0019) for financing this research work.

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#O3-5

VISUALIZATION OF LOCAL THERMALIZATION OF CONDUCTIVE FLUIDS EXPOSED TO REPETITIVE HIGH POWER ELECTRICAL PULSES

KEYNOTE SPEAKER

YAMASHITA Takumi, KAJIWARA Kenshi, KATSUKI Sunao

Kumamoto University, Kumamoto, Japan

ABSTRACT

This paper discusses the flow dynamics and temperature elevation of conductive viscous fluids flowing through a parallel facing electrode to which pulsed electric fields (PEFs) were repetitively applied, to deepen understanding of hydro-thermodynamic phenomena that can be obstacles in the industrialization of PEF sterilization. The flow state and temperature distribution between the electrodes were visualized using time-resolved Schlieren and interferogram, respectively. We observed both the steady state under repetitive PEF exposure and the transient behavior from single PEF exposure for various flow conditions differentiated by viscosity (1.0, 4.8, and 18.5 mPa·s) and average flow velocity (0.1 and 1.0 m/s). For laminar flow, the temperature near the electrodes increased more significantly than that in the central main stream because the low-velocity region received more energy from the PEF. The larger the viscosity, the larger the average flow velocity, and the longer the electrode, the more significant the local temperature increase. By contrast, for turbulent flow, local thermalization near the electrodes was greatly suppressed by convection in the direction transverse to the flow, even when the electrode was long. Design of a high-production-rate PEF sterilization system requires understanding of the thermodynamic behavior of each target fluid under repetitive exposure to PEFs to kill bacteria.

#O3-6

EXPERIMENTAL RESULTS ON CELL TREATMENT AND TISSUE ABLATION BY A TLT BASED PULSED ELECTRIC FILED GENERATOR

KEYNOTE SPEAKER

MA Rongwei[(1)], DENG Guanlei[(1)], MA Zhenhong[(1)], YIN Shengyong[(2)], LIU Zhen[(1)], ZHENG Chao[(1)], YAN Keping[(1)]

[(1)] College of Chemical and Biological Engineering, Zhejiang University, Hangzhou, China
[(2)] The first Affiliated Hospital, School of Medicine, Zhejiang University, Hangzhou, China

ABSTRACT

Nanosecond pulsed electric field emerges as a new modality in cancer therapy, by changing the permeability of the membrane system which directly cause cell death, and triggering immune response to inhibit tumor growth. A new nanosecond pulsed electric field generator was presented and applied on biological ablation. The generator was developed based on a spark gap switch (SGS) and a transmission line transformer (TLT). It can produce pulses with a peak voltage of 10-30 kV at a repetition rate of 1 to 1000 pps (pulses per second). The width of main pulse is about 20ns. Due to the mismatch between the biological load and the TLT, the distortions of the output pulses can be found. The biological application was tested by ablating human hepatocellular carcinoma cell line HCCLM3, patient-derived tumor xenograft model of pancreatic cancer in nude mice and porcine liver. Two needle electrodes were applied to deliver 500 pulses at 10Hz with the amplitude of 20kV in HCCLM3 treatment, 17kV in pancreatic tumor ablation and 25kV in porcine liver ablation. The treatments have shown efficacy in causing cell death, inhibiting tumor growth and keeping tubular structures. Moreover, the structure changes of cell membrane were observed after ablation by SEM in HCCLM3 ablation. The infiltration of immune cells was found in pancreatic tumor treatment. A sharp demarcation appeared between normal tissue and necrosis after porcine liver ablation with the ablated volume of 4×2×3cm3.

#O4-1

FAST THYRISTOR SWITCH TRIGGERING IN IMPACT IONIZATION WAVE MODE BY A SOLID-STATE SPIRAL GENERATOR

KEYNOTE SPEAKER

GUSEV Anton[(1)], LAVRINOVICH Ivan[(1)], BLAND Simon[(2)], PARKER Susan[(2)], YAN Jiaqi[(2)], SILVESTRE DE FERRON Antoine[(1)], PECASTAING Laurent[(1)], NOVAC Bucur[(3,1)]

[(1)] Université de Pau et des Pays de l'Adour, E2S UPPA, SIAME, Pau, France
[(2)] Imperial College London, London, United Kingdom
[(3)] Loughborough University, Loughborough, United Kingdom

ABSTRACT

Solid-state switches play important role in modern pulsed power generators, continuously improving their characteristics and expanding their area of applications, however producing fast dI/dt with large currents remains costly and problematic. Triggering of high-voltage semiconductor devices in impact-ionization wave mode is a promising method that significantly improves commutation characteristics of the high-voltage solid-state switches [1]. Realization of this triggering mechanism has been recently demonstrated for standard high-voltage thyristors [2], where subnanosecond switching time and dI/dt capability of more than 100 kA/µs were experimentally proven. This triggering technique requires applying the high-voltage fast rise time pulse to thyristor main electrodes; the triggering pulse value of the rate of voltage rise dV/dt must be higher than 1 kV/ns and its maximum voltage amplitude is two times higher than the thyristor static breakdown voltage. The triggering pulse generator, that meets these requirements, is the main barrier to developing this approach. To design an impact ionisation switch suitable for pulsed power applications, the triggering generator must be cheap, simple and ideally based on solid-state switches. In this research, a spiral generator [3] optimised for impact-ionization triggering has been studied. The first part of the work is devoted to the optimisation of the spiral generator for operation on the capacitive dummy load 200-400 pF. The second part describes triggering 2 kV standard thyristors with a wafer diameter of 20 mm. Experiments on both single and series-connected thyristors will be described. The third part of the work is focused on the current flow through the switch prototype and the evaluation of the switching efficiency.

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#04-2

SUPER BOOSTING GATE DRIVER FOR SUB-NANOSECOND SWITCHING OF HV SIC MOS TRANSISTOR

KEYNOTE SPEAKER

ANA DEL BARRIO MONTAÑÉS Alicia[1,2], SENAJ Viliam[1], SACK Martin[2], KRAMER Thomas[1]

[1] CERN, Geneva, Switzerland
[2] KIT, Karlsruhe, Germany

ABSTRACT

Recent works have shown that impact ionization triggering can be successfully applied to standard thyristors, thus boosting their dI/dt capability by up to a factor of 1000. This triggering requires a sufficiently high overvoltage to be applied to the anode-cathode terminals of the thyristor with dU/dt > 1kV/ns: hence, enough current is required to charge the thyristor's parasitic capacitance. Our approach consists of using a Marx topology with impact ionisation triggered thyristors as the main power switches; with the number and type of thyristors corresponding to the output voltage and current required by the final application. Traditional triggering generators based on drift step recovery diodes (DSRD) are bulky and would require a significant pre-charging time of over 100 ns. Faster and more compact pulse generators would allow the spread of this technology towards new applications, including particle accelerators. In our approach, the pulse necessary to trigger the Marx generator will be generated by a HV SiC MOS with ultra-fast gate super-boosting, resulting in a sub-nanosecond switching. To achieve this, the SiC MOS gate driver needs to be extremely compact, using state of the art components in low inductance packages and with good decoupling of its power supply. Our present gate driver output MOS, with rated rise time of 2.2 ns, also works in a super boosted regime and delivers up to 160 V output voltage with a rise time of <200 ps. Thanks to super boosting of the Si and SiC MOS devices, their commutation speed can be accelerated by a factor of 20 to 30. Our current tests use a 1.7 kV rated SiC MOS with datasheet rise time of 16 ns operating at 1.3 kV into a 50 Ohm load with an output pulse rise time of <600 ps. An extensive testing campaign proved that these devices reliably operate for more than 10^9 pulses without performance deterioration. This work also outlines the feasibility of a sub-nanosecond switching of 3.3 kV rated SiC MOS devices that became commercially available recently.

#O4-3

TEST OF A MULTI-GIGAWATT, 800 NS PULSE GENERATOR BASED ON METAL-OXIDE VARISTORS

KEYNOTE SPEAKER

YANG Hanwu, GAO Jingming, ZHANG Zicheng, XUN Tao, ZHANG Huibo, GE Xingjun

College of Advanced Interdisciplinary Studies, National University of Defense Technology, Changsha, China

ABSTRACT

High power microwave (HPM) sources usually require a well-defined rectangular pulse waveform, which is especially true for the case of long pulse (>100 ns), stable and high efficiency operation. Usually, such HPM driver requires a pulse forming network (PFN) or a Marx generator composing of PFNs (PFN-Marx). As PFN has a finite impedance, the output voltage will vary if the HPM load's impedance changes. We tested a long pulse generator which is composed of a conventional Marx generator and a column of metal-oxide varistors (MOV). MOV has such nonlinear I-V characteristic that its voltage holds nearly constant for a wide range of currents. Circuit simulation shows that by using MOV in parallel with the load a near square pulse can be obtained, and the voltage is more stable. Since the self-inductance of the MOV column will cause droop in the pulse's flat top, a low inductance zig-zag structure of MOV column is designed. In the experiment, 400 kV, 800 long pulse is achieved at a 50 Ω electron diode. Such long pulse driver allows experimental research of >300 ns long pulse HPM sources.

#04-4

ENERGY RECOVERY AND SWITCHING SURGE REDUCTION METHODS FOR PULSED POWER GENERATORS USING HIGH VOLTAGE SIC-MOSFETS

KEYNOTE SPEAKER

SATO Mitsuhiko[(1)], YANO Tomoya[(1)], YOKOTA Shunsuke[(1)], MAKIO Kousei[(1)], SAKUGAWA Takashi[(1,2)], KUROIWA Takeharu[(3)], SAKAMOTO Kunihiro[(3)]

[(1)] Graduate School of Science and Technology, Kumamoto University, Kumamoto, Japan
[(2)] Institute of Industrial Nanomaterials, Kumamoto, Japan
[(3)] National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan

ABSTRACT

We study the adaptation of silicon carbide (SiC) semiconductor power device, which has been attracting attention as next-generation power devices to pulsed power switching circuits. In particular, the switching characteristics of SiC metal-oxide-semiconductor field-effect transistor (MOSFET) are high voltage turn-on, low loss, active switching and high-speed turn-off. We report energy recovery in a magnetic pulse compression circuit using SiC-MOSFETs with maximum drain-source voltage (VDS) of 13 kV. The current rise gradient limits the switching of the SiC-MOSFET. We treated high di/dt turn-on switching by operating multiple SiC-MOSFETs in parallel switching circuit. Based on that, we determined the design of the pulse transformer and the charging voltage. We modified the gate drive circuit to enable fast switching. In order for the energy recovery operation to be successful, it is necessary to utilize the body diode parasitic on the SiC-MOSFET of the vertical structure. In addition, it is necessary to turn off the SiC-MOSFETs at high speed at the timing when the reverse current flows through the first-stage energy storage capacitor. We succeeded in finding the optimum turn-off timing by changing turn-off timing from 300 ns to 1500 ns. At this time, we also found a condition for suppressing the turn-off surge voltage. It was also clear that energy recovery reduces the energy consumption at the load by turn-off during energy transfer. Furthermore, we have succeeded in reducing the turn-off surge voltage using snubberless circuit not only energy recovery. We have also conducted experiments with the load resistance varied from 50 Ω to 50 kΩ and demonstrated that this energy recovery method can be used for various load values. The results suggest new applications for SiC-MOSFETs and contribute to the development of energy-saving technologies using energy recovery method.

Acknowledgments : This study was supported by Tsukuba Power Electronics Constellations (TPEC).

#O4-5

SOLID-STATE SOS+MCL APPROACH FOR PICOSECOND MULTI-GIGAWATT PULSE GENERATION

KEYNOTE SPEAKER

PEDOS Maksim, ALICHKIN Evgeniy, PONOMAREV Andrey, RUKIN Sergei, TIMOSHENKOV Sergei, TSYRANOV Sergei

Institute of Electrophysics UB RAS, Ekaterinburg, Russian Federation

ABSTRACT

The possibility of creating solid-state picosecond generators based on SOS+MCL approach having a peak power of tens of GW has been shown. In the approach, an input pulse of nanosecond duration from a solid-state generator with a semiconductor opening switch (SOS generator) is amplified in peak power and shortened in time by successive stages of gyromagnetic ferrite lines. The essence of the approach is that the lines in each stage operate in a magnetic compression mode (Magnetic Compression Line, MCL), which is realized at close values of the input pulse duration and the period of oscillations generated in the line. In this case, the main part of the input pulse energy is transmitted only to the first peak of the oscillations. We describe the SOS+MCL pulsed power system having a peak power over 70 GW at ~100-ps pulse duration. The results of numerical simulation of the MCL will be also given.

#04-6

10KV, 200KHZ HIGH REPETITIVE PULSED POWER MODULATOR BASED ON SOLID-STATE WIDE BAND-GAP SWITCH

KEYNOTE SPEAKER

JO Hyun-Bin, SONG Seung-Ho, RYOO Hong-Je

Chung-Ang-University, Seoul, Republic of Korea

ABSTRACT

In recent research on pulsed-power supplies for generating high repetition rate pulse, semiconductor switches with improved performance such as wide band-gap switches (SiC & GaN) have been used. However, to drive a switch with a small parasitic capacitance, unexpected turn-on switching must be further considered. In this paper, a design of a 10kV high repetition pulse modulator based on a SiC MOSFET was conducted. This modulator charges 12 capacitors in parallel. The voltage of One capacitor is charged to a maximum of 833V, and the voltage difference ratio of each of the 12 capacitors is designed to be within 5%.When generating a pulsed voltage, 12 switches are connected in series for a pulse of up to 10kV. In addition, bypass diodes are connected to both ends of the connected switch and capacitor. Because of this, it is designed to output stably without destroying the other switches even if one switch does not operate. An integrated gate driver of the main MOSFET and pull-down MOSFET is designed, and the increase in the modulator volume is minimized, resulting in a power density of 385 W/L. Through this design, the semiconductor switch-based high repetition pulse modulator of this paper outputs a pulse with a maximum output voltage of 10 kV, a pulse width of 200 ns, an average output of 10 kW with repetition rates of 200 kHz, a rising and falling time of 30 ns. In the experiment, the development reliability of this modulator was confirmed through the maximum rate pulse test.

#05-1

SYSTEM INTEGRATION OF THE LOS ALAMOS MK-X HELICAL FLUX COMPRESSION GENERATOR AND THE RANCHERO HIGH CURRENT GENERATOR FOR IMPLODING LINER EXPERIMENTS: LA-UR-21-23499

KEYNOTE SPEAKER

GOFORTH James[(1)], BACA Eva[(1)], BARNES Andrew[(2)], BULLIS Remington[(2)], FARNSWORTH Conrad[(2)], FOLEY Timothy[(1)], GIANAKON Thomas[(2)], GIELATA Janina[(2)], GUNDERSON Jake[(2)], GLOVER Brian[(2)], HERRERA Dennis[(2)], JAKULEWICZ Micah[(2)], JARAMILLO Dennis[(2)], NOVAK Alan[(2)], OONA Henn[(2)], RAE Philip[(2)], RAINEY Kevin[(2)], ROUSCULP Christopher[(2)], SEITZ Daniel[(2)], SHOFNER William[(2)], WATT Robert[(2)], YODER Jacob[(2)]

[(1)] *Los Alamos National Laboratory, Los Alamos, USA*
[(2)] *Los Alamos National Laboratory, Los Alamos, USA*

ABSTRACT

Los Alamos National Laboratory has a long history of developing and fielding high explosive pulsed power (HEPP) components and systems. In the recent years, the Ranchero flux compression generator (FCG) has been modified for improved high current performance, and a new helical flux compression generator (HFCG), the MK-X, has been tested at both low and high stress for providing higher initial flux for Ranchero FCGs than can be achieved with the existing capacitor bank at Los Alamos HEPP test facilities. Integrating these two FCGs into a system is the focus of current development, and a full system test will be performed by conference time. The system will consist of a MK-X coupled efficiently to an R43S6 FCG with an exploratory pulse forming network (PFN) on the output of the Ranchero (R43S6 has become the shorthand designation for a Ranchero module with a 43 cm coaxial section and a Swooped output using a 6 inch diameter coaxial high explosive charge). The PFN will condition current delivery to an imploding liner load. The MK-X HFCG is the subject of another paper in this conference, and a low stress test has delivered over 6 MA to a dummy Ranchero load. A high stress test subsequently produced over 12 MA into a reduced inductance load which had a prototype PFN at its output. The high stress test experienced partial failures in the early high-pitch section of the HFCG, but performed as predicted in the high current segments. The PFN yielded encouraging results and is also the subject of another paper in this conference. For the upcoming test, initial current for the MK-X will be reduced to take stress off the early segments, and approximately nine MA current will be delivered to the R43S6 FCG. The PFN is designed to conduct throughout the capacitor bank and MK-X portions of the current pulse, then open part way through the R43S6 waveform allowing current flow to the liner load. The goal is to deliver ~50 MA to the liner load and achieve implosion speeds approaching 2 cm/μs. Details of the system integration and an overview of results to date will be presented.-

#O5-2

PROJECT OF POWERFUL LONG-PULSE THZ-BAND FEL DRIVEN BY LINEAR INDUCTION ACCELERATOR

KEYNOTE SPEAKER

PESKOV Nikolai[1,2], ARZHANNIKOV Andrey[1], BELOUSOV Vladimir[2], GINZBURG Naum[1,2], NIKIFOROV Danila[1], SANDALOV Evgeny[1], SINITSKY Stanislav[1], SOBOLEV Dmitry[2], ZASLAVSKY Vladislav[2], ZHIVANKOV Kirill[1]

[1] Budker Institute of Nuclear Physics RAS, Novosibirsk, Russian Federation
[2] Institute of Applied Physics RAS, Nizhny Novgorod, Russian Federation

ABSTRACT

Project of high-power long-pulse THz-band FEL is under development in collaboration between BINP (Novosibirsk) and IAP RAS (N.Novgorod) driven by the linac "LIU" 5 - 20 MeV / 2 kA / 200 ns of the new generation. The aim of this project is to achieve a record sub-GW power level and pulse energy content up to 10 - 100 J at THz frequencies. Principal problems in realization of this generator include: formation of the electron beam with parameters acceptable for operation in the short-wavelength ranges, development of undulator for pumping operating transverse oscillations in the beam, and elaboration of electrodynamic system that can provide stable narrow-band oscillation regime in a strongly oversized interaction space.

Initial proof-of-principle experiments are planned to start at the "LIU-5" accelerator in the 0.3 THz frequency range, with prospects of transition to 0.6 THz range and higher frequencies after positive results would be demonstrated. In the report, the design parameters of the FEL project are discussed. Results of electron-optical experiments on the beam formation are presented. Structural elements of the FEL magnetic system based on helical undulator and a guide solenoid that provides intense beam transportation were elaborated. An electrodynamic system was proposed exploiting a new modification of oversized Bragg structures, so-called advanced Bragg structures, which have significantly improved selective properties. Structures of such type were designed with the diameter of 20 and 40 wavelengths for operation in specified frequency ranges.

This work is supported by the Russian Science Foundation (grant #19-12-00212).

#O5-3

INSTABILITY OF THIN RESISTIVE LINERS IN THE LINEAR APPROXIMATION

KEYNOTE SPEAKER

GARANIN Sergey, KRAVETS Ekaterina, DOLINSKIY Vasiliy

RFNC-VNIIEF, Sarov, Russian Federation

ABSTRACT

Magnetic implosion of liners is usually accompanied by the development of the Rayleigh-Taylor instability, which makes it hard to achieve high energy densities. However, the liners, which are thin compared to their skin layer (let us call them resistive), can also experience a different kind of instability, when parallel currents in different liner parts are attracted and draw these parts together dividing the liner into layers and filaments (filamentation, tearing instability). We consider the problem of perturbation development in an infinitely thin resistive liner accounting for the distribution of the magnetic field, spread of currents, and motion of matter assuming that the perturbations are linear. Considering potential applications for different liner configurations (Z and Q-pinch liners, flat flyers) and the fact that the most destructive instabilities develop from the shortest wavelengths, we restrict our analysis to the planar case, which ignores the curvature of the liner and magnetic field lines. We find that the instability develops for any perturbation wavelengths, similar to the case of the perfectly conducting liner [1], with the instability increment for all the wave numbers k being of the order of $\sqrt{kg}$ (g is the liner acceleration), but always less than $\sqrt{kg}$, and with the maximum increments for any directions of the wave vector k being greater than the increments of the perfectly conducting liner. One can often treat wire-array liners as resistive and hence use the results obtained (after merging the plasmas produced by individual wires) for the description of instability development.

[1] E.G. Harris, Phys. Fluids. 5 (1962) 1057–1062.

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#05-4

SIMULATIONS OF PULSE FORMING NETWORKS (PFN) BASED ON MAGNETICALLY DRIVEN GATES

KEYNOTE SPEAKER

GIANAKON Thomas, FOLEY Tim, GOFORTH Jim, GUNDERSON Jake, JAKULEWICZ Micah, ROUSCULP Chris, SEITZ Dan, ROBERT Watt

Los Alamos National Lab, Los Alamos,NM, USA

ABSTRACT

Two recent developmental high explosive pulse power flux compression generator (FCG) experiments at Los Alamos National Lab have offered the opportunity to re-examine the usage of magnetic gates as opening switches in a pulse forming network (PFN) to improve the current rise time on loads. The first experiment was a LANL Mark-X helical FCG with an initial inductance of 4.6 uH and with a flux compression time of 160 us. This drove a dual gate PFN (44 nH/GateA/6.5nH/GateB/2nH) load. This experiment delivered 12.5 MA to the first gate, which opened 100 us after the start of Mark-X flux compression and then delivered 12.0 MA to the second gate with a rise time on the order of 40 us. Gate B opened 44 us later with a similar rise time. Physical motion of both gates were recorded with Photo Doppler Velocimetry (PDV). The simulations predicted a rise time an order of magnitude faster. The second experiment (May 2021) is a LANL Mark-X helical FCG (4.6 us) driving a transition section (13 nH) plus the coaxial Ranchero43S6 FCG with 86 nH with a compression time of 33 us. This is used to drive a single gate (4.6nH/Gate) followed by a liner load (3.9 nH/Liner). The Mark-X should deliver 8-10 MA to the R43S6 which should deliver 50-70 MA to the gate which after opening should deliver 40-50 MA to the liner. The Gate in this experiment has been designed to open during the operation of the R43S6. An expectation exists that significant plasma will be produced that may disrupt the operation of the liner. Liner performance will be measured with PDV and is expected to be between 1 cm/us and 2 cm/us. Simulation comparisons with experimental observations of gate motion, liner motion, and current measurements will be presented. Further details of those experiments are described by other papers in this conference.

#O5-5

ALTERNATIVES FOR DECREASING DRIVING TIMESCALE FOR THE PHELIX TRANSFORMER CONCEPT

KEYNOTE SPEAKER

REINOVSKY Robert, ROUSCULP Christopher, ORO David

Los Alamos National Laboratory, Los Alamos, USA

ABSTRACT

For hydrodynamic, fluid dynamic and instability experiments, and some material properties and plasma experiments employing imploding condensed matter liners, pulsed power drive of 5-10 MA with 0.5 to 5.0 microseconds rise times are very attractive, especially for those experiments using advance diagnostic platforms such as LANL proton radiography. The highly reliable PHELIX 4:1 toroidal transformer technology driven by conventional (Atlas-like) low impedance pulse power modules at moderate (~100KV) output voltages has been successful in driving a variety of physics experiments at about 5 microsecond rise time over the last decade, but a 2 to 5 times decrease in rise time would enable an even broader families of experiments. Alternative powering approaches, retaining the toroidal transformer technology, including higher voltage drivers, inductive-store/opening switch combinations, pulse forming networks, and possibly distributed driver technology such as that embodied in the Sandia LTD-brick concept could achieve modest decrease in rise-time and/or increase current output at the secondary of the transformer while retaining the fundamental reliability, compactness, ease of operation and compatibility with advanced diagnostic capabilities.

In this paper we examine the possibilities for extending PHELIX performance by decreasing its fundamental circuit timescales.

#O6-1

EXPERIMENTAL AND NUMERICAL STUDIES OF A RELATIVISTIC MAGNETRON FED BY A SPLIT CATHODE

KEYNOTE SPEAKER

LEOPOLD John G.[(1)], TOV Meytal Siman[(1)], KRASIK Yakov E.[(1)], KUSKOV Artem[(2)], ANDREEV Dmitri[(2)], SCHAMILOGLU Edl[(2)]

[(1)] *Physics Department, Technion, Israel Institute of Technology, Haifa 320003, Israel*
[(2)] *Department of Electrical and Computer Engineering, University of New Mexico, Albuquerque, 87131-0001, New Mexico, USA*

ABSTRACT

A split cathode[1] is a novel source of magnetized relativistic electrons consisting of an annular emitter connected to a reflector by a conductor. As the electron source of a relativistic magnetron, it has the advantage that the emitter is placed outside the interaction region so that the cathode plasma does not cause pulse shortening. At the same time the reflector reflects the downstream electron current towards the interaction region. In experiments, using an axial split cathode - anode configuration, we found no current flow to the anode but confirmed that a large electron charge is trapped between the cathode and the reflector.[1] Here we present a split cathode in an inverse situation, that is, the cathode and the reflector are placed on the outer wall of a tube and the anode is on axis. We present PIC simulations and experimental results which confirm that a split cathode also performs well in this inverse situation.

1. J. G. Leopold, Ya. E. Krasik, Y. P. Bliokh, E. Schamiloglu, Phys. Plasmas 27, 103102 (2020).

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#06-2

STUDY OF HIGH CURRENT MAGNETRON IMPULSE DISCHARGE

KEYNOTE SPEAKER

MORELL Erwan[1,2], MINEA Tiberiu[1,3], LUNDIN Daniel[1,3], BALLAGE Charles[1,3], ROZIER Yoann[2], BAZINETTE Rémy[2], FORCHARD Thomas[2], CREUSOT Christophe[2], GIRODET Alain[2]

[1] LPGP, Orsay, France
[2] Supergrid-institute, Villeurbanne, France
[3] CNRS, Orsay, France

ABSTRACT

High current density magnetron impulse discharge (HCDMID) could be used in numerous applications like surface deposition, etching [1], ion thrusters sources... Magnetron-type discharges are widely used in both regimes - physical vapor deposition (PVD) and ionized PVD [2]. In pulsed mode, the peak power density over the target area, can reach or exceed 107 W/m2, leading to plasma conditions that drastically increase the ionization of the sputtered atoms due to the presence of magnetic field. As a consequence, high current in the discharge impulse could be achieved.
The interactions of cathode materials with the energetic species (electrons, ions, photons and reactive species) of these partially ionized gases, produced at low pressure (1-5 Pa) are creating new functionalities [3].

In this presentation, we will focus on the high-voltage waveforms ranging from 450 to 1000 V leading to reproducible discharge current densities higher than 10 A/cm². High-speed gated camera imaging, optical emission spectroscopy and other optical diagnostics will be reported and different mode of plasma will be discussed. The comparative study on plasma-surface interaction zone of the target will be reported for a better understanding of the physical mechanisms associated with the current density and the material to be considered.

[1] D. V. Mozgrin, I. K. Fetisov, and G. V. Khodachenko, “High-current low-pressure quasi-stationary discharge in a magnetic field: Experimental research,” 1995.
[2] N. Brenning, J. T. Gudmundsson, M. A. Raadu, T. J. Petty, T. Minea, and D. Lundin, “A unified treatment of self-sputtering, process gas recycling, and runaway for high power impulse sputtering magnetrons,” Plasma Sources Science and Technology, vol. 26, no. 12, p. 125003, nov 2017.
[3] T. J. Sommerer, S. C. Aceto, J. F. Trotter, D. J. Smith, C. A. Allen, W. N. G. Hitchon, and J. E. Lawler, “Operating modes of a magnetized cold cathode plasma in helium 50-6400 mTorr,” Journal of Physics D: Applied Physics, vol. 52, no. 43, p. 435202, aug 2019.

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#06-3

SAFETY METHOD USING HIGH POWER MICROWAVE(HPM) AS DEFENSE AGAINST VEHICLES

KEYNOTE SPEAKER

RAMMAL Mohamad[(1)], BONNIN Xavie[(1)], REINEX Gwenael[(1)], MAJED Mohamad[(1)], JECKO Bernard[(2)], MARTINOD Edson[(3)], ANDRIEU Joël[(3)]

[(1)] ITHPP, Thegra, France
[(2)] XLIM, Limoges, France
[(3)] XLIM, Brive la Gaillarde, France

ABSTRACT

This article describes a conceptual system of High Power Microwave (HPM) using RF GaN SSPAs (Solid-State Power Amplifiers) technology. As part of investing for the future, ITHPP has developed the DRAME (Dispositif Rayonnent Agile ModulablE French version) project that operates in Ultra Wide Band Frequency. This technique can be a solution for neutralizing / stopping vehicle and drones at a safe distance based on a concept of Electromagnetic waves radiation.

The High Power Electromagnetic Radiation (in L band from 1GHz to 1.45GHz) can be upset or damage the operation of integrates circuits by passing through the slots and holes of the targeted car causing a remote stopping. The system is made in two parts, a modular RF amplifiers using solid-state technology and Low Profile planar antenna called ARMA (Agile Radiating Matrix Antenna). The ARMA antenna is built by jointed pixels each to make N x M matrix. The ARMA matrix must be capable of generating radiating surfaces of particular shapes, associating all the elementary surfaces, according to the state of the pixels controlled in amplitude and in phase to produce a formed, reconfigurable and agile beam. To validate our concept, we are designed and manufactured at ITHPP company a breadboard of 5 pixels' operating in wide band from 1GHz to 1.45GHz. The low level experiments have been carried out in an anechoic chamber to verify the whole antenna system characteristics: reflection coefficient, Directivity, Realized Gain, Radiation Pattern. The test showed a good agreement between the CST simulation and the measurement. The high field levels of breadboard have been validated by connecting each pixel of 1D ARMA to an RF amplifier. It should be noted that the amplifiers have been characterized before the test in order to obtain the same phase in the input of pixels.

#06-4

DESIGN OF A HIGH-POWER UWB ANTENNA FOR THE NEUTRALIZATION OF IMPROVISED EXPLOSIVE DEVICES

KEYNOTE SPEAKER

HYVERNAUD Jérémy[(1)], MARTINOD Edson[(1)], BERTRAND Valérie[(2)], NEGRIER Romain[(1)], ANDRIEU Joël[(1)], LALANDE Michèle[(1)]

[(1)] XLIM, Brive, France
[(2)] CISTEME, Limoges, France

ABSTRACT

A high-power ultra-wideband antenna is presented for the purpose of remotely neutralizing improvised explosive devices. The developed antenna has a bandwidth between 230 MHz and 2 GHz, as well as a maximum realized gain of 18,7 dB. The antenna structure incorporates a solid dielectric (HDPE 1000) so that it can be powered, without risk of a possible breakdown voltage, by a Marx generator which delivers a bipolar pulse with a peak amplitude of +/-250 kV, a rise time of 170 ps, and duration of 1 ns. The peak radiated electric filed obtained in simulation is respectively 1 MV/m and 126 kV/m at a distance of 1 m and 10 m.

#06-5

ELECTRON-OPTICAL SYSTEMS BASED ON CATHODES WITH A HIGH CURRENT DENSITY FOR PLANAR SPATIALLY EXTENDED CHERENKOV-TYPE OSCILLATORS AND AMPLIFIERS

KEYNOTE SPEAKER

ZASLAVSKY Vladislav[1,2], MANUILOV Vladimir[2], KLIMOV Alexey[1], PALITSIN Alexey[1], GOYKHMAN Mikhael[1], GROMOV Alexander[1], RODIN Yury[1]

[1] *Institute of Applied Physics of the Russian Academy of Sciences, Nizhny Novgorod, Russian Federation*

[2] *Nizhny Novgorod State University, Nizhny Novgorod, Russian Federation*

ABSTRACT

Utilizing spatially extended electron beams is a well-known way of increasing both frequency and output power of vacuum millimeter-wave O-type tubes. This configuration allows increasing the current (and thus the total power) of the electron beam keeping the current density unchanged. In this paper, a trajectory analysis of electron-optical system (EOS) forming a ribbon high current density electron beam is carried out. A technique has been proposed for gun design taking into account the three-dimensional configuration of the EOS. As an example, formation system of a ribbon electron beam with energy of 600 keV current of 1 kA and transverse dimensions of 20 × 0.75 mm2 is considered. Recommendations for minimizing the velocity spread acceptable for effective electron-wave interaction are given, and the possibility of further increasing the transverse beam size is investigated. The results obtained within the framework of the theoretical approach are in good agreement with the experimental data obtained at the IAP RAS. In the experiment, thin sheet electron beam was injected from a blade-shaped explosive cathode and guided by 3 T magnetic field. To reduce the backward current, dumbbell-form cathode holder was used. On the basis of the formed beam, it is proposed to implement a spatially developed planar W-band surface wave oscillator with an output power of 100 MW.

#06-6

A SEMICONDUCTOR OPENING SWITCH BASED ON OFF-THE-SHELF COMPONENTS

KEYNOTE SPEAKER

DEGNON Mawuena Rémi[1,2], GUSEV Anton[1], SILVESTRE DE FERRON Antoine[1], PECASTAING Laurent [1], NOVAC Bucur[1,3], DAULHAC Gaëtan[2], BARANOV Aleksandr[2], BOISNE Sébastien[2]

[1] Université de Pau et des Pays de l'Adour, E2S UPPA, SIAME, Pau, France
[2] ITHPP ALCEN, Thégra, France
[3] Loughborough University, Loughborough, United Kingdom

ABSTRACT

An SOS effect is the nanosecond interruption of high-density current in a silicon structure. Based on this effect, SOS diodes were developed over three decades ago. That sparked a breakthrough in the development of solid-state pulsed power systems based on inductive energy storage since it allows the improvement of their important characteristics such as current density, pulse power, voltage and energy [1]. Due to high average power and long lifetime, the SOS generators are used for many industrial applications such as x-ray apparatus, particle accelerators, e-beam sterilization, laser pumping sources, etc. However, there is a limited number of manufacturers of SOS diodes in the world. Therefore, the possibility of commercially available diodes to replace the typical SOS diodes has been investigated in the present work. A test bench has been developed and optimized for the testing of off-the-shelf diodes in the SOS mode of operation. More than 25 types of commercially available diodes, including rectifying, avalanche, Schottky, TVS and Zener diodes, have been tested as opening switches. The specifications of the studied diodes are as follows: blocking voltage of 0.2-10 kV, die area of 0.01-0.81 cm² and recovery time of 0.1-20 µs. A voltage pulse with an amplitude of more than 3 kV, a rise time of 10 ns and a pulse width of 40 ns was obtained at the 110 Ω load. Finally, the results have been compared with a reference SOS diode of 0.25 cm² die area.

[1] S. N. Rukin, "Pulsed power technology based on semiconductor opening switches: A review," Rev. Sci. Instrum., vol. 91, no. 1, p. 011501, Jan. 2020.

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#07-1

THE SATURN ACCELERATOR RECAPITALIZATION PROJECT

KEYNOTE SPEAKER

Bryan OLIVER, Michael MAZARAKIS, Mark SAVAGE, Ken STRUVE, Ben ULMEN

Sandia National Laboratories, Albuquerque, NM, USA

ABSTRACT

The Saturn[1] accelerator at Sandia National Laboratories is one of the world's premier pulsed, high-power (~ 36 TW) high current (10 MA) generators. The accelerator drives a suite of high current e-beam diodes for bremsstrahlung x-ray production [2]. It is designed and built with 1980's pulsed-power components and technology and is in need of refurbishment. A number of areas for improvement have been identified and we are in the planning and execution stage of the first phase of a multi-year effort to replace and upgrade key components.

Saturn is a 36-module (~ 40 kJ, 1 TW per module) cylindrical architecture high current accelerator capable of driving 1.5 MeV, 8-10 MA, 25 ns pulse-width electron beams. Each module is arranged radially and is comprised (moving radially inward) of an energy storage section (Marx banks) housed in oil, an intermediate storage capacitor, an electrically triggered output gas-switch, a water pulse-forming section, vertical tri-plate transmission lines and stacked (water bottle) water transmission line interface, a vacuum barrier, magnetically insulated transmission line(s) and a vacuum diode region. Due to its age and long-time use, many major components within this architecture are in need of repair and or redesign. The principal goals of the project are to improve shot-to-shot reproducibility, increase shot rate (reduce shot turn-around time) and reduce component failure and unplanned maintenance. A summary of the overall project will be presented, with highlights of recent activity, including; development of a modern circuit model, new diagnostics insertion, diode optimization considerations, vacuum MITL and insulator design changes, and plans for a new output gas-switch.

[1] D.D. Bloomquist, R. W. Stinnett, D. H. McDaniel, J. R. Lee, A. W. Sharpe, J. A. Halbleib, L. G. Schlitt, P. W. Spence, and P. Corcoran. "Saturn, a large area X-ray simulation accelerator." In Proc. 6th IEEE Pulsed Power Conference, Arlington, VA, p. 310. 1987

[2] B.V. Oliver, V. Harper-Slaboszewicz, K. Struve and B. Ulmen, "Warm X-ray Source Development on the Saturn Accelerator". In Proc. 6th Euro-Asian Pulsed Power Conference and the 21st Int. Conference on High-Power Particle Beams, Estoril Portugal, p. 327, 2016

*Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

#07-2

FUNDAMENTAL STUDY OF HIGH ELECTRIC FIELD SURFACE FLASHOVER IN VACUUM

KEYNOTE SPEAKER

NEUBER Andreas[(1)], STEPHENS Jacob[(1)], BROOKS William[(1)], CLARK Raimi[(1)], YOUNG Jacob[(1)], MOUNHO Michael[(1)], HOPKINS Matthew[(2)]

[(1)] Texas Tech University, Lubbock, TX, USA
[(2)] Sandia National Laboratories, Albuquerque, NM, USA

ABSTRACT

A laboratory-scale testbed for studying anode-initiated surface flashover in vacuum is presented. Pulsed voltage at amplitudes approaching 500 kV with 10 ns risetime is applied to a cm-sized insulator gap with the insulator at a 45° angle. This type of field-electrode-surface geometry is modeled after conditions typically found in a large accelerator's insulator stack with a ~ 500 kV/cm average potential gradient. For the study of the fundamental physical mechanisms initiating flashover, the laboratory scale testbed has the advantage that diagnostic tools, such as optical emission spectroscopy, are more easily applied as the user may set the flashover path location *a priori*.

In the testbed, optical access to the insulator surface enables temporally resolved imaging of the flashover path, and it is expected that early light originates from the anode rather than the cathode since the anode electric field is roughly five times higher than the cathode field in this 45° insulator geometry. Thus, the corresponding anode field levels become sufficiently high to affect field emission from the insulator and localized solid insulator breakdown. While many of these processes are known to exist in principle, little quantitative information is available in the open literature. This study is aimed at uncovering the dominant mechanisms of high field, anode-initiated surface flashover through temporally resolved imaging, UV emission spectroscopy, laser deflection for gas desorption densities, and spatio-temporal X-ray diagnostics. The testbed design, diagnostics, and initial results are discussed.

SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525

#07-3

OPERATION OF A HIGH-IMPEDANCE MITL INTO AN UNDERMATCHED LOAD ON THE RITS-6 ACCELERATOR: LIMITATIONS ON INDUCTIVE VOLTAGE ADDER (IVA) OPERATION *

KEYNOTE SPEAKER

RENK Timothy[(1)], OLIVER Bryan[(1)], WEBER Bruce[(2)]

[(1)] Sandia National Laboratories, Albuquerque, USA
[(2)] Naval Research Laboratory, Washington DC, USA

ABSTRACT

The architecture of an Inductive Voltage Adder (IVA) is characterized by a series of adder cavities which generate the final output voltage. These cavities are located on the outer conductor of what becomes a magnetically insulated transmission line (MITL). In negative polarity operation, the inner conductor (negative) is positioned at the MITL center line as a cantilevered structure. A key parameter of the IVA-MITL system is the vacuum impedance of the MITL, which is determined by the ratio of the outer MITL diameter to the inner. The larger this ratio, the higher is the MITL vacuum impedance and the resulting output voltage. In a MITL, the surface electric field at the negative electrode exceeds the threshold for electron emission, leading to the generation of electron flow current. In proper operation, this flow current propagates in a relatively narrow sheath near the inner MITL surface. Then as the inner conductor radius in an IVA design is reduced, the vacuum impedance and output voltage rises, and the electron flow current decreases. Use of an IVA to drive a diode load introduces a complication compared to the case where the same load is driven by a standard high-voltage interface, due to the possible addition of the electron flow current to any current generated by the diode load itself.

It can be imagined then that an easy way to generate higher output voltage for a given IVA design is to reduce the inner MITL diameter. However, we present evidence here that beyond a certain point, a relatively high MITL vacuum impedance, particularly if coupled with a load impedance of equal or lower value, can compromise the performance of both the MITL and the load. The testbed for our experimental investigation is the RITS-6 IVA at Sandia National Laboratories, and the load used is a Self-Magnetic Pinch (SMP) diode.[1] The SMP diode has been optimized as a driver for flash x-ray radiography applications. In this diode, a thin pencil-like cathode (< 1.5 cm diameter) faces a planar anode. A sphere-like field shaper upstream of the diode is intended to divert flow current away from the diode region, although data confirms that this diversion is only short-lived. Experiments have been conducted with output voltages ranging from 3.5 to 12 MV. Most of the experiments were conducted using a center MITL resulting in a vacuum impedance of ~ 51 ohms (referred to as the 'Lo-Z MITL').

To reach the higher output voltages, the Lo-Z MITL was replaced by a smaller-diameter MITL that resulted in a ~ 103-ohm vacuum impedance ('Hi-Z MITL'). This impedance can be compared to the inferred diode impedance of ~ 65 ohms (initial) produced using the Lo-Z MITL and an SMP diode of cathode diameter 12.5 mm and A-K gap 12 mm ('12.5-12'). When the RITS SMP is operated at a lower output voltage of 4.5 MV, results obtained on RITS appear quantitatively equivalent to results at the 4 MV level obtained on a machine[2] with a high-voltage interface instead of an IVA. This implies that RITS-6 with the Lo-Z MITL in place behaves similarly to a machine where no electron flow is produced. When the Hi-Z MITL replaced the Lo-Z MITL, however, qualitatively different behavior was observed, which complicated considerably the process of analyzing shot performance. Among these are: 1) inability to estimate load voltage using conventional inductive correction from an upstream voltage source, this due to a large retrapping wave produced from coupling to an undermatched load; 2) a diode (radiation) current observed to decrease with time even as the generator current is increasing; and 3) a conversion of diode current to flow current during the power pulse, exactly opposite to what occurs with the Lo-Z MITL. Also, in tracking the behavior of the electron strike angle on the converter as a function of time[3], we observed that the conventional cIVx 'Radiographic' radiation scaling (where x ~ 2.2) begins to break down for voltage above 8 MV, and a scaling based on cubic scaling is more accurate. The root cause of these behaviors appears to be that 1) a certain level of electron flow is required, which may not be attained with the Hi-Z MITL in place, and 2) only a 'system-level' analysis where both flow and diode currents are included is valid. More details of these observations will be presented.

[1] K. D. Hahn et al, "Overview of Self-Magnetically Pinched-Diode Investigations on RITS-6", IEEE Trans. Plas.Sci 38 (2010) 2652-62.
[2] B. Etchessahar et al., Phys. Plasmas 20 (2013) 103117.
[3] T. J. Renk, B. V. Weber, I. M Rittersdorf, and T. J. Webb, Rev. Sci. Instr. 90 (2019) 114709.

*Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

#07-4

IMPEDANCE-MATCHED MARX, A NEW CLASS OF GENERATOR

KEYNOTE SPEAKER

GUEGAN Baptiste, BAYOL Frederic

ITHPP, Thègra, France

ABSTRACT

The concept of the Impedance-matched Marx (IMM) has been theorized in 2017 at Sandia Laboratories. This work* presents the tests-results of the first prototype of this new type of high pulsed power generator.

The IMM is a hybrid version of a Marx and a Linear Transformer Driver (LTD) generators. As for a LTD, the fundamental building block of an IMM is a brick, consisting of two capacitors and one switch electrically connected in series. These bricks can then be assembled in parallel (increasing the output current), and in series (increasing the output voltage) in a view to build a multistage generator driving an impedance-matched transmission line.

Unlike a LTD, the IMM does not require the use of ferromagnetic cores, which can allow a mechanical conception based on a strip-line rather than a typical coaxial-line. This has the advantage to improve considerably the compactness of the generator for MA applications, and to facilitate the possibility to add modules in parallel to reach such current. Unlike a Marx, the IMM does not require the use of a pulse forming line associated to a MV switch for fast output applications. This reduces eventually the generator size, decreases its complexity, and participates to increase its global efficiency. In this presentation, we will review the results of the first IMM prototype, consisting of 8 stages of 8 bricks, assembled to drive a strip transmission line. This generator is capable to produce outputs voltage of ~800kV and current of 90kA (pulse width of the order of 70 ns), delivering a peak electrical power of ~60GW into a 9.5Ω matched-impedance load.

*Work supported by a contract funded by the French Ministry of Armed Forces (DGA).

#07-5

REPETITIVE PULSED ELECTRIC FIELDS IN A LARGE VOLUME OF WATER VERIFIED WITH MEASUREMENT OF OPTO-ELECTRIC EFFECT

KEYNOTE SPEAKER

WOODYARD Matthew, NOVAC Bucur, SENIOR Peter, STOBBS Jessica

Loughborough University, Loughborough, United Kingdom

ABSTRACT

The output of a compact Tesla based pulsed power system is used to induce intense pulsed electric fields in a large volume of water (≈ 1 L) measured using Kerr effect diagnostics. The application of this technology can be found in novel food processing techniques as well as the medical domain. This paper will present the operation and results of the complete system.

#07-6

REVISITING THE PHYSICS OF HIGH-CURRENT, FOIL OPENING SWITCHES WITH MODERN CODES

KEYNOTE SPEAKER

ROUSCULP Christopher, GIANAKON Thomas, WATT Robert, FOLEY Timothy

Los Alamos National Laboratory, Los Alamos, USA

ABSTRACT

Metal foils have been used extensively as high-power opening switches. The configurations usually consist of an electrically thin (δx < skin-depth) foil between dielectric insulating tampers. The dimensions of the foil fuse are governed by the simple equation for resistance, R = ϱ*length/area, where ϱ the resistivity is a function of temperature and density. The general principle is to Joule heat the metal to vaporization causing a 102 increase in resistivity, but limiting it from the plasma state where resistivity drops. Previous computational fuse models included 0-D conservation of mass, momentum, and energy with simple resistivity models.

Here we apply modern MHD codes and the most recent EOS and conductivity tables to study the physics of foil opening switches in detail. In the ideal case, all of the tamped foil material follows the liquid/vapor co-existence curve prior to vaporization. Thus, the performance of fuse is largely determined by the accuracy of the resistivity along this path. We present the sensitivity of a fuse calculation to various tables. At high-currents, Lorentz forces within the foil and at the current joints cannot be neglected. Further, axisymmetric geometry can lead to uneven heating effectively creating a set of unequal, series resistors that can hinder performance. Finally, there is the question of heat dissipation of the vapor by the insulator layers. Granular tampers (e.g., glass microspheres) have been shown to be more effective than layered polymers (e.g., polyimide films). We speculate that the higher surface area and porosity is responsible for quenching the heat of the vapor. Here, we compare computational results to previous, well-diagnosed experimental studies and explore some new designs.

#O8-1

INTEGRATION TEST OF PLASMA FILLED ROD PINCH DIODE RADIOGRAPHIC SOURCE

KEYNOTE SPEAKER

JONES Aled[(1)], BIDDLE Lester[(1)], CHILDS Matt[(1)], EVANS Matt[(1)], HAYNES John[(1)], RUTLEDGE James[(1)], WILLIAMS Phil[(1)], BAYOL Frédéric[(2)], COE Anthony[(2)], GASTON Clément[(2)], MOULY Patrick[(2)], PIASER Arthur[(2)], VAN DE WIEL Kévin[(2)], VAURS Mathieu[(2)]

[(1)] AWE, Aldermaston, United Kingdom
[(2)] ITHPP, Thégra, France

ABSTRACT

In order to enhance capability to diagnose explosively driven hydrodynamic experiments, AWE, in concert with ITHPP, is building two new flash radiographic sources. These must be capable of outputting 20 Rads (CaF_2) at 1 m, within 100 ns, from a 1 mm source, with a Bremsstrahlung end point energy between 1 MeV and 2 MeV. To achieve this 2 MV, 650 kA, Pulsed Power Machines (PPMs) will be coupled to Plasma Filled Rod Pinch (PFRP) x-ray diodes. The PFRP diodes are pre-filled by plasma guns, in turn initiated by 25 kV, 25 kA Plasma Gun Drivers (PGDs). The PPMs are detailed in a parallel submission to this conference.

An integration test coupling together the first of each PPM, diode and PGD was conducted. During initial optimisation the plasma pre-fill conditions and the operating power of the PPM were adjusted, with implications on the output dose, source size, and reproducibility as well as the attrition rates of hardware. A suitable operating point was then rapidly found.

Diagnosis of the radiation field indicated that the system could exceed the requisite x-ray power whilst meeting the source size and x-ray photon energy metrics.

#08-2

DIELECTRIC QUALITY ASSESSMENT METHODS FOR COMPLEX CERAMIC TUBES USED FOR THE LHC INJECTION KICKER BEAM SCREENS

KEYNOTE SPEAKER

STADLBAUER Tobias, BARNES Michael, BRACCO Chiara, DUCIMETIERE Laurent, KONTELIS Dimitrios, KRAMER Thomas, TRUBACOVA Pavlina, WETERINGS Wim

CERN, Geneva, Switzerland

ABSTRACT

Fast pulsed magnets, which operate at high voltage, are used for deflecting injected beam onto the equilibrium orbit of the CERN Large Hadron Collider (LHC). A beam screen is placed in the aperture of these Injection Kicker magnets (MKI) to reduce heating of the magnet ferrite yokes by the circulating proton beams. The beam screen is a ceramic (alumina) tube with 24 conductors embedded in the inner wall. The inside of the tube has a semi-conductive coating (Cr2O3), which decreases beam induced surface charge up and the influence of unavoidable voids between the screen conductors and the ceramic tube. The magnet conductors are in close vicinity to the outside of the alumina tube and the fast pulsed magnetic field causes high voltages to be induced on the screen conductors. Hence, the ceramic tube is subjected to high electric fields and the dielectric quality of the tube must be reliable. Therefore, defects in the alumina tube must be quantified, before installation in the magnet, to prevent serious electrical breakdowns and thus project delays with significant downtime and cost. Extensive studies have been carried out to adapt standard quality control methods and to investigate possible new measurement methods. FEM simulations are conducted to optimize the measurement techniques. Several tubes with different production qualities and defects have been analyzed. Partial discharge measurements are compared to capacitive, magnetic, tomographic, microscopic, and visual results. A validated test concept is presented allowing simple preliminary tests during the manufacturing process, followed by detailed analysis in the high voltage (HV) laboratory to identify small defects, voids and cracks which could lead to serious problems in the future.

#08-3

A SOURCE OF PULSED BEAMS OF CHARGED PARTICLES BASED ON A DOUBLE PULSE GENERATOR

KEYNOTE SPEAKER

ZHURAVLEV Mikhail, REMNEV Gennagy, BUHARKIN Andrey, PYATKOV Igor, RYZHKOV Vladislav

Tomsk, Tomsk Polytechnic University, Russian Federation

ABSTRACT

The paper presents the design and parameters of an intense pulsed ion beam (IPIB) accelerator based on a generator of double high-voltage pulses of 40 ns duration with a pause between the pulses varied from 100 to 500 ns. The accelerator generator includes single and double forming lines charged by two synchronized high-voltage pulse generators of microsecond duration. The duration of the pause between pulses is determined by the synchronization system. Coaxial forming lines are filled with glycerin and include two gas spark gaps with stabilizing corona discharge. The polarity of both high-voltage nanosecond pulses of the generator can be reversed. The maximum output voltage of the first and second pulses is 200 kV and 450 kV, respectively. The generator output impedance is 13.5 ohms. The first pulse plays the role of a plasma-forming one. In studies on the collective acceleration of ions, the plasma on the anode dielectric insert is formed due to surface breakdown on a pulse of positive polarity. A comparison is made of the collective ion acceleration with and without preliminary plasma formation.

#08-4

CODE-TO-CODE BENCHMARKING OF 2D HIGH ENERGY BEAM TRANSPORT IN A GAS CELL

KEYNOTE SPEAKER

MEDINA Brandon[1], GRUA Pierre[2], HEBERT David[2], SZALEK Nicolas[3], GARDELLE Jacques[2], CARTWRIGHT Keith[1], MOORE Chris[1]

[1] Sandia National Labs, Albuquerque, USA
[2] CEA/CESTA, Le Barp, France
[3] Universite de Pau et des Pays de l'Adour, Pau, France

ABSTRACT

We present here code to code comparisons of high energy, collisional beam transport between the plasma/beam transport codes EMPIRE and GAZEL. The domain is a simple 2D conducting box filled with 0.1 mbar neutral Ar background gas and a relativistic (500keV) electron beam is injected into the domain, similar to the conditions in the RKA gas cell [1]. The EMPIRE code can be run as a fully kinetic Particle-In-Cell (PIC) problem with Direct Simulation Monte Carlo (DSMC) collisions or as a hybrid problem with both fluid and PIC charged species which collide with a background neutral fluid via fluid-fluid rate based interactions and PIC-fluid Monte Carlo Collisions (MCC) that produce a charged fluid of low-energy secondary plasma. GAZEL is a hybrid code in which utilizes deterministic collisions between the fluid and beam particles via a pseudo-fluid generated from space averages of the beam computational particles. We compare both fully kinetic EMPIRE results with hybrid EMPIRE and hybrid GAZEL results and find reasonably good qualitative agreement given that the simulations did not use identical interaction sets or cross section data. Quantitative comparisons of several quantities of interest will be performed and will be reported on.

[1] Gardelle, J. et al., ``Revisiting the propagation and focusing of a high intensity electron beam in a low-pressure gas cell'', 44th ICOPS, May 21-25, 2017.

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#08-5

EFFECTS OF VACUUM IMPEDANCE CHANGES ON MITL FLOW USING 3D ELECTROMAGNETIC PIC SIMULATIONS

KEYNOTE SPEAKER

POWELL Troy, CARTWRIGHT Keith, POINTON Timothy, BILLER Andrew, GRABOWSKI Theodore

Sandia National Labs, Albuquerque, USA

ABSTRACT

Vacuum impedance changes in Magnetically Insulated Transmission Line (MITL) flow has been shown via simulation to have profound impact on MITL flow patterns. Using EMPHASIS, a 3D Unstructured Time Domain Electromagnetics Particle-In-Cell (PIC) code, it was shown that the HERMES III extended MITL exhibits significant power loss due to changes in vacuum impedance.

Results are compared with those using QUICKSILVER, a structured EM PIC code and EMPIRE, another unstructured EM PIC/Fluid/Hybrid code. All codes agree with each other, and, more importantly, with experimental current measurements. Further evidence of electron loss in the MITL is given by strong thermoluminescent dosimeter (TLD) readings along the outer surface of the MITL anode.

The extended MITL on HERMES III has been redesigned with constant impedance and now shows considerably reduced current loss. It is shown that when delivering current to a Bremsstrahlung diode this increases the gamma dose measured on the external faceplate of the diode by at least a factor of two. As a result, doses measured at greater distances from the faceplate are also increased. Geometry choice as well as comparison between simulation and experimental performance of the redesigned MITL is reported and discussed. The new MITL has current sensors on both the anode and cathode at several locations along the MITL so the voltage can be estimated1,2 and that approximation can be compared to the simulations. Electron temperature in the MITL can have a large effect upon the estimated voltage2. The pressure was varied in simulation and compared to the experimental data to determine the approximate experimental electron temperature. These data are then correlated with the dose measurements made on the surface of the faceplate as well as at greater distances from the diode.

1. P. F. Ottinger and J. W. Schumer, “Rescaling of Equilibrium Magnetically Insulated Flow Theory Based on Results from Particle-In-Cell Simulations”, Physics of Plasmas Vol. 13, June 2006

2. P. F. Ottinger, J.W. Schumer, D. D. Hinshelwood, and R. J. Allen, “Generalized Model for Magnetically Insulated Tranmission Line Flow”, IEEE Transactions on Plasma Science, Vol. 36, No. 5,

#08-6

DEVELOPMENT OF SOLID-STATE SWITCH AND HIGH PRECISION CAPACITOR CHARGER FOR KICKER MODULATOR SYSTEM

KEYNOTE SPEAKER

KIM Tae-Hyun[(1)], BAE Jung-Soo[(1)], SON Seong-Ho[(1)], KWON Chang-Hyun[(1)], KIM Hyoung-Suk[(1,2)], YU Chan-Hun[(2)], AHN Suk-Ho[(3)], JANG Sung-Roc[(1,2)]

[(1)] University of Science and Technology, Daejeon, Korea, Republic of.
[(2)] Korea Electrotechnology Research Institute, Changwon, Korea, Republic of.
[(3)] Pohang Accelerator Laboratory, Pohang, Korea, Republic of.

ABSTRACT

Conventionally, thyratron has been used for many high-power systems. However, due to its drawback such as unpredictable lifetime, jitter and maintenance cost from replacement and auxiliary power supplies, lots of studies on solid-state switch to replace thyratron are being actively conducted. In this paper, development of an IGBT-based 15kV, 10kA solid-state switch and a high precision capacitor charging power supply (CCPS) for kicker modulator system is described. The targeted load is a kicker magnet which has 0.867uH and requires half sinusoidal current of 10kA less than 6us. On the basis of 32 IGBTs (SKM900GA12E4, SEMIKRON), a structure reducing the internal inductance of the developed switch is proposed in order to achieve the required current condition. The proposed structure also plays a role in moderating undesirable effect of magnetic field from the high current to peripheral components. In terms of synchronization of gate signals, multiple transformers sharing primary winding is applied. So as to neglect leakage inductance of each of transformers, a gate drive circuit including its own voltage source to attain fast raise of gate-emitter voltage is proposed. With respect to deliberate pulse reproducibility, the CCPS of 4kW power based on LCC resonant converter, which operates at switching frequency of 1MHz, is developed by using SiC MOSFET. Reliability test and experiment in actual system of the developed switch and the CCPS are being planned with Pohang Accelerator Laboratory (PAL). Detailed discussion will be done in conference.

#09-1

PULSED STREAMER DISCHARGE GENERATION WITH ARBITRARY WAVEFORM SOLID-STATE NANOSECOND PULSED POWER TECHNOLOGY

KEYNOTE SPEAKER

HUISKAMP Tom, AZIZI Mahdi, TON Chiel, VAN OORSCHOT Jeroen

Eindhoven University of Technology, Eindhoven, Netherlands

ABSTRACT

Recently, we developed the solid-state Impedance-matched Marx Generator (IMG) [1], with the purpose of nanosecond transient plasma generation; either for plasma activated water [2] or pulsed streamer discharges for air purification [3]. In this contribution we will present recent results on pulsed streamer discharge generation with a 10-kV version of a solid-state IMG. This IMG consists of eight 1.5-kV stages, where each stage comprises four parallel-connected SiC MOSFETs and each MOSFET is driven by a gate-boosting circuit to enable very fast switching [4]. The IMG is capable of 5-ns rise-time pulses on a resistive load and 6 to 7-ns rise time pulses on the load formed by the corona-plasma reactor in this study (we used a cylinder-wire reactors with an outer diameter of 16 mm and 20 mm). Because the stages of the IMG can be controlled at will, arbitrary waveform pulses can be generated. The purpose of the study was to perform some first experiments on waveform variation (e.g. rise time variation, stepped waveforms, etc.) and see the effects on the generated streamer plasma and if we can "control" the streamers with the IMG. For this purpose, we used an iCCD camera to observe the streamers. The results show that for these relatively low voltages and small plasma reactor dimensions the rise-time variation has little effect on the streamers (other than the time at which they start propagating) and that by using a stepped waveform we can "pause" the streamer propagation in the reactor, which is a first simple step in showing that we can indeed control the streamer propagation with arbitrary waveforms.

[1] T. Huiskamp and J. J. Van Oorschot, "Fast pulsed power generation with a solid-state impedance-matched Marx generator: Concept, design, and first implementation," IEEE Transactions on Plasma Science, vol. 47, no. 9, pp. 4350–4360, Sep. 2019.
[2] J.J. v. Oorschot, M. Azizi, A.J.M. Pemen and T. Huiskamp "Fast & Flexible Impedance-Matched Solid-State Marx Generator for PAW Generation," EAPPC 2020, Aug. 29 – Sep. 02 2021, Biarritz, France.
[3] M. Azizi, J.J. v. Oorschot and T. Huiskamp, "Ultrafast 30-kV nanosecond solid-state Impedance-matched Marx generator for transient plasma generation," EAPPC 2020, Aug. 29 – Sep. 02 2021, Biarritz, France.
[4] M Azizi, J. J. van Oorschot, T Huiskamp, "Ultrafast Switching of SiC MOSFETs for High-Voltage Pulsed-Power Circuits", IEEE Transactions on Plasma Science, vol. 48, no. 12, 2020.

#09-2

EXPERIMENTAL CHARACTERIZATION OF PULSED ARC UNDER WATER

KEYNOTE SPEAKER

THOUIN Julien[(1)], BENMOUFFOK Malyk[(1)]
FRETON Pierre[(1)], GONZALEZ Jean-Jacques[(1)]
RACINEUX Guillaume[(2)], MARCHE Emmanuel[(2)]

[(1)] Laboratoire LAPLACE, Université Paul Sabatier, Toulouse, France.
[(2)] Institut de Recherche en Génie Civil et Mécanique, Ecole Centrale Nantes, Nantes, France

ABSTRACT

The topic of this work is the study of a 10 millisecond underwater pulsed arc. These types of electric arcs are used in several industrial applications such as electrohydraulic forming, crushing, blasting and so on.

For these types of applications, the arc can be ignited either by applying over voltage between the electrodes leading to the propagation of an ionization front and the creation of a conducting channel or using a copper wire as a fuse element between the two electrodes. In both cases, the birth of a plasma channel expanding inside a water vapour bubble can be observed.

There is only a limited amount of information available on the arc under these conditions and it is necessary to understand the thermal plasma's physical properties, the arc's electrical characteristics and the different sources of loss in order to properly understand and optimize the electro-hydraulic conversion process.

Industrial applications use this rapid energy deposition process in order to generate underwater shock waves and use this electro-mechanical conversion shape or break up materials. Indeed, the rapid increase of temperature and pressure within the plasma channel, generates a primary shock wave and, later, a mechanical wave with the expansion of the plasma bubble.

The aim of our work is to characterize the plasma generated, which is located at the interface of the pulsed power and mechanical topics. Generally, studies analyse the energy efficiency by observing the electro-mechanical ratio. The plasma is rarely characterized.

In this work, we will prospect several kinds of measurements: determination of the plasma temperature with a high temporal resolution based on time-resolved emission spectroscopy measurements, high speed visualization of the plasma expansion, electrical characterization of the plasma column and cathode and anode sheaths. An energy balance will be proposed including electrode and radiation losses. The methodology of the spectroscopic analysis will be provided. This work was done with an arc duration of about 10ms. It is longer than characteristic times of these application (<1ms)

but it allowed us to build our experimental setup in simple configuration before changing the time scale in order to observe shorter discharges with rapid slow rate during the first half period. Eventually we would like to provide a complete characterization of the plasma for several time scales and determine main parameters in order to increase performances of the associated process. To complete this study, we have also developed a magneto-hydro dynamic model that we will try to validate with our experimental setup.

This work has been partially funded by the CNRS Energy unit (Cellule Energie) through the project PROFORMEI.

#09-3

ELECTRICAL DISCHARGES USED ACOUSTIC WAVEFORM GENERATORS

KEYNOTE SPEAKER

DELMOTE Philippe, BIETH François, HAMERY Pascal, DE MEZZO Sébastien

ISL, Saint-Louis, France

ABSTRACT

This study aims to evaluate the potential of electrical pulsed power to generate acoustic signals. The explosive nature of an electric arc is a well-known mechanism; the intense heat produced from the discharge causes a sudden expansion of air, resulting in a blast of significant amplitude. These fast pulses and the very high peak pressure levels exhibit a specific propagation behaviour. Depending on the emitted waveforms, such acoustical pulses can be seen as possible representatives of Mach waves (N-type waves), explosive charges or muzzle wave of a weapon (Friedlander-type waves). They are therefore of great interest for laboratory use.

Two types of configurations have been evaluated. First, systems based on high voltage discharges between a pair of electrodes, commonly known as spark gap switches, have been considered. A single source of high amplitude using a 17 stages Marx generator has been tested. This generator delivers an electrical discharge to an external spark gap equipped with adjustable electrodes. Thanks to the voltage multiplication inside the generator and the possibility to increase the charging voltage of each stage, the energy delivered to the sound generator drastically increases allowing to reach 162 dB SPL. The second experiment focuses on the synchronization of a pair of sound sources. In order to investigate this point, a dedicated system made of two Marx generator stages has been built. Both stages are remote controlled using a third electrode which is externally triggered. Measured sound levels exceeded the value of 120 dB SPL, enabling nonlinear propagation studies in laboratory.

The second type of test deals with the performances of a single source with an emphasis on the shape and the amplitude of the signal. Here, the proposed configuration consists of high current discharges into thin metallic wires. The electrical source is made of a 50 kJ capacitor (10 kV - 1 mF) connected to a Thyristor and a coil. During the discharge, the resistive heating vaporizes the wire and an electric arc through that vapour appears. Measured sound levels exceeded the value of 163.5 dB SPL (3000 Pa) during 200 µs, which is typical of detonations, but without using explosive materials.

First experiments have shown the potential offered by this technology in the field of acoustic research. Key points (amplitude, rise time, signal reproducibility) have been reached in this work. As perspectives, further improvement could be made to obtain a better source compactness and to allow tuning of the emitted waveforms (e.g. pulse positive phase duration).

#09-4

INFLUENCE OF FLUID STATIC PRESSURE AND TEMPERATURE ON ELECTRICAL DISCHARGES MODE IN LIQUIDS

KEYNOTE SPEAKER

IMBERT Tony[(1)], REESS Thierry[(2)], DE FERRON Antoine[(2)], PECASTAING Laurent[(2)], DEMOL Gauthier[(1)], GUEGAN Baptiste[(1)]

[(1)] ITHPP, Thegra, France
[(2)] Universite de Pau et des Pays de l'Adour, E2S UPPA, SIAME, Pau, France

ABSTRACT

Depending on practical applications in the field of electrical discharges in liquids, the controlling of the propagation mode of the electrical discharge is key. It is now well know that the breakdown voltage in tap water under atmospheric conditions is affected by the duration of the applied voltage. In one hand, pulses shorter than a microsecond induce supersonic propagation mode and breakdown fields can increase up to a few MV/cm. On the other hand, voltage impulses longer than a microsecond lead to a decrease breakdown field values (from 100kV/cm to a few tens of kV/cm) and to the subsonic propagation mode.

It is important to understand the influence of static pressure and temperature on the transition between the two discharge modes.

This paper presents an experimental study of a water gap voltage breakdown as a function of water pressure and temperature and particularly focused on the propagation time of the discharge phenomena in liquid in order to estimate the transition between modes. This transition between modes is directly linked to the electric field between electrodes, which is estimated by electrostatic simulations. While the value of the electric transition field is known around 300 kV / cm for tap water under atmospheric conditions, the study determined this threshold when the liquid pressure and temperature is higher. Tests were performed with different coaxial geometry electrodes and several storage capacitive benches. An energy balance of the discharge formation is obtained from this experimental data.

This presentation is complementary with a second one entitled "Influence of electrical conductivity on electrical discharges mode in liquids".

#09-5

INVESTIGATION OF PERFORMANCE OF SUPERSONIC UNDERWATER ELECTRICAL DISCHARGE AS A PULSED ACOUSTIC SOURCE

KEYNOTE SPEAKER

STOBBS Jessica, NOVAC Bucur M., SENIOR Peter, WOODYARD Matthew

Loughborough University, Loughborough, United Kingdom

ABSTRACT

The discharge characteristics of supersonic electrical breakdown of water are investigated for various electrode geometries, with particular attention to the influence the geometry has on the pressure disturbance produced, the most powerful component of which is produced upon the establishment of a plasma channel that bridges the electrode gap. Diagnostics include an ultrahigh-speed camera system which is used to observe the self-luminous, tendril-like structures that signify the prebreakdown stage, and the development of the plasma channel that signifies breakdown. Electrical diagnostics include measurement of current through the electrodes, the potential difference across them and a D-dot probe to provide insight into the level of electromagnetic radiation that is emitted with each impulse.

Finally, a study of the acoustic properties of this phenomenon is performed across a large bandwidth, with a hydrophone providing information relating to the duration, power, and frequency content of the impulse.

#09-6

PULSED ARC ELECTROHYDRAULIC DISCHARGES GENERATED BY CAPACITOR BANKS VERSUS MARX GENERATOR : CHARACTERIZATION OF GENERATED PRESSURE WAVES

KEYNOTE SPEAKER

BACQUEYRISSES Yoan[1,2], REESS Thierry[2], DE FERRON Antoine[2], TCHALLA Viviane[2], NOVAC Bucur M.[3,2], TUJAGUE Rémi[1], MORELL Alain[1]

[1] ITHPP, Thégra, France
[2] Universite de Pau et des Pays de l'Adour, E2S UPPA, SIAME, Pau, France
[3] School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, Loughborough, Leicestershire, United Kingdom

ABSTRACT

Due to energy and environmental constraints, the pulsed arc electrohydraulic discharge (PAED) technology is being currently studied for application in rock fracturing. A study of the peak pressure wave generated in water in free field is imperative to better understand the parameters influencing rock fracturing.

The main aim of this paper is to present a comparison between the PAEDs produced by different capacitor banks, ranging from 1 µF to 42 µF, and those generated by a high voltage Marx generator. The experimental arrangement is mainly composed of the high-energy generators discharging into water through a pair of submerged electrodes, with a set of diagnostic methods used for accurately obtaining both electric and acoustic data. During the tests, the charging voltage was varied from 5 kV to 40 kV for the capacitor banks and up to 300 kV for the Marx generator.

The main acoustic and electric results will be presented, together with the development of a phenomenological theory, to better understand the peak pressure wave variation with different electrical, geometrical and time related parameters. The conclusion of these studies allows the design of future very high-efficiency systems to be used in generating strong pressure waves in water.

#O10-1

MULTI-PROBE RADIOGRAPHY WITH LASER DRIVEN PARTICLES/X-RAY SOURCES

KEYNOTE SPEAKER

FAVALLI Andrea [1], BROUGHTON David [1], HUANG Chengkun [1], ILIEV Metodi [1], JUNGHANS Sylvia [1], LI F [1], PALANIYAPPAN Sasikumar [1], REINOVSKY Robert [1], SINGH P [1], CANDEIAS LEMOS N [2], MACKINNON A [2], PAK A [2], SALLEE R [3]

[1] Los alamos national laboratory, Los Alamos, USA
[2] Lawrence Livermore National Laboratory, Livermore, USA
[3] University of Michigan, Ann Arbor, USA

ABSTRACT

Fast, high precision, radiographic diagnostics using simultaneously probes of different species, (e.g. keV to MeV X-rays, keV to 10's MeV neutrons), and a variety of detection and recording techniques provide a valuable approach for diagnosing dynamic experiments and exploring static objects in both fundamental and applied applications. A multi-probe radiographic technique can be applied to examine the motion of material in high speed hydro-dynamic experiments with sub-microsecond time resolution; in experiments exploring the physics of high energy density plasmas; and in condensed matter to study shock-wave experiments. Similarly, the multi-probe approach can be applied to inspect the contents of containers, packages for global nuclear security applications.

Our team has been studying multi-probe radiography using short-pulse ultra-high intensity laser beams to produce high intensity X-rays and neutron bursts. The high intensity and very small source size of the laser-driven neutron/X-ray sources make them particularly suitable for radiography applications. Results of a recent campaign of experiments at the Laboratory for Laser Energetics, University of Rochester, will be reported. The experiments were performed at the Omega EP facility, where a combination of a short-pulse laser and long pulse lasers were used to produce both the probing source and to drive a representative dynamic, as a condensed matter experiment. In the second part of the talk, we will report and discuss the results obtained at LANL Trident laser facility in producing both an intense neutron pulsed source and a high intense X-ray pulsed source for multi-probe radiography of special nuclear materials.

#O10-2

AN ULTRA PORTABLE X-PINCH FOR PROBING WARM DENSE MATTER

KEYNOTE SPEAKER

BLAND Simon[(1)], STRUCKA Jergus[(1)], YAN Jiaqi[(1,2)], PARKER Susan[(1)], SCHWARTZ Nick[(2)]

[(1)] Imperial College London, London, United Kingdom
[(2)] Xi'an Jiaotong University, Xi'an, China
[(3)] University of Illinois, Illinois, USA

ABSTRACT

Determining the properties of Warm Dense Matter (WDM) necessitates the use of advanced X-ray based diagnostics including diffraction and absorption spectrometry. As many experiments that produce WDM do so for only a few ns, the probing X-rays must be short pulsed, ideally with a high enough yield to produce data on a single experiment. They must also have the correct spectral characteristics – e.g. having a smooth continuum for absorption spectrometry. Such requirements often restrict experiments to large scale facilities like 3rd generation Synchrotrons and XFELs, which have exemplary capabilities, but can also have very limited time available for individual users.

At Imperial College we have been developing several X-pinch based X-ray sources to provide a complementary capability to large facilities, with the aim of promoting 'in house' WDM research at Universities. This would encourage new researchers in the field and provide a method to optimize experiments prior to their use elsewhere. In an X-pinch two or more crossed fine metallic wires are driven by a fast rising current pulse. The magnetically driven implosion of the crossing point emits a short pulse of X-rays that could then be utilized for diagnostics - however, at present, X-pinches are relatively unknown outside the pulsed power community with the complexity of their drivers and lack of portability hampering wide-spread use.

We report on new X-pinch systems that are extremely portable (~50kg) and designed to be easy to use. The X-pinches are capable of currents >100kA and emit ~100mJ of >10KeV radiation on ns timescales. We present the results of radiography, spectrometry and diffraction experiments utilizing these X-pinches, and discuss their continued development. The latest design includes solid-state triggering systems, inbuilt charging and could rely on new 3D printing techniques for its insulating structure.

Acknowledgements: This research was supported by EPSRC, First Light Fusion, Sandia National Labs and the US DoE under DE-NA003764 & DE-SC018088.

#O10-3

AN INDIRECT ITERATIVE METHOD TO COUPLE THE GENERATOR TO MHD LOAD FOR FUTURE Z-PINCH

KEYNOTE SPEAKER

ZHOU Quan, ZOU Xiaobing, WANG Xinxin

Tsinghua University, Beijing, China

ABSTRACT

For the future Z-pinch accelerator, the radiation-magneto-hydrodynamics (MHD) simulation of the load is urgently needed to investigate its performance. And more accurate results can be obtained if a detailed generator model is coupled to the MHD model. However, because of the non-TEM modes in the monolithic radial transmission lines (MRTLs), the field-circuit coupling model for the generator is too complex to be coupled to the MHD model directly. Therefore, an indirect iterative method is proposed. In this method, the load is simplified to a resistor and an inductor connected in series.

The iterative loop n is: using the load current Iload,n-1(t) calculated in the previous loop, the MHD model calculates the load resistance Rload,n(t) and load inductance Lload,n(t) in a complete calculation time; using the load parameters Rload,n(t) and Lload,n(t), the field-circuit coupling model calculates the load current Iload,n(t) in a complete calculation time. The initial load current Iload,n=0(t) is obtained from the field-circuit coupling model connecting the zero-dimensional model for the load. The loop continues until the load current converges. Using a simple drive source, the reliability of this method is proved and then it is used for the simulation of Z800 accelerator, a future Z-pinch accelerator, with wire array.

After three iteration loops, the final parameters, such as the load current and radiation power are obtained. The indirect iterative method is useful for evaluating the load performance in a coupled load generator system without the need for a lot of code development on the already established MHD model.

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#O10-4

PHELIX CONTAINMENT CASSETTE - DESIGN AND VALIDATION TESTING

KEYNOTE SPEAKER

GARCIA Vincent, ROUSCULP Christopher, ORO David, HUDSPETH Matthew, FREDENBURG David, LLOBET Anna, GRIEGO Jeffry, ZOCHER Marvin, RIGLIN Jacob, NEUKIRCH Levi, REINOVSKY Robert, FREEMAN Matthew, BRADLEY III Joseph, MERRILL Lee, GAUS Henry, FIERRO Franklin, LAMAR John, DONOVAN Patrick, OLIVAS Eric

Los Alamos National Laboratory, Los Alamos, USA

ABSTRACT

The Precision High Energy-Density Liner Implosion Experiment (PHELIX) magnetic implosion system has been used for many pulse power research applications, including high energy materials research and hydrodynamic instability characterization. PHELIX's portable and modular design enables the system to be reconfigured for each experiment at different sites. The PHELIX cassette is the primary component which undergoes redesign to accommodate the varying experimental requirements. The cassette consists of an anode, cathode, insulator, interface to the transformer, a magnetic field generating window, a cylindrical driver, target window, and target.

The latest cassette design covered in this paper prioritizes containment via three primary design enhancements that also maintain the high electromechanical efficiency needed to propel the cylindrical driver to 1km/s with approximately 90kV. The first improvement is the capability to isolate target window contents before and after liner implosions. The added benefit of this self-contained cassette is its ease of installation and removal as one piece. The second design improvement is a symmetrical magnetic field window which improves the B field uniformity and ultimately the uniformity of the driving force applied to the target. The third improvement is the axial opacity optimization for proton radiography. Verification and Validation of the design included the use of hydrodynamic modeling, Finite Element Analysis, and testing at both a component and system level.

The new containment PHELIX cassette design adds to the system's modular capabilities and opens the door to a suite of new experimental opportunities. Examples include accommodating experiments currently limited to 1-D flyer plate configurations due to the lack of containment abilities, exploratory research into pulsed power cartridge technology, and other high hazard experiments examining implosion characteristics of materials.

#O10-5

SKIN ELECTRICAL EXPLOSION OF FLAT CONDUCTORS

KEYNOTE SPEAKER

CHAIKOVSKY Stanislav[1,2], DATSKO Igor[1], LABETSKAYA Nataly[1], VAN'KEVICH Vladislav[1], ORESHKIN Vladimir[1]

[1] *Institute of High Current Electronics of the Siberian Branch of the Russian Academy of Sciences, Tomsk, Russian Federation*

[2] *Institute of Electrophysics of the Ural Branch of the Russian Academy of Sciences, Ekaterinburg, Russian Federation*

ABSTRACT

Studies of the skin electrical explosion of conductors are of interest for various applications. One of the problems is associated with the current losses in the magnetically insulated transmission lines of the pulsed generators capable of producing currents of amplitude 30–50 MA and rising time of 100 ns that are currently being developed. Such pulsed power machines are supposed to be used for controlled thermonuclear fusion based on Z pinches. Experiments with electrically exploding copper foils of thickness 100-200 microns and width 5-10 mm were performed on a MIG generator at current up to 2.5 MA and its rising time 100 ns. The estimates have indicated that the magnetic field enhancement at the foil edges may result in the formation of a shock wave propagating from the foil edge to its center. Using a four-frame optical camera with an exposure time of 3 ns the self-emission of the foil surface was registered. The different stages of plasma formation and instability development, in particular, formation of a plasma channel along the foil longitudinal axis were captured. Experimental results will be presented and discussed in the paper.

The work was supported by the Russian Science Foundation (grant No. 20-19-00364).

#O10-6

CALCULATION STUDY OF THE Z-PINCH DYNAMICS OF RESISTIVELY THICK ALUMINUM RODS

KEYNOTE SPEAKER

KREHER Seth[1,2], ROUSCULP Chris[1], BAUER Bruno[2], KLEMMER Aidan[2]

[1] *Los Alamos National Laboratory, Los Alamos, USA*
[2] *University of Nevada, Reno, Reno, USA*

ABSTRACT

The fundamental limits of high-current conduction are of interest to magnetically driven ICF and other applications. Nonlinear Ohmic heating and conductor motion lead to instabilities such as the Electrothermal Instability (ETI) and Magneto-Rayleigh Taylor (MRT) that disrupt current flow. Here, the LANL, resistive MHD code, FLAG, is used to model well-diagnosed, uncoated Al rod loads (R0 ~ 400 mm > skin-depth) in a Z-pinch configuration fielded on the Sandia Mykonos pulse generator (trise ~ 0.1 ms, Ipeak ~ 1 MA). Results are compared to PDV measurements. Initial rod compression due to Lorentz forces in the solid state agree well with experiments. After melt, during expansion, results with a tabular EOS that utilizes Maxwell constructs in the bi-phase region show better agreement to data than ones with Van der Waals loops. As predicted, the state of the outer layer of the rod follows the liquid/vapor coexistence curve. Finally, calculational sensitivity to EOS and conductivity are studied to better understand the expansion dynamics.

#O11-1

DEVELOPMENT AND TEST OF A HIGH POWER CONVENTIONAL PULSER FOR RADIOGRAPHY APPLICATION

KEYNOTE SPEAKER

BAYOL Frederic[(1)], COE Anthony[(1)], GASTON Clement[(1)], GOUY Pierre-Alban[(1)], LAASRI Abdellah[(1)], LAPORTE Patrice [(1)], MOULY Patrick[(1)], PIASER Arthur[(1)], VAN DE WIEL Kévin[(1)], VAURS Mathieu[(1)], JONES Aled[(2)], EVANS Matt[(2)], HAYNES John[(2)], RUTLEDGE James[(2)], WILLIAMS Phil[(2)]

[(1)] ITHPP, Thégra, France
[(2)] AWE, Aldermaston, United Kingdom

ABSTRACT

This work concerns the development and testing of a radiography pulser (~2MV, 650kA, ~100ns) to improve the hydrodynamics testing capabilities of the Atomic Weapons Establishment (AWE) in Aldermaston (UK). Two pulsers to be built and validated to fire on a Plasma Filled Rod Pinch diode (PFRP) to provide two ultra-bright X-ray sources will be installed on two-radiography axis separated by 45° (see parallel submission in this conference). The machines have a handed design to accommodate their installation in a refurbished building. The design uses a high voltage high-energy 20 stage balanced Marx charged at a maximum of +/-100kV.It uses specifically developed switches operating under pressurized dry air. The machines do not use any SF6. This Marx is fired with a small jitter to charge a ~50ns deionized water Pulse Forming Line up to a maximum voltage of ~4.2MV (with the Marx operating at +/-90kV). The discharge of this line occurs thanks to a multi-channel triggered oil switch providing a low inductance and associated fast switching. The ~100ns width pulse generated is transmitted by a water transmission line to a vacuum chamber using a radial monolithic interface. This output is similar to the Naval Research Laboratory Gamble II generator on which the AWE has developed and tested its PFRP diode. Initially, the generator was tested on a resistive load prior to using a Large Area Diode providing the ~3Ohm expected impedance. The Marx tank has a double hydraulic actuator operated side-hanging door under which the Marx can slide out and hang for ease of assembly and maintenance.

This publication will present the electrical and general mechanical design of these generators. It will highlight the main troubles encountered throughout testing and will describe and detail the various improvements. Finally, it will relay the test results on both the resistive load and the LAD. The first generator has been delivered to AWE and the second is under testing.

#O11-2

CHARACTERISTIC RESEARCH OF THE PROPYLENE CARBONATE AFTER NANO- MODIFICATION

KEYNOTE SPEAKER

ZHANG Zicheng, LI Diangeng, HOU Yanpan, ZHANG Jiande, LIU Shifei

National University of Defence Technology, Changsha, China

ABSTRACT

Propylene carbonate (PC), has the advantages of great permittivity, high dielectric insulating strength and wide range of environmental adaption. However, the applications of propylene carbonate in pulsed power system has been restricted by the significant polarity effect (differences between the positive breakdown strength in positive polarity and the negative breakdown strength). In this paper, the breakdown characteristics of PC under microseconds pulse have been systematically studied by adding nano-particles. The results show that the breakdown strength of pure PC in the positive polarity is about twice that of the negative polarity. While after nano modification, the breakdown strength in the negative polarity increases significantly with the breakdown strength in the positive polarity decreases significantly, which significantly reduces the difference of withstand voltage. In addition, the nano-particles can reduce the dielectric strength difference between the cathode and anode under the quasi homogeneous field. The energy band theory of nano-fluids (NFs) was established to analyse the breakdown characteristics of NFs. Finally, NFs were applied in pulsed forming line (PFL) of pulsed power source, and the pulsed power source can operate with 20 GW output power and 65 ns duration at 5 Hz rep-rate across a 10 Ω vacuum diode load.

#O11-3

250KV/60NS HIGH-PULSED POWER GENERATOR FOR THE 3RD AXIS OF EPURE FACILITY

KEYNOTE SPEAKER

CADILHON Baptiste [1], VERMARE Christophe [1], MARCILLIERE Guillaume [2], BOGULAWSKI Adrien [2]

[1] CEA, Le Barp, France.
[2] ITHPP, Thegra, France

ABSTRACT

EPURE is a three axis flash radiography facility which will be operational in three axis configuration by the end of 2022 in Valduc, France. The 3rd axis x-ray machine is a Linear Induction Accelerator (LIA). It uses mostly the same technologies as the 1st Axis, AIRIX, with the main exception being that the 32 HV generators are replaced by 16 HV generators of a new design, developed at CEA and fabricated in collaboration with ITHPP.

The generator produces a negative and rectangular high-voltage (HV) 250 kV pulse, with a 60 ns voltage plateau. Two simultaneous pulses are created from the discharge of two parallel 500 kV, 12.5 Ω water pulse forming lines. Main air pressurized spark-gap switches are triggered by a low divergence 266 nm Nd:YAG laser to minimize the trigger jitter.

The HV pulse is designed to accelerate an electron beam using vacuum induction cells. Each of the 16 generator powers a block of four cells. Electrical energy is transmitted to these cells by eight 50 Ω / 300 kV cables.Generators and induction cells are currently assembled in Valduc. On-site HV tests are performed to prepare the accelerating line for final commissioning. We present here the final design of the generator and its electrical performances.

#O11-4

FAST & FLEXIBLE IMPEDANCE-MATCHED SOLID-STATE MARX GENERATOR FOR PAW GENERATION

KEYNOTE SPEAKER

J.J. VAN Oorschot, AZIZI M., PEMEN A.J.M., HUISKAMP T.

Electrical Energy Systems, Eindhoven University of Technology, Eindhoven, Netherlands

ABSTRACT

In this contribution we present a 20-stage Marx generator for Plasma activated water (PAW) generation. The generator is flexible in output voltage (0-20kV), rise time (5ns-us), pulse width (20ns-100us), repetition rate (0.1Hz-20kHz) and voltage shape. It features a coaxial output connection with integrated D-dot and B-dot sensors for voltage and current measurement. Currents of up to 500A can be delivered, reaching 10MW peak pulse power. A continuous power delivery of 1kW to a load is measured at about 90% efficiency. By using the impedance-matched topology as developed in Sandia [1] and proven in [2], the inductance is kept low and the rise time of the generated pulses can be maintained at the output waveform. An FPGA control system is used to accurately and individually control the switching of each stage at 2.5ns precision. The control system allows for delay-calibration in switching the stages at the same time, droop compensation of the output pulse and live changing any of the pulse parameters during operation. Furthermore, because of its flexible pulses and high output currents, many kinds of loads can be connected. The generator is specifically designed for plasma generation for the generation of Plasma Activated Water (PAW) [3] to investigate the relation between the high voltage pulse shape and PAW generation.

[1] W. A. Stygar et al., “Impedance-matched Marx generators,” Phys. Rev. Accel. Beams, vol. 20, 040402 (2017)

[2] T. Huiskamp et al., “Fast Pulsed Power Generation with a Solid-State Impedance-Matched Marx Generator: Concept, Design and First Implementation”, IEEE T. Plasma Sci., vol. 47, 4350 - 4360 (2019)

[3] A.J.M. Pemen et al., “Power Modulator for High-Yield Production of Plasma-Activated Water,” IEEE Transactions on Plasma Science, vol. 45, no. 10, pp. 2725–2733, Oct. 2017, doi: 10.1109/TPS.2017.2739484.

#O11-5

DETAILED ANALYSIS AND INTERPRETATION OF THE MERLIN INDUCTIVE VOLTAGE ADDER COMMISSIONING DATA

KEYNOTE SPEAKER

SINCLAIR Mark

AWE, Reading, United Kingdom

ABSTRACT

The MERLIN IVA successfully completed its commissioning in the UK in 2019 and is now in the process of being dismantled, shipped and rebuilt in France. The gap in operations has given the opportunity to perform a detailed analysis of the electrical and other data that was recorded.

This presentation will give an overview of the results and data that has been obtained, for the Marx generator, oil line, PFL operation and the MITL. The data for the MITL operation is of particular interest as MERLIN has the rare feature in IVAs in that the load is time isolated from the rest of the machine so that load effects only become visible after the electrical pulse has finished. As the load is undermatched to the drive impedance, this decoupling has enabled the tracking of various features of operation, in particular the retrapping wave that comes back from the load.

#O11-6

FPGA BASED PROGRAMMABLE PULSE GENERATOR FOR SOLID-STATE MARX GENERATORS

KEYNOTE SPEAKER

VAN OORSCHOT Jeoreen, AZIZI Madhi, HUISKAMP Tom

Electrical Energy Systems, Eindhoven University of Technology, Eindhoven, Netherlands

ABSTRACT

In this contribution, we present an FPGA control system to generate the control signals needed for our Flexible Solid-State Marx generator (see [1]). The control system generates (at least) 20 individual control signals with 2.5ns precision and up to seconds in length. It is implemented on a Pynq-Z2, a cheap FPGA development board with embedded ARM SoC. The system is live-reprogrammable, so the Marx output pulse shape can be changed multiple times per second. Furthermore, bursts of pulses can be made by repeating a pulse shape. An interface in Python takes care of translating Marx pulse shape to control signals, including calculating deadtime. This interface can be combined with any measurement system to create a feedback loop. For instance, an oscilloscope can measure the Marx output pulse and tune the control signals to improve the measured waveform. Alternatively, the system can be connected to a plasma diagnostics system and change the pulse shape based on the plasma behavior. Finally, we present some preliminary results on future improvements, including a delay system using programmable delay lines in the FPGA to reduce the time precision from 2.5 ns to about 20ps.

[1] J.J. v. Oorschot, M. Azizi, A.J.M. Pemen and T. Huiskamp “Fast & Flexible Impedance-Matched Solid-State Marx Generator for PAW Generation”, EAPPC 2020, Aug. 29 – Sep. 02 2021, Biarritz, France.

#O12-1

A LINEAR INDUCTION ACCELERATOR AS THE 3RD FLASH RADIOGRAPHY SOURCE OF THE FR-UK EPURE FACILITY

KEYNOTE SPEAKER

VERMARE Christophe [1], BOHEZ Wilfried [1], CADILHON Baptiste [1], CARON Michel [1], CASSANY Bruno [1], COURTOIS Laurent [1], FOURMENT Claude [1], GALTIE Alain [1], GEORGES Alain [2], GUILHEM David [1], HABLIZIG François [1], MAISONNY Rémi [3], MODIN Patrick [1], NICOLAS Rémi [2], NICOLOSO Joël [4], PASINI Eric [1], POULET Frédéric [2], SOUTENAIN Philippe [1], WOLFF Hervé [2], DU RUSQUEC Aymar [5], GROSSET-JANNIN Antony [6], DEWET Philippe [7], FENOLAR Cédric [7], PIREYRE Thomas [7]

[1] CEA/DAM, Le Barp, France
[2] CEA/DAM, Is-sur-Tille, France
[3] CEA/DAM, Gramat, France
[4] CEA/DAM, Bruyères-le-Châtel, France
[5] THALES, Vélizy, France
[6] SEIV, Mérignac, France
[7] Cap Gemini, Mérignac, France

ABSTRACT

A new Linear Induction Accelerator (LIA) will be commissioned in 2022 on the EPURE Facility in France. This accelerator will act as an intense Flash X-rays source dedicated to hydrodynamic experiments radiography. The ongoing manufacturing and installation on the CEA VALDUC site is part of the phase #2 of the French / UK TEUTATES program. This source will be used on the 3rd axis of this Facility. LIAs used for flash radiography share specifics performances as relative low electron beam energy (15-20 MeV), high current (2-3kA) and short pulse duration (50-80 ns). The major sub-systems are: an injector, several induction cells and HV generators, a target assembly and additional equipment as fast debris blocker and beam-stop.

The propose contribution focuses on the scientific and technical challenges of such LIA, takes opportunity to describe the EPURE facility and will be completed by some project details as overall cost, planning and industrial contributions.

#O12-2

NUMERICAL SIMULATION OF PHELIX SHALLOW CASSETTE LINER PERFORMANCE TESTS

KEYNOTE SPEAKER

ZOCHER Marvin, ROUSCULP Christopher

LANL, Los Alamos, USA

ABSTRACT

Precision High Energy Density Liner Implosion Experiment (PHELIX) is the name given to a Los Alamos National Laboratory (LANL) developed compact pulsed-power platform that can be used to investigate the response of media to intensive dynamic loading. A variant of the PHELIX platform that has been recently developed incorporates a new shallow cassette design configuration. This new shallow cassette configuration was designed with two major enhancements in mind: (1) improved containment/confinement capabilities, and (2) ease of installation and removal of the sample cassette. In preparation for conducting tests involving the implosion of materials of interest, two performance tests were conducted for the purpose of evaluating liner performance: one with a driving potential of 70 kV, the other with a driving potential of 75 kV. These produced peak currents of about 2.76 and 2.86 MA, respectively; and peak velocities of about 1200 and 1400 m/s, respectively. The primary diagnostics in these experiments involved the measurement of currents (using Faraday guages) and velocities (using PDV probes).

The focus of this work relates to the modeling of these two tests using LANL-developed numerical methods. The experiments were modeled using the finite volume continuum mechanics code FLAG. The experiments were modeled assuming 2d axisymmetry. In discussing this work we shall provide details of the numerical modeling as well as comparisons of predicted values of current and velocity to empirical data. We shall include discussions of the various approximations and simplifications that were used in our modeling along with an assessment of the impact of those approximations and simplifications. We shall include discussions related to our modeling approach including meshing considerations, nodal relaxation, and the like.

#O12-3

GENERATION OF HIGH-POWER WIDEBAND TERAHERTZ RADIATION IN LONG-PULSE LINAC-BASED FREE ELECTRON LASERS

KEYNOTE SPEAKER

GINZBURG Naum, KOCHAROVSKAYA Ekaterina, SERGEEV Alexander, FIL'CHENKOV Sergey, MALKIN Andrey

Institute of Applied Physics RAS, Nizhny Novgorod, Russian Federation

ABSTRACT

We construct a quasi-linear theory of free electron lasers (FELs), in which kinetic regime of electron-wave interaction occurs due to the use of intense electron beams with significant velocity spread. Under assumption of the field accumulation in a high quality resonator, we find the stationary distributions of spectral density of the excited resonator modes at various levels of the beam current exciding its threshold value. For the current significantly exceeding this value, a plateau is shown to emerge in the energy distribution function of electrons with a width proportional to the oscillation bandwidth. We estimate the parameters in application to long-pulse FELs which under development based on the linac at the Budker Institute (Novosibirsk). We demonstrate the possibility of efficient transformation up to 10% of energy of relativistic electron beam with a current of 250A, particles energy of 4.5 MeV and the initial energy spread of 3% into the wideband THz radiation with a power up to 100 MW. Unlike the existing THz FELs, the radiation is represented by single long pulses with a duration of up to 200 ns and with an energy content of up to 20 J.

This work was supported by RSF grant No. 19-12-00212.

#012-4

ANALYTICAL CALCULATIONS AND NUMERICAL SIMULATIONS OF INTENSE RELATIVISTIC ELECTRON BEAM GENERATION AND TRANSPORTATION IN A SMOOTH CYLINDRICAL WAVEGUIDE

KEYNOTE SPEAKER

ISLAM K. Nusrat, ANDREEV Andrey D., SCHAMILOGLU Edl

The University of New Mexico, Albuquerque, USA

ABSTRACT

The aim of this study is to compare results of computer particle-in-cell (PIC) simulations of a thin annular electron beam generation and transportation in a smooth cylindrical waveguide (SCW) immersed into a strong magnetic field with analytical theory to calculate the Fedosov-Belomytsev current. The simulation results are obtained using the MAGIC PIC code for the experimental vacuum diode geometry of the SINUS-6 high-current electron beam accelerator. The analytical results are obtained by calculating the Fedosov-Belomytsev current for a thin annular electron beam generated from the cathode inside an SCW and accelerated downstream of the problem from zero initial kinetic energy of electrons at the cathode. The analytical solution is based on an electrostatic calculation of the electric field potential in the cathode region immersed in an infinite magnetic field. This leads to the calculation of the Fedosov potential by considering two initial conditions determining, respectively, the anode and the cathode potentials. The Fedosov-Belomytsev current is subsequently calculated as the vacuum current limit determined by the Fedosov potential and the cathode-anode potential difference. Results of MAGIC simulations show that the kinetic energy of electrons at some distance from the cathode, where electrons cease to accelerate downstream of the cathode, is determined by the electrostatic Fedosov potential. PIC simulations and analytical calculations show good agreement. Comparison of the obtained results with experimental measurements on the SINUS 6 Accelerator are discussed in a companion presentation, “Experimental Measurements, Numerical Simulations, and Analytical Calculations of Intense Relativistic Electron Beam Parameters on the SINUS-6 High-Current Electron-Beam Accelerator.”

This work is supported by AFOSR MURI Grant FA9550-20-1-0409.

#O12-5

EXPERIMENTAL STUDIES OF ELECTRON BEAM PROPAGATION IN ARGON

KEYNOTE SPEAKER

SZALEK Nicolas[(1)], GARDELLE Jacques[(2)], HEBERT David[(2)], GRUA Pierre[(2)], MEDINA B. M.[(3)], MOORE Chris[(3)], CARTWRIGHT Keith[(3)]

[(1)] UPPA, Pau, France
[(2)] CEA/CESTA, Le Barp, France
[(3)] SNL, Albuquerque, USA

ABSTRACT

The recent progress of the joint Sandia National Laboratories (SNL) and CESTA experiment are presented. The RKA generator is set to produce a 500 keV, 3 kA electron beam [1]. This beam propagates in a 400 mm-long cylindrical experimental chamber filled with Argon at pressure varying from 10-4 up to 1 mbar. This chamber is installed after the diode whose anode foil ensures insulation between gas and vacuum.

The experimental diagnostics include standard electrical measurements such as B-dot probes and capacitive dividers. A Rogowski coil measures the beam current which passes through the anode foil. Then, the propagated current is monitored as a function of distance inside the chamber thanks to a movable Faraday Cup.

A 4-images frame camera is used to observe two kinds of visible light emissions. First, when the beam impinges a movable silica plate, it emits Cerenkov light that is analyzed to provide information on spatial and temporal electron beam homogeneity. Secondly, because the chamber is equipped with two transparent lateral windows, beam path and plasma light can be observed.

In addition, a PDV system and a microwave interferometer can be installed close to the lateral windows in order to estimate plasma electron density.

The aim of these studies is to use the experimental data to validate both the EMPIRE code developed at SNL [2] and the CALDER code at CEA [3].

We present the most recent experimental results which are then compared with the results of simulations.

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[3] F. Pérez, L. Gremillet, A. Decoster, M. Drouin and E. Lefebvre, Phys. Plasmas 19, 083104 (2012)

#O12-6

XRAM GENRATOR INVESTIGATION WITH A 1MJ DEMONSTRATOR

KEYNOTE SPEAKER

BERARD Maxime, BROMMER Volker

French-German Research Institute of Saint-Louis, Saint-Louis, France

ABSTRACT

The electric power supply for an electromagnetic launcher has to provide energy in the mega-joule range within an acceleration time which only lasts for milliseconds. Today's giga-watt pulsed power generators are based on large capacitor banks and are therefore unsuitable for most mobile applications. Thus, power supply research focuses on size reduction by means of alternative technologies like inductive storage. The XRAM topology, in which several inductors are charged in a series connection and discharged in a parallel connection, is a concept for inductive current multiplication. This technique requires simultaneous switching of closing and opening switches and was realized by using thyristors which are turned off by a counter-current pulse (inverse current commutation with semiconductor devices - ICCOS). At the French-German Research Institute of Saint-Louis, several aspects of this technology have been investigated and several demonstrators for different energies have been developed. Nowadays, the development of inductive pulsed power generators advances towards energy levels relevant for future applications. This contribution presents the development of a 1 MJ XRAM generator which demonstrates the suitability of this technology by supplying the medium-caliber ISL railgun RAFIRA during dynamic experiments. Experimental results are presented, where the XRAM generator was charged to 842 kJ with a current of 40 kA. This current was successfully commutated and 10 times multiplied by the ICCOS opening switches. An 80 g brush projectile was accelerated to 1120 m/s within the ISL's railgun RAFIRA. The railgun current was switched off at the time of the projectile's bore-exit, thus approximating a rectangular current pulse shape. Those results are compared to data recordings of Experiments with capacitor banks as railgun power supply.

#O13-1

STRUCTURE AND DYNAMICS OF PULSED-POWER DRIVEN ROTATING LABORATORY PLASMAS

KEYNOTE SPEAKER

VALENZUELA-VILLASECA Vicente[(1)], SUTTLE Lee G.[(1)], ONG Liina[(1)], SUZUKI-VIDAL Fransisco[(1)], HALLIDAY Jack W. D.[(1)], RUSSELL Danny R.[(1)], MERLINI Stefano[(1)], MIRFAYZI Reza S.[(1)], CHITTENDEN Jeremy P.[(1)], KOEPKE Mark E.[(2)], HARE Jack D.[(3)], TUBMAN Eleanor R.[(4)], LEBEDEV Sergey V.[(1)]

[(1)] Imperial College, London, United Kingdom
[(2)] West Virginia University, Morgantown, USA
[(3)] Massachusetts Institute of Technology, Boston, USA
[(4)] Lawrence Livermore National Laboratory, Livermore, USA

ABSTRACT

We present experiments on pulsed-power-driven differentially rotating plasmas with applications to astrophysical accretion disks and jets [1, 2]. The experiments are conducted on the MAGPIE generator (1 MA, 500 ns duration), which drives the oblique convergence of 8 individual plasma jets producing a hollow-like, rotating plasma column. The set-up also drives a highly collimated jet propagating axially from the rotating plasma column, similar to the jets accelerated from accretion disks in astrophysical environments.

The formation and the temporal evolution of the axial outflow are observed using both optical and extreme ultraviolet (XUV) self-emission imaging diagnostics, whilst laser interferometry provides measurements of the density depletion at the outflow axis. Optical Thomson scattering measurements show that the outflow is differentially rotating with a maximum rotation velocity of 20 km/s, with a velocity distribution consistent with a quasi-Keplerian flow. The role of the magnetic field in the outflow collimation is discussed. The measured electron and ion temperatures and electron temperature ~ 30 eV and ~ 50 eV, from which the laboratory plasma can be inferred to lie in the low-magnetic-Prandtl-number regime Pm ~ 10^−3, comparable to the regime associated with protostellar accretion disks.

#O13-2

HIGH PULSED MAGNETIC FIELD SENSOR BASED ON HYBRID CO-SUBSTITUTED MANGANITE/GRAPHENE STRUCTURE

KEYNOTE SPEAKER

NERIJA Zurauskiene[1,2], RASUOLE Lukose[1,3], SKIRMANTAS Kersulis[1], VOITECH Stankevic[1,2], MYKOLA Koliada[1], VALENTINA Plausinaitiene[1,4], SAULIUS Balevicius[1]

[1] Department of Functional Materials and Electronics, Center for Physical Sciences and Technology, Vilnius, Lithuania
[2] Faculty of Electronics, Vilnius Gediminas Technical University, Vilnius, Lithuania
[3] IHP – Leibniz-Institut für innovative Mikroelektronik, Frankfurt (Oder), Germany
[4] Faculty of Chemistry and Geosciences, Vilnius University, Vilnius, Lithuania

ABSTRACT

An increasing demand of magnetic field sensors with high sensitivity at room temperatures and spatial resolution at micro-nanoscales has resulted in extensive investigations of physical phenomena in advanced materials, and development of novel devices. For measurement of pulsed magnetic fields in scientific and industrial equipment the specific requirements for the sensor's design and increased field ranges of operation have to be satisfied. It has been demonstrated that nanostructured manganite films exhibiting negative colossal magnetoresistance (CMR) effect can be successfully used for magnetic field sensors operating up to megagauss. The demand of magnetic field sensors with scaled effective volume resulted in the research of magnetoresistive properties of two-dimensional (2D) materials such as graphene, which has a very high mobility of charge carriers. The graphene exhibits Lorentz force induced positive magnetoresistance phenomenon and can achieve large magnetoresistance (MR) values at high magnetic fields, however, at low fields the MR is low due to classical quadratic dependence on field. On the contrary, the nanostructured manganite films show significant MR at low fields.

In this study, the results on the development of magnetic field sensor based on a combination of nanostructured Co-substituted manganite La-Sr-Mn-Co-O film and single/few-layer graphene are presented. The ways to increase the sensor's response signal and sensitivity optimizing the manganite growth technology and graphene layer configuration are demonstrated. It was obtained, that the hybrid manganite/graphene structure allows to increase the sensitivity of the hybrid magnetic sensor in a wide range of magnetic fields in comparison with single manganite or graphene sensors..

#O13-3

FREE TARGET ACCELERATION BY UNDERWATER ELECTRICAL EXPLOSION OF A WIRE ARRAY

KEYNOTE SPEAKER

MALER Daniel, ROSOSHEK Alexander, EFIMOV Sergey, VIROZUB Alexander, KRASIK Yakov

Technion - Israel Institute of Technology, Haifa, Israel

ABSTRACT

Studies of the equation of states (EOS) of different materials at extreme pressures and densities are of great importance for various fields of research. A commonly used method to achieve extreme conditions is shock compression. Shock compression can be achieved by numerous techniques, one of them is the flyer plate which can be accelerated using either explosives, gas guns, or pulse magnetic field gradients. In our presentation, we will describe the experimental setup and results of accelerating flyer plates using a strong shock wave generated by the underwater electrical explosion of a planar wire array. The explosion of a planar Cu wire array was produced using a μs-timescale generator with stored energies of ~3 kJ and ~6 kJ for different charging voltages, delivering to the array a current pulse with amplitudes of ~230 kA and ~330 kA and rise time of ~1 μs. A Photonic Doppler Velocimetry (PDV) is applied for determining the velocity of a free-moving target.

In experiments, for various designs of Al targets, velocities of up to ~1.36 km/s were observed. The latter corresponds to an energy transfer efficiency of up to ~12% of the stored energy. Pressures reaching ~2×10^9 Pa behind the front of the shock propagating inside the target were realized. Dependencies of the target velocity versus the distance from the array and the effect of the water pressure accumulation using a thin dielectric plate placed in front of the target will be presented. One-dimensional hydrodynamic modeling coupled with SESAME EOS for water and wire material gives a satisfactory agreement with experimental results.

This research showed that in the case of pulse power generators with larger stored energy, this approach could be considered for the acceleration of targets used for studies of material properties at extreme conditions.

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#O13-4

INVESTIGATION OF MULTILAYER ELECTROMAGNETIC SHIELDING EFFECTIVENESS USING HIGH AND LOW PERMEABILITY MATERIALS

KEYNOTE SPEAKER

LEDUC Roman[(1)], RUSCASSIE Robert[(1)], LARBAIG Jean-Marie[(1)], DIENOT Jean-Marc[(2,1)], REESS Thierry[(1)]

[(1)] Université de Pau et des Pays de l'Adour, E2S UPPA, SIAME, PAU, France
[(2)] Université P. Sabatier -Toulouse III, Labceem, TARBES, France

ABSTRACT

Improvement over the past years of performances in powerful electrical systems (HPP generators, transformers, electric engines…), regarding power and rapidity leads to more critical electromagnetic compatibility (EMC) for their monitoring systems. The high-level of the dv/dt for switching activity of these systems trends to extend frequency spectral components, and equivalent wavelengths are closer to or under the size of components & tracks of PCBs. New potential electromagnetic couplings with devices can occur, and thus alteration of the functioning or physical degradation of the whole system. The EM immunization of a sensitive electrical system through EM shielding enclosures is well-known for decades. Yet, the challenge is to succeed in developing shielding solutions for embedded systems that may require to remain compact and not cumbersome. Then, it is necessary to investigate innovative shielding solutions, designs, and materials. In the context of our work, a high frequency data conversion system is developed to operate under EM disturbed environment. To take into account this constraint, we study shielding solutions against wide band far field EM radiations (300 MHz to 3 GHz). We have chosen especially to investigate multilayer shielding designs alternating high and low permeability metallic foils. In this work, it will be presented firstly the theoretical studies by the way of EM numerical simulations. Then we describe a specific experimental setup and protocol based on custom-made shielding test-bench. Both results obtained with different multilayer designs and materials will be analyzed and discussed to propose immunity solutions and optimizations of targeted system.

#O13-5

PULSED CORONA DISCHARGE ABATING AQUEOUS AND AIRBORNE ORGANIC COMPOUNDS: FINDINGS IN ENERGY EFFICIENCY ENHANCEMENT

KEYNOTE SPEAKER

PREIS Sergei[(1)], TIKKER Priit[(1)], ONG Liina[(1)], KASK, Maarja[(1)], DULOVA Niina[(1)], KRICHEVSKAYA Marina[(1)], BOLOBAJEV Juri[(1)], KORNEV Iakov[(2)]

[(1)] Tallinn University of Technology, Tallinn, Estonia
[(2)] National Research Tomsk Polytechnic University, Tomsk, Russian Federation

ABSTRACT

Gas-phase pulsed corona discharge (PCD) in the gas-liquid mixtures, where aqueous media are dispersed in an oxygen-containing gas, exhibits energy efficiency and practicability in oxidation of aqueous and airborne organic compounds unequalled among other advanced oxidation processes. This statement is confirmed in laboratory and pilot scale experiments described earlier [1-4] with various volatile and non-volatile compounds. The search for the ways of further enhancement of the PCD energy efficiency was found in extended gas-liquid interface [5], application of extrinsic oxidants addition [6], and addition of a surfactant [7, 8]. The presence of aqueous surface accelerates oxidation of airborne volatile organic compounds (VOCs) in PCD [9]. None of the approaches with the only exception of the VOCs abatement, is of universal character requiring detailed explanations.

Extension of gas-liquid interface in an aqueous media showered to the discharge zone results, at its initial stage, growth in oxidation energy efficiency with subsequent gradual saturation dependent on oxidation reaction kinetics, when oxidation rate becomes determined by the applied discharge power. Optimization of the treated solution spray density presents a task for future studies.

Unlike hydrogen peroxide, addition of persulfate to the acidic solutions profoundly accelerates oxidation of dissolved organic compounds providing noticeable economic benefits. Neither persulfate, nor peroxide showed any impact to PCD treatment in neutral or alkaline solutions leaving unassisted PCD the most feasible solution.

Addition of moderate amounts of sodium dodecyl sulfate (SDS) to aqueous solutions of an organic compound, as a rule, dramatically reduce the oxidation energy efficiency, but sometimes results in up to tripled oxidation rate. The behaviour of SDS as the oxidation rate regulator was explained using the model of molecular interaction screening the target pollutant from the surface-borne hydroxyl radicals or, in opposite, exposing the target molecules to the surface radical attack. The model predictions were confirmed experimentally, providing additional proof for the surface reaction hypothesis.

Oxidation of VOCs in the air-water mixture proceed with an oxidation rate surpassing all other results reported for electric discharge applications towards, for example, airborne toluene for at least an order of magnitude due to massive formation of hydroxyl radicals at the air-water interface.

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#O13-6

QUANTITATIVE CALCULATION OF BUBBLE PULSATION PROCESS OF UNDERWATER PULSED DISCHARGE

KEYNOTE SPEAKER

ZAHO Yong, LIU Yi

Huazhong University of Science and Technology, Wuhan, China

ABSTRACT

For the needle-needle electrode of underwater pulsed discharge, the length of the electrode gap will affect the development characteristics of the pre-breakdown process and the main discharge process, and ultimately affect the characteristics of the bubble pulsation and the secondary shock wave. At present, there is no way to quantify the effect of the gap length on the secondary shock wave and pulsation period. In this paper, a comprehensive experimental observation platform for bubble pulsation of underwater pulsed discharge is built. The mathematical models of injected energy and secondary shock energy, as well as pulsation period under different gap distances are established. According to the measured macro dynamic characteristics of bubble pulsation, the energy distribution in the process of bubble contraction is analyzed. The reason why the length of the gap affects the energy of the secondary shock wave is revealed. The comparison between the experimental results and the theoretical results shows that the mathematical model can be used to predict the secondary shock wave energy and pulsation period of bubbles. The results provide a basis for further analysis of the pulsation process of bubbles in water and for improving the theoretical system of pulsed discharge in water.

#O14-1

SOLID-STATE DUAL LINEAR TRANSFORMER DRIVER USING INDUCTIVE ENERGY STORAGE

KEYNOTE SPEAKER

YU Feng , SUGAI Taichi, WEIHUA Jiang

(1) *Nagaoka University of Technology, Nagaoka, Japan*

ABSTRACT

There have already a lot of circuit topologies for pulsed power generators using semiconductor switches. Different from traditional energy storage method, a bipolar solid-state linear transformer driver (LTD) using inductive energy storage is proposed. We utilize magnetic core as inductive storage storage(IES) medium to accumulate inductive energy before releasing pulses. The proposed generator is capable of operating in high repetition without reset circuit. A three-stage laboratory prototype of bipolar IES-based LTD is designed and assembled using six existed CES-based LTD modules, which can generate ~2.4kV bipolar peak pulses, 55ns pulse width on a 150Ω resistive load with charging voltage 80V. Finally, this proposed 3-stage LTD are evaluated under burst mode. As a result, the generator can operate at repetitive frequency of 400kHz without reset.

#O14-2

RESONANTLY CHARGED SEMICONDUCTOR-BASED MARX GENERATOR

KEYNOTE SPEAKER

MARTIN Sack, DENNIS Herzog, RUF Johannes, MUELLER Georg

Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany

ABSTRACT

For experiments on the treatment of biological material by pulsed electric fields an 8-stage semiconductor-based Marx generator has been designed and set up. It features a maximum charging voltage of 1 kV per stage, a peak pulse current of up to 500 A, and a maximum pulse repetition rate of 500 Hz. The generator has been designed for efficient setup and operation with respect to both energy savings and simplicity in architecture with the requirements for the generator being capable of operating at a predefined pulse length in the order of 10 µs and with a pulse shape defined by the properties of the pulse circuit only.

A conventional Marx generator architecture comprising charging coils and an RLC-pulse circuit has been chosen. The design has only one active semiconductor switch per stage. The presence of considerable inductance in the pulse circuit and a complete discharge of the pulse capacitors during every pulse under normal operating conditions allow for an energy-efficient operation of the switch in soft-switching mode.

In order to enable operation at a pulse repetition rate of up to 500 Hz the stages need to be re-charged sufficiently fast. Current-compensated charging coils have been employed. They feature a low inductance during charging due to operation in differential mode and provide a sufficiently high inductance for transient stage insulation in common mode during pulse application.

For resonant charging a capacitor bank and an additional coil have been inserted into the charging path between the capacitor charger and the Marx generator. The coil and the stage capacitors in parallel configuration during the charging phase form a resonant circuit. It is powered by the capacitor bank serving as an intermediate energy storage with a low internal impedance. Resonant charging of the stage capacitors enables doubling the charging voltage per stage with respect to the voltage provided by the capacitor charger. Thereby, as the stage capacitors are discharged completely after each pulse, for controlling the charging process no additional switch is required. Recharging starts immediately after each pulse.

The generator has been tested in connection with an artificial load impedance. So far, a successful operation of the generator has been demonstrated for a total duration of more than 20 h at an average input power level of up to 1.4 kW per stage. The power semiconductors on the stages are cooled by means of passive heat sinks without any forced air cooling. In continuous operation the surface temperature of the heat sinks is not higher than approximately 45 °C above the ambient temperature.

#O14-3

DIODE OPENING SWITCH AND MAGNETIC SWITCH BASED FULL SOLID-STATE HIGH VOLTAGE REPETITIVE NANOSECOND PULSE GENERATOR

KEYNOTE SPEAKER

DENG Zichen[(1)], YUAN Qi[(1)], DING Zhenjie[(2)], DING Weidong[(1)]

[(1)] *State Key Laboratory of Electrical Insulation and Power Equipment, Xi'an Jiaotong University, Xi'an, China*

[(2)] *Key Laboratory for Physical Electronics and Devices of the Ministry of Education, School of Electronic and Information Engineering, Xi'an Jiaotong University, Xi'an, China*

ABSTRACT

We present experiments on pulsed-power-driven differentially rotating plasmas with applications to astrophysical accretion disks and jets [1, 2]. The experiments are conducted on the MAGPIE generator (1 MA, 500 ns duration), which drives the oblique convergence of 8 individual plasma jets producing a hollow-like, rotating plasma column. The set-up also drives a highly collimated jet propagating axially from the rotating plasma column, similar to the jets accelerated from accretion disks in astrophysical environments.

The formation and the temporal evolution of the axial outflow are observed using both optical and extreme ultraviolet (XUV) self-emission imaging diagnostics, whilst laser interferometry provides measurements of the density depletion at the outflow axis. Optical Thomson scattering measurements show that the outflow is differentially rotating with a maximum rotation velocity of 20 km/s, with a velocity distribution consistent with a quasi-Keplerian flow. The role of the magnetic field in the outflow collimation is discussed. The measured electron and ion temperatures and electron temperature ~ 30 eV and ~ 50 eV, from which the laboratory plasma can be inferred to lie in the low-magnetic-Prandtl-number regime Pm ~ 10^−3, comparable to the regime associated with protostellar accretion disks.

#014-4

ULTRAFAST SWITCHING OF SIC MOSFETS FOR HIGH-VOLTAGE PULSED-POWER CIRCUITS

KEYNOTE SPEAKER

AZIZI Mahdi, VAN OORSCHOT Jeroen, HUISKAMP Tom

Electrical Energy Systems Group of the Department of Electrical Engineering at Eindhoven University of Technology, Eindhoven, Netherlands

ABSTRACT

In this contribution, an improved version of a gate-boosting driver circuit, which previously was proposed for IGBTs [1], is optimized and improved for SiC MOSFETs to decrease their switching time significantly [2]. The turn-on time of SiC MOSFETs mainly depends on the gate-driving technique and its implementation. In the gate boosting method a high voltage is applied to the SiC gate to increase the gate-driving current and decrease the charging time of the gate-capacitor. The proposed driver is studied and tested in detail and the results show that a MOSFET turn-on time of below 2 ns is achievable at a high operating voltage and moderate current and below 3 ns for a wider range of load current and operating voltage conditions. Furthermore, the output current pulse's rise time for a wide range of load conditions is below 9 ns and a current rise rate of 38.7 kA/µs is achieved at 356-A load current, which is significantly higher than the results of other driving techniques. The experimental results will be presented that verify the performance of the proposed gate-driving circuit in different working conditions.

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#O14-5

PRELIMINARY STUDY OF ULTRA-HIGH CURRENT THYRISTORS TRIGGERED IN IMPACT IONIZATION WAVE MODE

KEYNOTE SPEAKER

GUSEV Anton, MAYSONNAVE Thomas, SILVESTRE DE FERRON Antoine, PECASTAING Laurent

Universite de Pau et des Pays de l'Adour, E2S UPPA, SIAME, Pau, France

ABSTRACT

Short high-current pulses of hundreds of kA are used for the generation of megagauss-range magnetic fields, which are widely applied in high-energy-density physics, X-pinch and inertial fusion research. Besides, some industrial applications, such as pulse magnetic welding or rock fracturing, require repeatability, high average power and a long lifetime of the high-current pulse generator. Therefore, the development of a fast solid-state switch capable of withstanding hundreds of kA is of great interest.

The discovery of subnanosecond switching of the high-voltage silicon structures due to the initiation of the impact-ionization wave significantly improved the switching characteristics of the semiconductor devices [1]. Later, the study of the functioning of the low-frequency commercial thyristor triggered in impact-ionization wave mode has shown encouraging results on 56 mm wafer diameter thyristors [2]: blocking voltage of 5 kV, switching current of more than 200 kA, rate of current rise more than 50 kA/µs and pulse duration of 25 µs. According to the numerical simulation in [3], the thyristor active area depends on a dV/dt of the triggering pulse. It means that the higher current switching parameters are possible with a larger thyristor and more powerful triggering generator.

In this context, we have developed an experimental setup to study a switching process of the thyristors with a wafer diameter of up to 100 mm and a blocking voltage of up to 5 kV. A triggering Marx generator provides the dV/dt of several kV/ns on a few nF capacitive load which corresponds to the equivalent capacity of the thyristors under test. The transition from the blocking state to the conducting state in impact ionization wave mode without energy switching is presented. Prospects for further research on energy switching are discussed.

Acknowledgements: This research was carried under the framework of the E2S UPPA S2P2 chair supported by the French "Investissements d'Avenir" programme managed by ANR (ANR-16-IDEX-0002).

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#014-6

DEVELOPMENT OF FAST UP-SCALABLE 10-KV SIC-MOSFET SWITCHING MODULES

KEYNOTE SPEAKER

BISCHOFF Rainer, HIMMELSBACH Ralf, STOLL Meik

French-German Research Institute of Saint-Louis (ISL), Saint-Louis, France

ABSTRACT

We report on the development of new 10-kV SiC MOSFET-based switching modules, which can be easily scaled-up because of the principle of a serial connection of the SiC MOSFETs. In detail, the switching modules consist of two circuit boards, each one featuring either five 3-pin Wolfspeed/CREE 1200-V C2M0080120D or five 4-pin Wolfspeed/CREE 1200-V 3M0075120 SiC MOSFETs, that are getting stacked in order to minimize the area of the current loop between high voltage and ground connector and as a result the inductance of the structure. The main difference to other switching modules is the way of implementation of the power supply for the components of the gate control circuit and the generation of the gate-source voltage. Instead of batteries and DC-DC voltage converters, the SiC-MOSFET switching modules presented here directly generate all necessary voltages out of the applied HV charging voltage with voltage divider circuits of resistors and 33-V Zener diodes.

The 10-kV switching modules reached a current turn-on time of 15 ns with the C2M0080120D and of 12 ns with the 3M0075120 SiC MOSFETs at a drain current of 39 A. Three 10-kV modules equipped with 1200-V C2M0080120D SiC-MOSFETS were successfully connected to an up-scaled 30-kV switching module. Its current turn-on time was experimentally determined to 12 ns at a drain current of 30 A.

First tests were carried out with the SiC-MOSFET modules as closing switches inside a solid state MARX generator. A three-stage MARX generator was successfully tested. The maximum achieved output voltage was 24.3 kV at a charging voltage of 8.1 kV. The corresponding current rise time was 30.0 ns at a load current of 49 A.

#P1-1

RESEARCH OF SCATTERING PROPERTIES OF LEAD AND COPPER TARGETS FOR PROTONS WITH ENERGY RANGE FROM 60 TO 110 MEV AND CALCULATING CHARACTERISTICS OF THE RESULTING SECONDARY RADIATION

KEYNOTE SPEAKER

TRUNTSEVA Ruslana, TELNOV Aleksandr

FSUE RFNC-VNIIEF, Sarov, Russian Federation

ABSTRACT

Researching of the interaction of radiation with matter is relevant for most researchers over the past decades. The possibility of using a beam of accelerated protons from a multipurpose synchrotron accelerator of charged particles is considered. To form the required irradiation field area it is supposed to use a combination of a scanning magnets' system and a scattering target. For this problem, it is important to determine the properties of scattering targets, the characteristics of the transmitted protons, and the energy characteristics of the corresponding secondary radiation.

The range of proton energies from 60 to 110 MeV is discussed. Calculation results of scattering properties of lead and copper targets with thickness from 10 to 200 μm are presented. The calculations are performed by Monte-Carlo method. Geant4 based software is used as a tool for numerical modeling.
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#P1-2

REVISITING THE EFFECT OF A THIN ION BARRIER FOIL ON THE ELECTRON SPOT SIZE IN A RELATIVISTIC ELECTRON BEAM DEVICE FOR X-RAY FLASH RADIOGRAPHY

KEYNOTE SPEAKER

FOURMENT Claude[(1)], DUDES Adrien[(1)], PASINI Eric[(2)]

[(1)] CEA-CESTA, Le Barp, France
[(2)] CEA-DAM, Gramat, France

ABSTRACT

Flash radiography is a technique used at CEA in order to image dense objects in fast motion during hydrodynamics experiments. It requires an intense emission of high energy (~10 MeV) X-rays during a short duration (<100 ns). This radiation is due to Bremsstrahlung emission generated by the interaction of an intense, pulsed relativistic electron beam (REB) with a high atomic number solid target. Typical parameters of the electron beam are 20MeV kinetic energy, 2kA current and 60ns duration. The ability to focus this beam onto the target is of crucial importance since it determines the X-ray source size and finally the resolution of the image.

Experimental as well as numerical studies [1-3] showed in the past that ions are emitted by the target and propagate upstream in the REB, leading finally to a broadening of the electron spot. The possibility of using an ion barrier foil (IBF) to limit the propagation of the ions in the REB has been studied numerically [2,3]. Sampayan et al. reported the use of such an IBF on the ETA-II device, which leads to an improvement of the X-ray source size and stability when a pre-plasma was generated on the target [4].

We report on an experiment devoted to observe the effect of an IBF on the REB propagation. The experiment was performed on the FEVAIR injector at CEA CESTA, with beam parameters 3.4 MeV, 1.9 kA, 60 ns. We observed directly the Optical Transition Radiation emitted at the target surface, which allows us to measure the effect of the IBF on the electron spot. The influence of the IBF material, thickness and position is investigated.

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#P1-4

INVESTIGATIONS ON DIODE CURRENT, CORE BIASING AND ANALOGUE MODULATION OF AN INDUCTIVE ADDER

KEYNOTE SPEAKER

BARNES Michael[(1)], DE GERSEM Herbert[(2)], KRAMER Thomas[(1)], WOOG David[(1)],

[(1)] CERN, Geneva, Switzerland
[(2)] Technische Universität Darmstadt, Darmstadt, Germany

ABSTRACT

The inductive adder (IA) is a solid-state pulse generator that can be used to generate fast high-power pulses for various applications. An example of an application is as a pulse generator for kicker magnets in particle accelerators. In industry high power pulse generators can, for example, be used for food processing, to optimise production processes. An IA has been developed for the injection kicker system of the future circular collider (FCC). A mis-kick of the FCC beam cannot be tolerated, hence, this system must be highly reliable, for machine protection reasons. An advantage of the IA over other technologies is the use of semiconductor switches that can all be referenced to ground potential. Furthermore, the output waveform can be modulated to compensate for droop or ripple. The design of the IA can be realised in a modular way, which can reduce costs, allow for redundancy, and make rapid component replacement possible. The modular design makes it possible to also adapt the IA to various applications for a wide range of pulse requirements. The IA is also seen as potential replacement for ageing pulse generators, which rely on obsolete gas insulated pulse forming lines, in the CERN PS complex. This paper introduces the design of the IA and demonstrates that, based on a PSpice simulation model of the IA, the current through free-wheeling diodes can reach high peak values during normal operation and, hence, this must be carefully considered during the design of an IA with a low characteristic impedance. The reason for the high current peak is explained and an analytical expression is presented to estimate the value. Furthermore, measurements conducted on a prototype IA, which has both passive analogue modulation layers and a biasing circuit, are presented which demonstrate droop compensation of an output waveform. In addition, the influence of different magnetic core materials in the modulation layer and different modulation resistor values is shown and the design and biasing of a passive modulation layer for droop compensation is discussed.
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#P1-5

MHD SIMULATIONS OF PHYSICAL PROCESSES IN SPHERICAL PLASMA-FOCUS CHAMBERS CONSIDERING NEUTRON GENERATION

KEYNOTE SPEAKER

GARANIN Sergey, DOLINSKIY Vasiliy, MAKEEV Nikolai, MAMYSHEV Valentin, MASLOV Vladimir

RFNC-VNIIEF, Sarov, Russian Federation

ABSTRACT

Results of the development of a two-dimensional MHD code for the computational analysis of current plasma shell dynamics in spherical chambers with plasma focus are presented. In this work we used equations of magnetohydrodynamics with magnetic field diffusion, thermal conductivity, and plasma radiation. The magnetic field calculations were performed using an implicit scheme, which allows describing the plasma flow in the low-density region behind the plasma shell. Plasma conductivity was calculated by the formulas accounting for the possibility of anomalous resistivity in the plasma. The neutron yield was calculated considering the thermonuclear and acceleration mechanisms of neutron generation. Effects of the minimum residual gas density behind the plasma shell on the current plasma shell pinching were studied. Effects of magnetic field diffusion, thermal conductivity, and anomalous plasma resistivity on the plasma shell dynamics were considered. The calculations were performed for two spherical plasma-focus chambers with currents up to 1 MA and 2 MA and neutron yields up to 1012 and 1.5·1013 DT neutrons, respectively. A comparison of the calculated and experimental values of current, voltage and neutron yield allowed us to improve the parameters used in the calculations and to achieve close agreement between calculation and experiment.
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#P1-6

SAFETY METHOD USING HIGH POWER MICROWAVE(HPM) AS DEFENSE AGAINST VEHICLES

KEYNOTE SPEAKER

RAMMAL Mohamad[(1)], BONNIN Xavie[(1)], REINEX Gwenael[(1)], MAJED Mohamad[(1)], JECKO Bernard[(2)], MARTINOD Edson[(3)], ANDRIEU Joël[(3)]

[(1)] ITHPP, Thegra, France
[(2)] XLIM, Limoges, France
[(3)] XLIM, Brive la Gaillarde, France

ABSTRACT

This article describes a conceptual system of High Power Microwave (HPM) using RF GaN SSPAs (Solid-State Power Amplifiers) technology. As part of investing for the future, ITHPP has developed the DRAME (Dispositif Rayonnent Agile ModulablE French version) project that operates in Ultra Wide Band Frequency. This technique can be a solution for neutralizing / stopping vehicle and drones at a safe distance based on a concept of Electromagnetic waves radiation.

The High Power Electromagnetic Radiation (in L band from 1GHz to 1.45GHz) can be upset or damage the operation of integrates circuits by passing through the slots and holes of the targeted car causing a remote stopping. The system is made in two parts, a modular RF amplifiers using solid-state technology and Low Profile planar antenna called ARMA (Agile Radiating Matrix Antenna). The ARMA antenna is built by jointed pixels each to make N x M matrix. The ARMA matrix must be capable of generating radiating surfaces of particular shapes, associating all the elementary surfaces, according to the state of the pixels controlled in amplitude and in phase to produce a formed, reconfigurable and agile beam. To validate our concept, we are designed and manufactured at ITHPP company a breadboard of 5 pixels' operating in wide band from 1GHz to 1.45GHz. The low level experiments have been carried out in an anechoic chamber to verify the whole antenna system characteristics: reflection coefficient, Directivity, Realized Gain, Radiation Pattern. The test showed a good agreement between the CST simulation and the measurement. The high field levels of breadboard have been validated by connecting each pixel of 1D ARMA to an RF amplifier. It should be noted that the amplifiers have been characterized before the test in order to obtain the same phase in the input of pixels.

#P1-7

TWO-FLOW ABSOLUTE LINEAR INSTABILITY FOR SPHERICALLY SYMMETRIC STATES OF DYNAMIC EQUILIBRIUM OF VLASOV-POISSON PLASMA: A PRIORI EXPONENTIAL LOWER ESTIMATE AND COUNTEREXAMPLES TO SOME CLASSICAL RESULTS

KEYNOTE SPEAKER

BIBILOVA Sofya[(1)], GUBARES Yuriy [(2,1)]

[(1)] *Novosibirsk National Research State University, Novosibirsk, Russian Federation*
[(2)] *Lavrentyev Institute for Hydrodynamics SB RAS, Novosibirsk, Russian Federation*

ABSTRACT

The Vlasov-Poisson (VP) model is one of the most popular mathematical models in the kinetic theory of gases. The popularity of this model is due to its numerous applications, in particular, to the kinetic theory of particles that move in electric or gravitational fields. However, the main reason for close interest in the VP model is that it is used in research of high-temperature rarefied plasma and, especially, in development of methods for controlling thermonuclear fusion (CTF).
The resolution of CTF problem is impossible without solving the problem on stability for plasma dynamic equilibria, so development of the mathematical theory for stability is important in study of plasma and its properties.

Some fundamental results in this direction were obtained earlier by such authors like Gardner, Holm, Newcomb, Penrose, Rosenbluth, and others. For instance, the sufficient condition of linear stability for dynamic equilibrium states of the Vlasov-Poisson plasma was constructed. Subsequently, it was shown that this sufficient condition for linear stability prohibits small perturbations in the form of normal waves growing with time. Finally, it was generalized to the case of finite perturbations.

In one of his previous articles, Yuriy G. Gubarev, co-author of present report, inverted the sufficient condition of linear stability for the subclass of one-dimensional dynamic equilibrium states of the VP plasma and proved that small growing perturbations in the form of normal waves exist in spite of this sufficient condition for linear stability holds.

In present report, these results will be extended to the problem on linear stability for one subclass of spherically symmetric dynamic equilibrium states of the Vlasov-Poisson plasma, containing electrons and a single species of ions, in the case when stationary distribution functions of ions and electrons are isotropic over the physical continuum, but variable in the velocity space.

By the method of bundle of energy and motion integrals, the sufficient condition for stability is obtained for these dynamic equilibrium states against small spherically symmetric perturbations.

Unfortunately, this condition is formal in nature. There are such perturbations for which the Vlasov equation partially degenerates. The stability condition does not affect these perturbations. An analytical example is constructed that confirms this result. Also, it is a counterexample to the Newcomb-Gardner theorem and the Penrose criterion.

To classify the applicability area for the sufficient condition of linear stability, the VP model is reformulated in the mixed Eulerian-Lagrangian variables. It is shown that the sufficient condition for stability exists when some additional conditions are imposed on small spherically symmetric perturbations so that these perturbations are an incomplete unclosed subclass of solutions to the problem under consideration. This stability condition coincides with the known result of Newcomb-Gardner-Rosenbluth. Therefore, their result is formal in its nature too.

This allows us to prove the absolute instability for the studied subclass of dynamic equilibrium states of the Vlasov-Poisson plasma to small spherically symmetric perturbations.

To achieve the set goal, the problem is being rewritten in terms of the Lagrangian displacements field. For the Lyapunov functional, original differential inequality is obtained and integrated by the Chaplygin method. As a result, sufficient conditions of linear practical instability are derived, and the a priori exponential lower estimate is constructed for small spherically symmetric perturbations growing over time without any restrictions on the considered dynamic equilibrium states of the VP plasma.
Thus, the set goal is achieved, and the desired absolute linear instability is proved by the direct Lyapunov method. This means that the Newcomb-Gardner-Rosenbluth sufficient condition for linear stability is inverted.

An analytical example of the studied dynamic equilibrium states of the Vlasov-Poisson plasma and small spherically symmetric perturbations imposed on them is constructed that confirms the last results. Moreover, it is also a counterexample to the Newcomb-Gardner theorem and the Penrose criterion.
Note that the found sufficient conditions for linear practical instability are constructive. They can be applied as a testing and control mechanism both at realization of physical experiments on installations for CTF implementation and during performance of numerical calculations to find optimal modes of these installations operating.

Finally, the Earnshaw theorem is known in electrostatics: any equilibrium configuration of point electric charges is unstable if they are affected only by their own Coulomb forces of attraction and repulsion. Results of present report on absolute linear instability correspond to the Earnshaw theorem without reserve and extend its applicability area from analytical mechanics to statistical.

#P1-9

SHOCK-IONIZED DYNISTORS AND GENERATORS OF NANOSECOND HIGH POWER PULSES BASED ON THEM

KEYNOTE SPEAKER

LOROTKOV Sergey, ARISTOV Yury, KOROTKOV Dmitry

Ioffe Institute, St. Petersburg, Russian Federation

ABSTRACT

The results of optimization of silicon switches of thyristor type, which are able to turn on in a time of less than 1 ns after a nanosecond triggering pulse of high voltage is applied to them. The pulse initiates a shock ionization process in silicon. The main feature of the newly shock-ionized dynistors (SIDs) is that regions with another conductivity are created within both p+ and n+ emitters of their p+-n-p-n+ structures. The regions are evenly distributed over the area and are located coaxially. These regions form diode sections in the thyristor structure of the SIDs. The energy that is stored in the self capacitance of the diode sections, is used in the process of switching of the SIDs. As a result, the energy of the triggering pulse may be reduced. Generators that are based on SIDs with an operating voltage of 2.5 kV and on an assembly of SIDs connected in series are described. The generators are able to generate nanosecond current pulses with an amplitude of several kA at a repetition rate of hundreds Hz.

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#P1-10

DESIGN AND MODELLING OF A 6 GW TESLA TRANSFORMER-BASED PULSED GENERATOR FOR VIRCATOR STUDIES

KEYNOTE SPEAKER

APPIAH Gideon Nimo, NEIRA Ernesto, MARTINEZ David, ALBARRACIN Fernando, VEGA Felix, KASMI Chaouki, MORA Nicolas

Technology Innovation Institute, Abu Dhabi, UAE

ABSTRACT

Pulsed generators based on Tesla transformers have been used extensively in backward wave oscillators and electron beam accelerators, and the design parameters documented in [1]–[3]. One of the most important initial stages in developing pulsed generators is performing feasibility studies of the expected output parameters through numerical analysis and simulations. This paper details the design and modelling of a high-voltage pulse generator based on a Tesla transformer with open ferromagnetic core to drive a virtual cathode oscillator (vircator). Our model considers the selection of suitable primary and secondary circuit elements and the geometry of the Tesla transformer for optimum power transfer between the resonant circuits. The pulsed forming line is filled with deionized water for increased energy storage density of the line and increased output pulse duration. Maxwell equations are used to establish parameters such as the magnetizing inductance and leakage inductances of the Tesla transformer. The required circuit parameters and geometry of the generator producing voltage up to 250 kV and peak power of 6 GW when matched to a 10 Ω load were determined through numerical analysis, and then simulations were performed to validate the design process.
Index – pulsed generator, Tesla transformer, vircator, numerical analysis.

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#P1-11

PULSED POWER BEAMS EXCITATION FOR PHOTOLYSIS OF ORGANIC MOLECULES AND MODIFICATION OF POLYPROPYLENE SUPERFINE FIBERS

KEYNOTE SPEAKER

TCHAIKOVSKAYA Olga[(1)], BOCHARNIKOVA Elena[(1)], MAYER Georg[(1)], CHAIKOVSKY Stanislav[(2)]

[(1)] Tomsk State University, Tomsk, Russian Federation
[(2)] Institute of Electrophysics of the Ural Division of the Russian Academy of Sciences, Ekaterinburg, Russian Federation

ABSTRACT

Currently, spontaneous emission light sources based on the use of excimer and exciplex molecules are finding wider application in various fields of science and technology. These sources were called excilamps and allowed get high efficiency spontaneous emission. Many methods are used to excite excilamps: electron beam, barrier discharge, longitudinal pulsed discharge, microwave discharge, etc. In this study, we will present the results of the effect of UV-VUV radiation from excilamps on aqueous solutions of organic molecules and the surface of superfine polypropylene fibers. Photochemistry uses light as an energy source to initiate chemical transformations in solution and on the surface, too. Following this approach, a wide variety of photoreactions has already been obtained. Photochemistry has taken its place among green and sustainable technologies.

In the work, stationary and flow-through photochemical reactors were used [1-3].

KrCl (222 nm), XeCl (308 nm), Xe2 (172 nm) and XeBr (283 nm) excilamps were used as sources of UV irradiation. Static lamps had a cylindrical shape and were closed by a metal case with an output UV window of 75 cm2. The distance from the source (excilamp) to the irradiated solution was 3 cm. The volume of the irradiated solution was 50 ml in stationary photoreactor. The average radiation intensity supplied to the solution was up to 20 mW/cm2 from excilamps. The control time of irradiation of aqueous solutions containing organic compounds was: 0, 1, 2, 5, 10, 20, 30, 40, 60, 90 and 120 min. The flow-through ring reactor has working units connected by a peristaltic pump, and systems for monitoring and recording the loss of toxic substances after UV-VUV treatment. Using a spectrometer, electron and IR absorption, and fluorescence spectra were recorded, which were used to judge the processes occurring in the ground and excited states of the studied molecules and their photoproducts.

As a result of the experiment, the characteristic features of the behavior of the surface of the fibers after UV irradiation were revealed. It was shown that the studied samples have a high degree of crystallinity. It was found that after UV irradiation in the IR spectra of the polypropylene fiber, bands

appear associated with vibrations of carbonyl, hydroxyl and hydropyroxide groups, which indicates photooxidation of the fibers surface. It was found that organic molecules and their photoproducts are effectively adsorbed on the surface of polypropylene fibers [4], which is modified by pulsed power beams excitation.

Acknowledgments: This work was executed within the framework of State Assignment of the Ministry of Education and Science of the Russian Federation (Project No. 0721-2020-0033).

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#P1-12

A COMPACT CORELESS PULSED ELECTROMAGNETIC COUPLER FOR SMART GRID APPLICATIONS

KEYNOTE SPEAKER

BOUDARA Fatima Zahra[(1)], RIVALETTO Marc[(1)], PECASTAING Laurent[(1)], SILVESTRE DE FERRON Antoine[(1)], PAQUET Sylvain[(2)], BRASILE Jean Pierre[(2)]

[(1)] Universite de Pau et des Pays de l'Adour, E2S UPPA, SIAME, Pau, France
[(2)] EFFITECH, Pau, France

ABSTRACT

Nowadays the consumption of electricity is changed dramatically in a direction of continuously growing demand all around the globe. This leads to numerous environmental problems and climate emergency, pushing the countries to use more sources of sustainable and low-carbon electricity. Transport evolution is at the heart of this change. Although the market share of electric cars is only 2.5%, this number is increasing according to the dynamic growth of this market. Consequently, the power grid must be adapted in order to support this energy transition. Inductive Power Transfer (IPT) technology is a promising solution to meet the various challenges of the smart grid. In this context, the CEMPER project funded by the French Ministry for Defense studies electronic systems for the efficient power transfer between two distant points. The main innovation is related to the geometry of the coreless electromagnetic coupler. This geometry allows obtaining the optimal power transfer up to 200 kW with a DC-DC efficiency of 95% in a volume of less than 14 litres.

Firstly, the system developed was numerically modelled to verify its electrical performances. Then, it was tested experimentally at a high-power level in order to validate its operation in conditions close to real applications. In addition, the compliance of the systems with the ICNIRP 2010 standard was confirmed by direct measurements of the magnetic flux density and electric field. In the final part of the work, the thermal management of the electromagnetic coupler was also investigated by two methods: a simplified mathematical model and 3D numerical one.

#P1-13

MHD SIMULATIONS OF TURBULENT DEVELOPMENT OF THE SAUSAGE INSTABILITY OF A Z-PINCH

KEYNOTE SPEAKER

GARANIN Sergey, DOLINSKIY Vasiliy

RFNC-VNIIEF, Sarov, Russian Federation

ABSTRACT

Two-dimensional axially symmetric MHD simulations were used to study z-pinch waist narrowing considering small-scale short-wavelength perturbations, i.e. considering two-dimensional turbulence development. Effects of magnetic diffusion and thermal conduction were supposed to be minor and treated as significant only in the regions where they must be incorporated (at plasma/vacuum interfaces and near the axis). We considered the evolution of a cylindrical plasma column with a sinusoidal boundary perturbation and small-scale random density perturbations driven by constant current. The calculations demonstrated that the growing turbulence does not allow narrowing of the waist to an arbitrarily small radius and axial outflow of the plasma out of the waist region. The amplitude of initial perturbations has some effect on the maximum compression parameters, because, with its increase, narrowing develops faster and the short-wavelength perturbations are able to grow and cover the compression region to a smaller extent. During the compression of the waist there is no generation of high voltages near the axis, which could promote ion beam formation and neutron generation by the accelerating mechanism. The calculations also predict rather fast MHD arrangement of a marginally stable Kadomtsev equilibrium. Since no unlimited compression is possible in the Z-pinch waist, it seems that plasma fusion ignition will hardly be attainable there even at multi-mega-ampere driver currents.

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#P1-14

MODELING OF THE ELECTROTHERMAL BEHAVIOR OF A SIC MOSFET CHIP DURING A SHORT CIRCUIT AND ADAPTATION TO AN ENTIRE POWER MODULE

KEYNOTE SPEAKER

DUMOLLARD Yannick[1,2], BATISTA Emmanuel[1], PECASTAING Laurent[2], DIENOT Jean-Marc[3,2]

[1] Alstom, Tarbes, France
[2] Université de Pau et des Pays de l'Adour, E2S UPPA, SIAME, Pau, France
[3] Université Paul Sabatier, Toulouse III, Tarbes, France

ABSTRACT

This paper presents a predictive model of Silicon Carbide (SiC) Metal Oxide Semiconductor Field Effect Transistor (MOSFET) chip behavior during a short circuit phasis. This model describes the non-linear behavior and electrothermal dependence of the transconductance, the drain-source resistor, and the threshold voltage. The thermal model is based on an equivalent electrical circuit, called Cauer's model, coupled to a behavioral equation-based MOSFET electrical model. The equations parameters identification is based on the component datasheet and dedicated measurements. A genetic algorithm and the least-square method have been used to fit the equation with dedicated measurements. The chip described have been used to simulate an entire power module during a short-circuit. These models ensure a good correlation between the measured and simulated current during a short circuit.

#P1-15

FORMATION OF REPETITIVELY PULSED TITANIUM ION BEAMS OF HIGH POWER WITH A SUBMILLISECOND PULSE DURATION

KEYNOTE SPEAKER

RYABCHIKOV Alexander[(1)], SIVIN Denis[(1)], VAKHRUSHEV Dimitrii[(1)], TARAKANOV Vladimir[(2)]

[(1)] Tomsk Polytechnic University, Tomsk, Russian Federation Institution
[(2)] National Research Nuclear University "MEPhI", Tomsk, Russian Federation

ABSTRACT

The development of methods to modify materials based on the synergistic high-intensity implantation and simultaneous energy impact on the ion-doped layer involves using the pulsed and repetitively-pulsed beams of metal ions and gases with micro-submillisecond duration with high pulsed power density. This work focuses on the experimental studies and numerical modelings of the pulsed and repetitively-pulsed titanium ion beams' formation from the vacuum arc plasma with energy density in a pulsed beam of up to several tens of J/cm2 using the KARAT code. The experiments were carried out using the metal ion source's power supply system "Rainbow 5". The continuous plasma flux was formed by an axially symmetric vacuum-arc plasma generator. The accelerating voltage pulse duration was varied by changing the forming line in the range from 50 to 450 μs. The accelerating voltage amplitude varied in the range from 10 to 40 kV. To clean the ion beam from the micro-droplet fraction, the "solar eclipse" effect with the disk electrode installation between the arc evaporator's cathode and the target was used instead of a louvered plasma filter. At the vacuum arc evaporator's outlet, a grid focusing electrode in the form of a part of a sphere is installed. An equipotential space for ion beam's transport and ballistic focusing is formed by this electrode, together with additional cylindrical and flat electrodes, where the target is located. The possibility of stable generation of titanium ion beams with a pulsed power density from 104 to 105 W/cm2 is shown at different pulse durations, accelerating voltage amplitudes and frequencies.

#P1-16

PRELIMINARY MULTIPHYSICS MODELING OF A 1M SANDWICHED ELECTROMAGNETIC ACCELERATOR PROTOTYPE

KEYNOTE SPEAKER

ALMANSOORI Mae, ROUF BABA Abdul, ALBARRACIN-VARGAS Fernando, MARTINEZ David, APPIAH Gideon Nimo, GALVIS Juan, AL KAABI Mohammed, AL ALI Abdulla, KASMI Chaouki, MORA Nicolas

Directed Energy Research Centre, Technology Innovation Institute, Abu Dhabi, UAE

ABSTRACT

Recently, many breakthroughs have been made by electromagnetic propulsion technology in several fields, such as in aerospace [1] and defense technologies [2, 3], mainly because of its ability to accelerate the payload to hyper-velocities within milliseconds. In this work, a sandwiched 1m electromagnetic accelerator (EMA) design with a pneumatic pre-acceleration system is proposed and validated through numerical simulations. Time-dependent finite element-based Multiphysics modeling was implemented to compute the temperature distribution along the two parallel current-carrying rectangular copper rails (3cm x 1cm x 100cm) with a rectangular bore and the exit velocity of a C-shaped armature of about 2g (i.e. the projectile). Four numerical assessments were conducted to obtain the results: pre-acceleration, electromagnetic, coupled heat transfer, and coupled dynamic analyses. In the pre-acceleration region, a constant pressure was applied to accelerate the armature to an initial velocity before entering the electromagnetic acceleration region. For the second region, the rails were fed with a current waveform with a peak amplitude of 80kA obtained through SPICE simulation. Four pulse forming units are successively triggered with a specified time delay resulting in a pulse duration of about 3ms. The time-dependent heat generation due to Joule's heating showed ohmic losses up to 7.0 x 10^8W/m^3, resulting in a 45°C increase in the rails-armature contact region. Regarding the velocity, it was found that with a maximum supplied energy of 150kJ and applied constant pressure of 500psi, the 2g armature is subjected to a 2.5kN force allowing the muzzle velocity to be higher than 1000m/s.

[1] M. Ghassemi, M. Varmazyar, Stress analysis of the rails of a new high velocity armature design in an electromagnetic launcher, International Journal of Impact Engineering, Volume 35, Issue 12, Pages 1529-1533, 2008, doi: 10.1016/j.ijimpeng.2008.07.033.
[2] I. R. McNab and F. C. Beach, "Naval Railguns," in IEEE Transactions on Magnetics, vol. 43, no. 1, pp. 463-468, Jan. 2007, doi: 10.1109/TMAG.2006.887446.
[3] S. Hundertmark and O. Liebfried, "Power Supply Options for a Naval Railgun," in IEEE Transactions on Plasma Science, vol. 46, no. 10, pp. 3599-3605, Oct. 2018, doi: 10.1109/TPS.2018.2864560.

#P1-18

HIGH POWER BROADBAND PULSE GENERATION USING ASYMMETRIC BLUMLEIN LINE

KEYNOTE SPEAKER

ACHOUR Yahia[(1)], STARZYNSKI Jacek[(2)]

[(1)] Ecole Militaire Polytechnique, Algiers, Algeria
[(2)] Warsaw University of Technology, Warsaw, Poland

ABSTRACT

The generation of high power radiated electromagnetic pulses is one of the most challenging and attractive topics in the pulsed power field. This is due to the various applications in which it could be applied and the complex physics behind which requires to work in extreme conditions especially the high power and the very short time.

The simplest way to build such devices is to connect a high power pulse generator to an antenna. The high power pulse created by the pulse generator is transferred to the antenna and a part of it is radiated as an electromagnetic wave.

From literature, many structures of pulsed power generators can be found. Some of them are based on MARX topology, others use a combination of transmission lines such as Blumlein line generators. Unlike Marx generators, Blumlein line based ones have the advantage to provide a well-defined impedance at their outputs. This facilitates the antenna design and improves the impedance matching between the generator and the antenna.

However, the classical Blumlein line generates rectangular pulses which are not convenient for such application. This is because this type of pulses has a spectrum that starts from DC to a specific frequency fixed by the pulse width. Thus a big part of the pulse energy will not be radiated due to the limited bandwidth of the antenna, especially from the low-frequency side.

One of the solutions to this problem is to use bipolar pulses instead of rectangular ones. This type of pulses has no DC component (or reduced one), which means that the spectrum is shifted to the high-frequency side. This increases energy in the radiated frequency band and thus the efficiency of the generator.

The presented paper describes a new idea of generating broadband bipolar pulses using an asymmetric Blumlein line. Generally, a Blumlein line consists of two identical lines. This leads to a perfect rectangular pulse. However, if the delay time of the two lines is not identical, then the obtained pulse will show an oscillating behaviour. Then It can be tuned to get the central frequency and bandwidth of the generated pulses as required by the antenna by acting on the lines delays, or in other words, dimensions.

The paper discusses the design and the simulation of a high voltage pulse generator, based on this idea, which can produce pulses of maximal power of 2 GW and amplitude of 300 kV. The main energy lobe is located around 50 MHz. A real prototype was built and tested, the obtained results confirm the validity of the proposed technique.

#P1-19

CURRENT SPREADING OVER THE WIDTH OF THIN FOILS (IN SERPENTINE-LIKE SYSTEMS) OR FLAT CURRENT-CONDUCTING LAYERS

KEYNOTE SPEAKER

GARANIN Sergey, KRAVETS Ekaterina

RFNC-VNIIEF, Sarov, Russian Federation

ABSTRACT

We consider the problem of current spreading over the width of thin foils (in serpentine-like systems) or flat current-conducting layers. To simulate the evolution of current distribution across the width of thin current-conducting layers or foils, an integro-differential equation is developed, which makes the two-dimensional magnetic-field problem one-dimensional. An infinite periodic system of flat serpentine-like foils is considered. We demonstrate that current distribution in foil in this system initially corresponds to the perfect conductivity of foil and then relaxes to uniform distribution. In the foils used as opening switches, currents are expected to have time to get uniformly distributed across their width in the process of current delivery to the load, so the corrections for nonuniform current distribution in the opening switches should be small.

#P1-20

HIGH FREQUENCY SIGNALS SYNCHRONIZATION USING FPGA-SOC TECHNOLOGY FOR SECURITY SYSTEM IN A RADIOGRAPHY EQUIPMENT

KEYNOTE SPEAKER

LEDUC Roman[(1)], RUSCASSIE Robert[(1)], LARBAIG Jean-Marie[(1)], COURTOIS Laurent[(2)], DIENOT Jean-Marc[(3,1)], REESS Thierry[(1)]

[(1)] Université de Pau et des Pays de l'Adour, E2S UPPA, SIAME, PAU, France
[(2)] French Atomic Energy and Alternative Energies Commission (CEA), CESTA, France
[(3)] Université P. Sabatier -Toulouse III, Labceem, TARBES, France

ABSTRACT

For the last years, the continuous technological progress regarding high pulsed power (HPP) generators or various other specific systems requiring precise speed and power control, induces the growing need of robust EM shielded and competitive numerical technologies for monitoring such systems. The increasing use of monitoring systems and ability to process data in a more customized way highlights one technology which perfectly fits to the request : the FPGA-SoC (System On a Chip). This technology gathers in one single device the performances of an FPGA such as rapidity & parallelism of operations (FPGA reference clock of 50 MHz, PLLs, transceiving data up to 3 Gbit/s…), and the features of a micro-processor operating an embedded OS. The SAD (Système Anti Débris / Anti Fragment System) developed in collaboration with CEA Cesta, is a protection system integrated along the electron beam accelerator of the radiography facility called EPURE. Its role is to prevent target fragments from going back in the conduct and damaging equipment during the impact of the e^- beam. The SAD requires a monitoring system synchronizing and emitting numerous signals via optical fibers, which is also capable of storing and processing related data onto the local network. In this publication, we will present the choices that were made for the FPGA-SoC board implementation regarding performances and appropriate features for the application, as well as design rules for an optimized EM compatibility of the embedded system.

#P1-21

COMPACT HIGH-CURRENT PULSE GENERATOR FOR LABORATORY STUDIES OF HIGH ENERGY DENSITY MATTER

KEYNOTE SPEAKER

EFIMOV Sergey, GLEIZER Svetlana, MALER Daniel, FLYAT Eugene, ROSOSHEK Alexander, LEOPOLD Jochanan, KRASIK Yakov

Technion - Israel Institute of Technology, Haifa, Israel

ABSTRACT

We present the design and parameters of a compact and mobile high-current pulse generator, which can be applied in the study of warm dense matter in university laboratories. The generator dimensions are 550 × 570 × 590 mm3, the weight is ~70 kg, and it consists of four “bricks” connected in parallel. Each brick, made up of 2 × 40 nF, 100 kV low-inductance capacitors connected in parallel, has its own multi-gap and multichannel ball gas spark switch, triggered via a capacitively coupled triggering by a positive polarity pulse of ~80 kV amplitude and ~15 ns rise time. At a charging voltage of ~70 kV, the generator produces a ~155 kA current pulse with a rise time of ~220 ns on a ~15 nH inductive short-circuit load and a ~90 kA amplitude current pulse in the underwater electrical explosion of a copper wire.

#P1-22

USING ELECTROSTATIC FINITE ELEMENT MODELLING TO PREDICT HIGH-VOLTAGE INSULATION TESTS FOR SWITCHGEAR COMPONENTS

KEYNOTE SPEAKER

ALFEREZ Nicolas[(1)], DUCHESNE Cyrille[(2)], BATISTA Emmanuel[(1)]

[(1)] Alstom Group, SEMEAC, France
[(2)] Deep Concept, PAU, France

ABSTRACT

The aim of this study if to define new design rules based on Finite Element Modelling (FEM) to predict High-voltage insulation tests within the air of switchgear component.
In Railway application, the standard EN50124 impose creepage and clearance distances on high-voltage component to avoid any dielectric breakdown. For 25kVac applications, this standard requires a dielectric test validation based on humidity/pollution criteria and on overvoltage risk during operation e.g. in some case a 25kV component can be tested at 125kV for extreme external condition.
Considering a dielectric strength of the air at 3.3kV/mm and calculating Electrical field mean value (Emoy=V/d) are not sufficient to ensure the success of this validation test, component geometry has a major impact on the Electrical field repartition and homogeneity and has to be taken into account in the analysis.
Electrostatic Finite Element Modelling is an efficient way to compute this Electrical field repartition depending on the 3D model of the component and can help predict the dielectric test and help designers to estimate the performance of their design early in project development.
The design rules presented in this work were based on 3D modelling to estimate the electrical field repartition and additional experimental tests were realized in a dedicated test bench to determine the breakdown voltage.
A comparison between measurement and simulation will be presented for an Alstom 25kV switchgear component.
This study was realized in Shift 2 Rail European program with the grant agreement number 101014935.

#P1-23

THEORETICAL STUDY ON THE INFLUENCE OF CORRUGATED SHAPE AND SIZE ON DISPERSION CURVES IN COAXIAL SLOW WAVE STRUCTURES

KEYNOTE SPEAKER

CHEN Siyao, ZHANG Jun, ZHANG Jiande

College of Advanced Interdisciplinary Studies,National University of Defense Technology, Changsha, China

ABSTRACT

In recent years, coaxial slow wave structures (SWSs) are widely used in millimeter wave generators as the core component of microwave traveling wave tube (TWT) and backward wave oscillator (BWO). In this paper, the dispersion equation of coaxial SWSs is derived and solved numerically by using the field matching method. Based on the dispersion relation, the influence of corrugated shape and structural parameters on the dispersion curves is studied. Furthermore, in order to provide reference for theoretical design and experimental debugging, the selection method of structural parameters is given under different application background.

#P1-24

IMPROVEMENT ADHESION AND PROPERTIES OF PROTECTIVE COATINGS ON ZIRCONIUM ALLOYS AND AUSTENITIC STAINLESS STEELS BY PRE-TREATMENT WITH HIGH-INTENSE PULSED ION BEAMS

KEYNOTE SPEAKER

REMNEV Gennady[(1)], TARBOKOV Vladislav[(1)], PAVLOV Sergey[(1)], SLOBODYAN Mikhail[(2)], SMOLYANSKIY Egor[(1)]

[(1)] Tomsk Polytechnic University, Tomsk, Russian Federation
[(2)] Tomsk Scientific Center SB RAS, Tomsk, Russian Federation

ABSTRACT

The report discusses the possibility of using pre-treatment of metal substrates with a high-intense pulsed ion beam (HIPIB) to form an intermediate surface layer for the subsequent deposition of protective coatings. Austenitic stainless steel and the Zr-1%Nb alloy, widely used in the nuclear industry, have been studied. Data on changes in adhesion and protective properties of the coatings deposited by reactive magnetron sputtering are reported. The effect of substrate pre-treatment on the structure of the coatings has been investigated, and the dependences of microhardness, microstructure, and phase composition of the formed surface layer are shown. The HIPIB energy density range has been varied from 0.5 to 3.0 J/cm2 at pulse duration of 100 ns and an accelerating voltage of 200 kV. In conclusions, the possibilities and prospects of the combined method to improve the performance of structural materials operating under extreme conditions are discussed.

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#P1-25

DESIGN AND TEST OF A HIGH PRF 0.5 MV MARX GENERATOR TO DRIVE PFLS

KEYNOTE SPEAKER

ARIZTIA Laurent[(1)], IBRAHIMI Njomza[(1)], SILVESTRE DE FERRON Antoine[(1)], ZHABIN Alexey[(1)], RIVALETTO Marc[(1)], M.NOVAC Bucur[(2,1)], PECASTAING Laurent[(1)]

[(1)] Universite de Pau et des Pays de l'Adour, E2S UPPA, SIAME, Pau, France
[(2)] Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, Loughborough, United Kingdom

ABSTRACT

During the last decades, new developments in the pulsed power technology for application to food processing, water treatment, medical domain and defense industry were accompanied with an increased research interest worldwide. This paper details the design, development, and test of a 13 stage, 0.5 MV, high PRF Marx generator used to feed monopolar and bipolar PFLs for applications to both military and bio-medical domains. The design phase was conducted by thorough analytical calculations and numerical simulations using the PSpice electronic circuit simulation software. The fast-switching process of the generator is based on spark gaps, operated under pressurized air, leading to generation of output voltage pulses with an amplitude approaching 0.5 MV and with a rise time of 25 ns. Each stage of the Marx is charged by a 50 kV – 160 mA DC charger through an inductor and a diode connected in series. The equivalent capacitance of each stage is approximately 3.9 nF, allowing the generation of 40 J pulses, with a PRF up to 50 Hz. The tests show a good agreement between the experimental data and the theoretical predictions.

#P1-26

DESIGNING QUASI-FORCE-FREE CONFIGURATIONS OF NON-DESTRUCTIVE MEGAGAUSS MAGNETS

KEYNOTE SPEAKER

SHNEERSON German, NEMOV Alexander, LAGUTKINA Anna

Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russian Federation

ABSTRACT

A general methodology for designing quasi-force-free configurations of non-destructive magnets aimed at achieving pulsed megagauss fields is presented. The proposed approach is based on a combination of analytical estimations, finite-element analysis and optimization techniques, which allow developing axisymmetric configurations of magnets that are characterized by a low ratio of the mechanical stresses in windings to the magnetic pressure of generated field. A procedure for obtaining three-dimensional models of magnets of the basis of their axisymmetric configurations is described and illustrated on examples. Ways of further development of the concept, promising achieving even stronger fields, are highlighted.

#P1-28

HIGH VOLTAGE ELECTRICAL PULSES FOR THE EXRACTION OF MYCOSPORINE -LIKE AMINO ACIDS FROM THE AGAROPHYTE GELIDIUM SESQUIPEDALE

KEYNOTE SPEAKER

MCREYNOLDS Colin[1,2], SILVESTRE DE FERRON Antoine[1], BOUSSETTA Nadia[3], GRIMI Nabil[3], FERNANDES Susana[2], PECASTAING Laurent[1]

[1] Universite de Pau et des Pays de l'Adour, E2S UPPA, SIAME, Pau, France
[2] Universite de Pau et des Pays de l'Adour, E2S UPPA, IPREM, CNRS, Anglet, France
[3] Sorbonne Universités, Université de Technologie de Compiègne, Laboratoire de Transformations Intégrées de la Matière Renouvelable, EA 4297, Compiègne, France

ABSTRACT

Gelidium sesquipedale (Rhodophyta) is a red seaweed harvested on Atlantic coasts from the French Basque Country to Morocco for the extraction of agar-agar or agarose. Apart from these natural polymers, this seaweed also produces mycosporine-like amino acids (MAA), UV-absorbing water-soluble molecules (known as "nature's sunscreens"), of great interest for the cosmetics industry. Electrical pulses (pulsed electric fields and electrical discharges) were used as physical methods of extract MAAs from fresh and dry Gelidium sesquipedale in distilled water at equivalent energy. Solutions of algae at 1:100 (weq. dry/v) were treated with up to 500 individual high voltage (40 kV) electrical pulses of 200 J, from 0 to 250 kJ/kgsolution inducing dynamic pressure waves or 20 kV/cm pulse electric fields of 5 µs depending on the geometry of the treatment chamber. UV-Vis Spectrophotometry and High-Performance Liquid Chomatography –Tandem Mass Spectrophotometry techniques were used for the MAA identification and quantification. In this presentation, we will discuss the differences in MAA yields obtained with electrical discharges and pulsed electric fields at equivalent energy. These results were compared with those obtained through conventional extraction method using ball-miled Gelidium sesquipedale powder.

#P1-29

LOW-IMPEDANCE HIGH-POWER PULSED GENERATOR BASED ON FORMING LINE WITH BUILT-IN TESLA TRANSFORMER

KEYNOTE SPEAKER

LIU Shifei, ZHANG Jiande, ZHANG Zicheng, WANG Yuwei

College of Advanced Interdisciplinary Studies, changsha, China

ABSTRACT

In order to meet the application needs of gyromagnetic nonlinear transmission lines, the pulsed power generator is required to output short duration pulse with fast rising edge in high repetitive-rate mode, and meanwhile should have low-impedance characteristic. In this paper, a low-impedance high-power pulsed generator based on forming line with a built-in Tesla transformer is investigated and developed. The generator includes a 14 Ω coaxial forming line, a SF6/N2 gas switch, and a resistive dummy load, which can steadily operate in 100 Hz mode and suits the needs above. The pulsed forming line adopts transformer oil as insulation medium and has a large shell radius to reduce impedance. The maximum forming line charging voltage is 600 kV in single-shot mode, while the charging voltage is 520 kV in repetitive-rate mode. The output pulse duration is 10 ns with a 2 ns rising edge and its amplitude for a slightly undermatched load is 220 kV at a repetition rate of 100 Hz. The experiments conducted showed the feasibility of the low-impedance nanosecond periodically pulsed generator based on an oil forming line charged from the high-coupling Tesla transformer. These efforts expand the technical route of the pulse forming line with built-in Tesla transformer and set a good foundation for its application in future.

#P1-30

DESIGN AND IMPLEMENTATION OF A 250 KJ PULSED POWER SUPPLY MODULE FOR ELECTROMAGNETIC LAUNCH EXPERIMENTS

KEYNOTE SPEAKER

AKDEMIR Huseyin, CIVIL Anıl, CAVBOZAR Ozgur, YURDAKUL Burak, DURNA Emre, TAN Evren, KARAGOZ Mustafa

ASELSAN Inc., Ankara, Turkey

ABSTRACT

Pulsed power supplies (PPSs) are used in many applications such as development of high voltage components, laser sources, accelerators and launchers. In this study, a capacitive pulsed power supply module is designed and tested for electromagnetic launch (EML) experiments. Designed and implemented PPS module is mainly composed of two parallel capacitors, a pulse shaping inductor and two parallel thyristor-diode stacks. The nominal charge voltage level is 6.5 kV and the peak value of the current is 140 kA. The PPS module can be remotely controlled. Furthermore, the capacitor voltage and discharge current are remotely readable. The trigger and all control signals are transmitted by fiber-optic cables to minimize the effect of electromagnetic interference and provide electrical isolation. All implementations have been carried out in Aselsan Electromagnetic Launch System Laboratory. Some significant design steps and test processes of the 250 kJ PPS modules are discussed in the relevant sections of this paper. Effect of parallel connected semiconductor stacks on current sharing due to circuit parasitics, and proposed balancing method for current sharing are also discussed as part of the work. The findings of this study can make significant contributions to future studies.

#P1-31

THEORETICAL AND PRACTICAL STUDIES OF FLASHOVER ALONG CYLINDRICAL DIELECTRIC WITH COAXIAL ELECTRODES IN ATMOSPHERIC AIR

KEYNOTE SPEAKER

ZHABIN Alexey[(1)], SILVESTRE DE FERRON Antoine[(1)], ARIZTIA Laurent[(1)], RIVALETTO Marc1, NOVAC Bucur [(2,1)], PECASTAING Laurent[(1)]

[(1)] Universite de Pau et des Pays de l'Adour, E2S UPPA, SIAME, Pau, France
[(2)] Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, Loughborough, United Kingdom

ABSTRACT

This paper proposes a procedure, based on the analysis of the electric field distribution, for obtaining the flashover voltage along the surface of a dielectric. The analysis is made for the electric field distribution along a cylindrical dielectric with coaxial electrodes at atmospheric pressure. The electric field near the triple point is used to estimate the voltage of the streamer inception. Then, the voltage required for a stable streamer propagation between its head and the counter electrode is calculated. The highest of these voltages is finally obtained as the flashover voltage.
The paper then presents experimental tests undertaken to verify the above-proposed procedure. DC voltage and voltage impulses with different durations and rise-times are applied onto the electrodes to determine the surface breakdown voltage. The dependence of the flashover voltage on the distance between the electrodes is reported and compared with the theoretical predictions. The results of these studies will allow the precise design of a 0.5 MV system currently under development.

#P1-32

LIFETIME TEST PLATFORM OF MICA PAPER CAPACITORS UNDER MICROSECOND PULSE

KEYNOTE SPEAKER

LIU Shifei, ZHANG Zicheng, ZHANG Jiande, ZHANG Haorang

College of Advanced Interdisciplinary Studies, Changsha, China

ABSTRACT

In this paper, a repetitive-rate microsecond pulse test platform was established, to research the lifetime characteristic of mica paper capacitors. The test platform is mainly divided into two parts. The first part includes an air-core transformer with 40 times transformation ratio, a primary electrolytic capacitor and two thyristors. The another part contains a mica paper capacitor, a SF6/N2 gas switch and a water dummy load. This platform can output voltage up to 60 kV and operate in a repetitive rate of 20 Hz for 25 s or 10 Hz for 1 min. The discharge voltage waveform can be adjusted by water dummy load. One mica paper capacitor can be tested for ten thousand times at least. The relationship between the capacitance loss, dielectric loss and quality factor of capacitors and the lifetime of capacitor was recorded and analyzed. The results and analysis showed that the decrease in capacitance, dielectric loss and quality factor before and after discharging were directly related to the lifetime of the mica paper capacitor. Through this test platform, the influence of charging voltage and repetitive-rate operation on the lifetime characteristics of capacitors can be studied. Moreover, the failure mechanism of pulse capacitors under repetitive-rate operation mode can be investigated.

#P1-33

PRELIMINARY EXPERIMENT OF A MEDICAL PULSED POINT LIGHT SOURCE SYSTEM

KEYNOTE SPEAKER

ZOU Jian, ZENG Naigong, ZHANG Tianjue

China Institute of Atomic Energy, BEIJING, China

ABSTRACT

In order to explore the feasibility of pulse power technology in early diagnosis of breast cancer, a spot light source platform based on pulse power system was established. The system consists of a pulse driver, a focusing lens system and a pulse x-ray tube. The pulse driver adopts the axial side vertical structure, which is compact and mobile. It is composed of capacitor module, gas switch module, charging and rectifying module, measuring module and output section. The design of pulse x-ray tube adopts a unique mechanism of cold cathode reflection bombarding the anode target to produce X-ray, which can effectively improve the accuracy of x-ray point source position The material and distance of anode and cathode can be adjusted according to different driving voltage. The experimental results show that: when the output voltage of the pulse source is 150kV, the rise time is about 10ns, and the pulse width is about 100ns, the system can radiate sub nanosecond X-ray with a diameter of about 100 μ m and an energy of about 15kev, and the high-resolution imaging image of organism can be obtained by using the X-ray.

#P1-34

POWERFUL CHERENKOV MASERS WITH 2D SLOW-WAVE STRUCTURES BASED ON HIGH- CURRENT RELATIVISTIC ELECTRON BEAMS OF SHEET AND TUBULAR GEOMETRY

KEYNOTE SPEAKER

PESKOV Nikolai[1,2], ABUBAKIROV Edward[1], ARZHANNIKOV Andrey[2], DENISENKO Andrey[1], GINZBURG Naum[1,2], KALININ Petr[2], SANDALOV Evgeny[2], SINITSKY Stanislav[2], STEPANOV Vasily[2], VIKHAREV Alexander[1,2], ZASLAVSKY Vladislav[1]

[1] Institute of Applied Physics RAS, Nizhny Novgorod, Russian Federation
[2] Budker Institute of Nuclear Physics RAS, Novosibirsk, Russian Federation

ABSTRACT

Project of Ka-band Cherenkov surface-wave oscillator (SWO) of sub-GW power level is elaborated based on high-current explosive-emission accelerator “Sinus-6” 0.5 MeV / 5 kA / 20 ns (IAP RAS) forming relativistic electron beam (REB) of a tubular geometry with diameter of about 40 mm. To ensure high-coherence of the radiation from such large-size REB, we exploit the original idea of using two-dimensional (2D) distributed feedback implemented in the 2D doubly-periodical slow-wave structures. Present paper is devoted to results of simulations and first experimental studies of this Ka-band Cherenkov maser of cylindrical geometry. In the proof-of-principal experiments under the transverse oversize parameter of the system (perimeter to the wavelength) of about 16, the narrow-band oscillations was obtained with the power level of ~ 250 - 300 MW. Optimization of parameters aimed at further power enhancement is in progress currently.

Project of powerful W-band Cherenkov maser of planar geometry is under development in collaboration between IAP RAS and BINP RAS at the “ELMI” accelerator. This accelerator forms electron beam 1 MeV / 5 - 7 kA / 3 μs of sheet geometry with the transverse cross-section of 0.3 cm x 18 cm. In present paper, design parameters of this project are discussed and results of the simulations are presented, which demonstrate possibility to achieve in the considered scheme a stable narrow-band oscillation regime with output power of the GW-level under the transverse oversize parameter (width to the wavelength) of up to 50. Experiments on realization of this super-power Cerenkov maser are started.

This work is partially supported by the RFBR (grants #18-02-40009 and #19-08-00550) and the IAP RAS Program #0030-2021-0027.

#P1-35

DEVELOPMENT OF A STANDARD MEASURING SYSTEM FOR THE CARATERIZATION OF HIGH VOLTAGE NANOSECOND PULSES

KEYNOTE SPEAKER

SAIF KHAN Mohammad[1,2], AGAZAR Mohamed[1], LE BIHAN Yann[2]

[1] Laboratoire National de Métrologie et d'Essais (LNE), Trappes, France
[2] Laboratoire Génie Electrique et Electronique de Paris (GeePs), Gif-sur-Yvette, France

ABSTRACT

To develop the metrology infrastructures needed for accurate measurements of High Pulsed Power in nanosecond range (one nanosecond rise time and 100 nanoseconds duration), a standard calculable measuring system is under development at LNE. It should be capable to measure pulses up to 500 kV with uncertainties better than 3 % for voltage peaks and one nanosecond for time parameters. The system consists of two measurement chains covering a bandwidth from DC to at least 1 GHz. The main element of these chains are dividers, a capacitive voltage divider (CVD) based on the coaxial line principle for the first one and a resistive voltage divider (RVD) for the second one. One of the reasons behind two separate chains is to have a supplementary validation of the output signals in their common bandwidth. The CVD is a part of the high voltage transmission line and the RVD is integrated in the 50 Ω resistive load itself. The most critical parts of these dividers are the low voltage arms. The electromagnetic modelling and simulations of these two dividers have been performed and the results obtained are optimized in order to get, as much as possible, a flat frequency response for both dividers in the considered bandwidth. Different geometries, dielectric materials have been studied and several laboratory tests have been performed to evaluate the electrical breakdown of the components. These results together with possible measurements results will be presented at the conference.

#P1-36

PULSED GAS DISCHARGE DRIVEN BY SOLID-STATE LTD

KEYNOTE SPEAKER

YANG Junxiang, SUGAI Taichi, TOKUCHI Akira, JIANG Weihua

Nagaoka University of Technology, NAGAOKA, Japan

ABSTRACT

Memory effect Induced by residual charges of atmospheric pressure gas discharge load has been studied by using a flexible pulsed power based on solid-state linear transformer driver (SSLTD) scheme. In this presentation, the residual charges phenomenon has been studied by two pulses with different time intervals. The first experimental results that, with an appropriate time interval (0 ns< t < 800 us), the gas breakdown voltage of the second pulse is usually lower than the first pulse. The second experiment results that, the trend of the second pulse current will change with the pulse interval, even though the amplitude of the applied voltage is the same. That is, when the two pulses are too close to each other (0 ns< t < 1000 ns), the discharge current of the second pulse always increases with the pulse interval increase. Then, when the pulse time interval increase step by step from 1 us to 200 us, the current of the second pulse will decrease with the pulse time interval increase. And with the pulse time interval increase step by step from 200 us to 1 ms, the current of the second pulse will increase with the pulse time interval increase. An explanation for this phenomenon has been explored by using a model that considers the effect of residual charge left by the first pulse. The findings obtained by this paper will help us understand the fundamental characteristics of pulsed atmospheric gas discharge.

#P1-37

JOULE HEATING IN INITIATION OF DISCHARGE IN WATER

KEYNOTE SPEAKER

ZHANG He, LIU Yi, ZHAO Yong, LIN Fuchang

Key Laboratory of Pulsed Power Technology (Huazhong University of Science and Technology), Ministry of Education, Wuhan, China

ABSTRACT

In the process of microsecond pulsed discharge in water, it is generally considered that the discharge occurs in the gaseous phase in water. The formation of the gaseous phase needs sufficient heat, among which Joule heating plays an important role. In this work, the aim is to use the quantitative schlieren method to measure the temperature around the electrode in the initiation process of the discharge. Base on the temperature distribution, the Joule heating effect can be studied quantitatively. A schlieren system was set up for the optical diagnosis of the discharge process in water. Through a series of calculation steps, the radial temperature distribution near the electrode was obtained based on the gray values of the schlieren image. The effects of applied voltage, gap distance, and liquid conductivity on the temperature field were studied. The results suggest that if the Joule heating effect is strong enough, the water near the electrode will be heated to the boiling point, and then vapour will be generated. If the electric field intensity is still maintained at a high level after the process of heating, discharge will occur in vapour, and then streamer will be generated.

#P1-38

A SEMICONDUCTOR OPENING SWITCH BASED ON OFF-THE-SHELF COMPONENTS

KEYNOTE SPEAKER

DEGNON Mawuena Rémi[1,2], GUSEV Anton[1], SILVESTRE DE FERRON Antoine[1], PECASTAING Laurent [1], NOVAC Bucur[1,3], DAULHAC Gaëtan[2], BARANOV Aleksandr[2], BOISNE Sébastien[2]

[1] Université de Pau et des Pays de l'Adour, E2S UPPA, SIAME, Pau, France
[2] ITHPP ALCEN, Thégra, France
[3] Loughborough University, Loughborough, United Kingdom

ABSTRACT

An SOS effect is the nanosecond interruption of high-density current in a silicon structure. Based on this effect, SOS diodes were developed over three decades ago. That sparked a breakthrough in the development of solid-state pulsed power systems based on inductive energy storage since it allows the improvement of their important characteristics such as current density, pulse power, voltage and energy [1]. Due to high average power and long lifetime, the SOS generators are used for many industrial applications such as x-ray apparatus, particle accelerators, e-beam sterilization, laser pumping sources, etc. However, there is a limited number of manufacturers of SOS diodes in the world. Therefore, the possibility of commercially available diodes to replace the typical SOS diodes has been investigated in the present work. A test bench has been developed and optimized for the testing of off-the-shelf diodes in the SOS mode of operation. More than 25 types of commercially available diodes, including rectifying, avalanche, Schottky, TVS and Zener diodes, have been tested as opening switches. The specifications of the studied diodes are as follows: blocking voltage of 0.2-10 kV, die area of 0.01-0.81 cm² and recovery time of 0.1-20 µs. A voltage pulse with an amplitude of more than 3 kV, a rise time of 10 ns and a pulse width of 40 ns was obtained at the 110 Ω load. Finally, the results have been compared with a reference SOS diode of 0.25 cm² die area.

[1] S. N. Rukin, "Pulsed power technology based on semiconductor opening switches: A review," Rev. Sci. Instrum., vol. 91, no. 1, p. 011501, Jan. 2020.

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#P1-39

DEVELOPMENT OF THE 6 MA – 1 µS DRIVER GEPI-2 FOR ISENTROPIC COMPRESSION EXPERIMENTS

KEYNOTE SPEAKER

ZUCCHINI Frederic, LASSALLE Francis, LASSALLE Benjamin, PLOUHINEC Damien, COMBES Philippe, MONDON Yann, LAMPLE Regis, SOL David, CHANCONIE Thierry, TOURY Martial

CEA, Gramat, France

ABSTRACT

A new high current driver, named GEPI-2, is under development to maintain and improve the CEA capabilities for dynamic material studies through isentropic compression experiments. This driver will provide a 6 MA – 1 µs pulse to a low inductance (< 17 nH) strip line load, for load widths reaching 140 mm.

Several components of the dismantled Z-pinch driver SPHINX, such as the 1 µs LTD stages, have been reused to build this new generator. GEPI-2 is composed of twelve parallel branches of four 1 µs LTD stages staked in series. A 5-meter diameter double radial line has been designed to connect the 12 branches to the load and integrate a crowbar system for pulse shaping.

Details of the design of the GEPI-2 driver and results of initial tests will be presented here.

This work is supported by the DGA (Direction Générale de l'Armement)

#P1-40

DURABILITY STUDY OF BULK CU-NB COMPOSITES IN HIGH MAGNETIC FIELDS OF MICROSECOND DURATION

KEYNOTE SPEAKER

SPIRIN Alexey, PARANIN Sergey, KRUTIKOV Vasiliy, ZAYTSEV Evgeniy, KHRUSTOV Vladimir, ZAYATS Sergey, KOLEUKH Dianna

Institute of Electrophysics UB of RAS, Yekaterinburg, Russian Federation

ABSTRACT

The nanostructured Cu-Nb composite, characterized by high conductivity and tensile strength [1], is a candidate material for the development of tool coils (inductors) for advanced magnetic pulse processing (MPP) technologies exploiting high magnetic fields (HMF) with an amplitude of 30–50 T and 10–100 μs in duration. Using it in the form of a wire, reliable 70 T pulsed magnets of subsecond pulse duration are being developed [2], but it has not been used and studied under the generation of "short" HMFs of microsecond duration, which are preferable for MPP. The aim of this work is the development by powder approach of the bulk Cu-Nb composites, including layered structures on their basis, which can result in enhancing the material durability [3], and study their behavior in "short" HMFs of 30–40 T.

In this work, we used Cu-18% Nb composite wire 0.18 mm in dia obtained by melting and drawing technique (conductivity – 50% IACS, tensile strength – 1.57 GPa) and provided by the Nanoelectro LLC Company. It was used as a raw material to obtain a coarse powder (wire fragments) of 0.5–1 mm in size by cutting the wire and a powder with particles 20–64 μm in size by ball milling of the wire fragments in petrol. To form the layered structures with layers that differed in resistivity such additions as Y2O3 or TiC (micron-sized powders) were added to the base Cu-Nb powder in amounts 10 and 20 vol.%. Mixing the powders was performed by ball milling with petrol. Powders were pressed into pellets 2.5–8 mm thick and 8–32 mm in dia by magnetic pulsed compaction in vacuum (pressure pulse – up to 1.5 GPa in amplitude, preheating at 430°C). Some compacts were subjected to anneal in vacuum for 1 hour at temperatures 700–900°C to study the influence of thermal treatment on materials density, conductivity, structural characteristics, and mechanical properties. For testing the materials in HMFs, some samples of 32 mm in dia were cut into bars with a length of 32 mm having a cross-section 2×8 mm close to that of commercial Cu-18%Nb multicore rectangular wire of the same manufacturer. It was done to compare the commercial and lab materials in close conditions. The bars cut of the pellets and

commercial wire were the brazed parts of a duplex field shaper (DFS) which was placed inside a capacitor-driven single-turn inductor. Replaceable DFSs and the inductor were made of steel. At the first stage, the testing conditions were: magnetic field amplitude – 35 T, half-period – 15 μs, discharged current amplitude – 470 kA.

Some results are as follows. Samples with a high relative density of 91–99%, depending on the type of powder, were obtained. Due to the intense ball milling, powder materials were characterized by an increased concentration of structural defects, internal stresses, and lattice distortion of Cu and Nb as compared to the initial wire. Thus, for as-obtained samples from the base powder, the resistivity was twice as higher as that of the wire (3.45 μOhm·cm) as well as the HB (HV) microhardness was 10% higher than that of the commercial Cu-18%Nb multicore wire (CS 2×8 mm, HB 260); at that, the microhardness of as-obtained samples from the wire fragments was only 70% with respect to the latter one. This trend persists after annealing. The addition of TiC and Y2O3 particles results in resistivity increase by 1.3–1.5 and by 1.7–1.8 times, respectively, as compared to the base material; this also enhances by 30–40% the HB (HV) microhardness of mixed materials and their thermal stability, as well. The HMF testing reveals a proper behavior of the multicore wire in a 35 T magnetic field without significant change in surface morphology after 100 pulses (the testing is continued). Testing the sample made of base powder was stopped at 40th pulse due to the brazed joint failure. Despite the sample was cracked after the testing, its full damage and plasma jets at the working surface due to the "saw effect" did not occur. Testing the sample made of wire fragments is continued now (pulse number is 60). Material degradation from pulse to pulse occurs at the boundaries between the wire fragments which contain a pure copper phase as the wire artifact – a shell of the initial wire. Note, these first results are obtained on as-compacted samples (without sintering). The extended results concerning the samples after sintering will be highlighted and discussed in the conference paper.

The work was partly financed by RFBR, RFBR and BRFBR, RFBR and ROSATOM grants (Nos. 19-08-00931, 20-58-00029, and 20-21-00050). The authors are thankful to V. Pantsyrnyi and N. Khlebova for the provided Cu-Nb microcomposite wires (Nanoelectro LLC, Moscow, Russia).

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#P1-41

52-KV COMPACT SOLID-STATE PULSED POWER MODULATOR FOR S-BAND 3.1MW MAGNETRON

KEYNOTE SPEAKER

SONG Seung-Ho, RYOO Hong-Je

Chung-Ang University, Seoul, Republic of Korea

ABSTRACT

This paper describes a high voltage, high power density pulsed power modulator for S-band 3.1MW Magnetron. The modulator is designed to target the medical linear particle accelerators (LINACs) gentry mounted power systems or military portable microwave generators. A capacitor charger and pulse generator of the modulator have a forced air cooling system that does not require an external additional cooling device. A pulse generator consists of 5 stages, and single stage consists of 12 cells that are charged to 900V. A multi-core, multi-winding transformer is designed to supply isolated charging power to 60 cells. The transformer consists of one primary winding, 5 cores and bobbins, and 30 secondary windings. A gate circuit for generating pulses is designed to be a driving system that does not require an isolated DC power supply to satisfy both synchronized operation and miniaturization and weight reduction. Single high voltage cable is connected in series with a small core of each gate driver to satisfy a supply of isolated signals and power to all gate circuits. In addition, the primary winding loops are structurally designed to minimize EMI due to high dv/dt and di/dt. A high-voltage pulsed power modulator with specifications of 52-kV, 160-A, and 12-kW is implemented. The volume is measured as 120L and a maximum power density of about 69kW/L is achieved. Finally, the developed pulsed power modulator is verified with experimental results that will be discussed in following paper.

#P2-1

GENERATORS OF HIGH VOLTAGE DISCHARGES IN GASES AND LIQUIDS

KEYNOTE SPEAKER

LOROTKOV Sergey, ARISTOV Yury, KOROTKOV Dmitry

Ioffe Institute, St. Petersburg, Russian Federation

ABSTRACT

Generators of high power pulses of high voltage with a rise time of a few micro- or nanoseconds are considered. Each generator include a low-voltage circuit with an inductive energy storage, a step-up transformer, and a high voltage power circuit. The generators are able to generate voltage pulses with an amplitude of 40 kV and current pulses with an amplitude of 1 kA at a repetition rate of several kHz. The operation principle of the generators provides high stability of the amount of energy that is stored in the inductive storage. The amount of energy does not change over a wide range of both input voltage and load resistance. The main advantage of the newly developed generators is their high efficiency in such conditions, when the load resistance changes sharply. The results of the use of the generators for creation of microsecond discharges in water saturated with air bubbles and for generation of nanosecond discharges in an experimental facility for creation of silicon from a gaseous mixture SiF4+H2 are given.
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#P2-2

GENERATION OF SUPERSONIC WATER JETS BY UNDERWATER ELECTRICAL EXPLOSION OF WIRE ARRAYS

KEYNOTE SPEAKER

MALER Daniel[(1)], EFIMOV Sergey[(1)], ROSOSHEK Alexander[(1)], BLAND Simon[(2)], KRASIK Yakov[(1)]

[(1)] Technion - Israel Institute of Technology, Haifa, Israel
[(2)] Imperial College London, London, United Kingdom

ABSTRACT

Studies of matter at extreme pressures and densities are the subject of High Energy Density Physics (HEDP) which is of great importance for basic physics, including physics of astrophysical objects and various applications. To conduct such studies in a laboratory environment, different systems with stored energy of $>10^5$ J are used, namely Z-pinch, plasma focus, powerful pulsed laser system, multistage gas guns, high energy heavy ion beams, and chemical explosives.

In our presentation, we will describe the preliminary results of supersonic water jets, generated by underwater electrical explosion of wire arrays, which can be used for HEDP research. We will show that the underwater electrical explosion of a cylindrical or conical wire array is accompanied by the generation of extremely fast (up to 3.5 km/s) water jet and shock in air. In experiments, a pulse generator with stored energy of ~5.7 kJ, current amplitude of ~300 kA, and rise time of ~1.2 μs was used for the underwater electrical explosion of a copper wire array. Streak and fast framing shadow imaging were applied to study the time-space resolved velocity of the jet, ejected from the array and propagating in air. The jet generation occurs due to extremely high pressure and density of water formed in the vicinity of the axis by the imploding shockwave. It was shown that the velocity of the jet ejected from the array side depends on the array geometry and the thickness of the water layer above the array. The results obtained showed that a major part of the energy deposited into the array is transferred to the kinetic energy of this jet and to the axial flow of water generated by the relatively slow radial expansion of wires.

This approach of generating supersonic water jets and strong shocks in air can be considered a promising method for HEDP research. Furthermore, by modifying the experimental configuration such as to collide two water jets, generated by opposing wire arrays explosion, the study of shocks interaction and high energy density jets can be performed, which is a subject of astrophysical intriguing phenomenon.

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#P2-3

LOW-ENERGY HIGH-INTENSITY NITROGEN ION IMPLANTATION OF STAINLESS STEEL WITH SUBSEQUENT MODIFICATION OF THE ION-DOPED LAYER BY PULSED HIGH-CURRENT ELECTRON BEAM

KEYNOTE SPEAKER

RYABCHIKOV Alexander, SIVIN Denis, KORNEVA Olga, LOPATIN Ilya, BOZHKO Irina, VAKHRUSHEV Dimitrii, STEPANOV Igor

Tomsk Polytechnic University, Tomsk, Russian Federation

ABSTRACT

The results of experiments on low-energy high-intensity implantation of AISI 321 stainless steel by nitrogen ions are presented. The treatment was carried out by a repetitively-pulsed beam of nitrogen ions obtained using a ballistic ion focusing system. The influence of subsequent modification of the ion-doped layer by the action on the surface of the pulsed high-current electron beam of microsecond duration is studied. It was shown that the surface modification occurs with the formation of a two-layer structure, and the thickness of the modified layer can reach 33 μm after 1 hour of low-energy high-intensity ion implantation. The hardness of the obtained surface layer is increased by 6 times, and the wear resistance is more than 100 times compared with initial one. The increase in hardness occurs due to the formation of iron nitrides, which is confirmed by the results of x-ray diffraction analysis and transmission electron microscopy.

#P2-4

RESEARCH PROGRESS OF PULSED X-RAY PHASE CONTRAST IMAGING

KEYNOTE SPEAKER

ZOU Jian, ZENG Naigong, ZHANG Tianjue

China Institute of Atomic Energy, BEIJING, China

ABSTRACT

In order to carry out X-pinch related experimental research, a new one-day experimental circuit has been established on the side of Light-II Pulse Power Generator (250 kA/ 50ns) at China Institute of Atomic Energy. On the basis of retaining the original pumping laser capacity of the device, X-pinch related experimental research can be carried out at the same time. Two groups of X-pinch were driven by Light-II, one group was placed in the anode and the other group was placed in the reflux disk. The time difference was used to conduct the backlight imaging experiment of plasma distribution in the process of X-pinch self-explosion, and the sequence images of different times of X-pinch development were obtained. In the picture, the halo layer, pinch, implosion and final collapse dissipation of the plasma at the X-pinch point can be observed. The experimental results are helpful to further understand the physical mechanism of X-pinch plasma development. At the same time, X-pinch biological phase contrast imaging experiment was carried out, and high-resolution biological imaging pictures were obtained.

#P2-5

COMPARATIVE ANALYSIS OF CAPACITIVE ENERGY SOURCE TOPOLOGIES FOR AN ELECTROMAGNETIC ACCELERATOR

KEYNOTE SPEAKER

ALBARRACIN-VARGAS Fernando[(1)], MARTINEZ David[(1)], APPIAH Gideon Nimo[(1)], GALVIS Juan [(1)], AL KAABI Mohammed [(1)], ALMANSOORI Mae [(1)], ROUF BABA Abdul [(1)], ALALI Abdulla [(1)], KASMI Chaouki [(1,2)], MORA Nicolas [(1)]

[(1)] Directed Energy Research Centre, Technology Innovation Institute, Abu Dhabi, UAE
[(2)] Faculty of Electrical Engineering at Helmut Schmidt University, Hamburg, Germany

ABSTRACT

The increasing interest in alternative propulsion technologies encompasses various fields, including defense, transportation, and space launching. These new technologies aim at replacing the well-established propulsion based on chemical propellants. Electromagnetic accelerators of macroparticles are part of this group due to their ability to reach velocities of several km/s, overcoming their chemically propelled counterparts. Capacitor-based energy store units are commonly preferred due to the availability and reliability of both high-rated capacitors and closing-type high-current switches. The topology of the energy store unit has important implications on peak current, control-system complexity, and mechanical wear of the system.

This work presents a comparative analysis between two energy unit configurations; namely, the pulse forming network (PFN) and the multiple pulse forming unit (mPFU), in terms of peak current in the load and kinetic energy reached by a 2-gram payload. We consider a 150-kJ store unit discharged into a series-RL load, representing the rail-payload system, including internal losses and stray inductances. Velocities around 1400-m/s can be reached with both configurations. However, peak current with the PFN is expected to be significantly higher than that from the mPFU, under the same capacitance-per-stage condition. Moreover, the strong dependence of the pulse shape on the load impedance limits the use of the PFN as heat and contact degradation increase the system resistance. On the other hand, despite the need for several switches and crowbar diodes for the mPFU, which increases costs and complexity, this configuration can be triggered sequentially, allowing the optimization of velocity and control over peak current during operation.

#P2-6

AN INTENSE THZ SMITH- PURCELL SOURCE

KEYNOTE SPEAKER

GOEURY Alexandre, GARDELLE Jacques

(1) CEA/CESTA, Le Barp, France

ABSTRACT

Smith-Purcell (SP) devices are promising sources of THz radiation. At CESTA we have been studying them for several years and we produced 100 W at 100 GHz by using a single-shot 80 kV field-emission diode. We are currently designing a compact thermionic CW electron gun in order to increase the emitted frequency toward 1 THz. The two main challenges are beam alignment control and beam size reduction. To operate at 1 THz, we require constant beam size of a few tens of µm during grazing propagation above a 1cm-long grating. The experimental set up is described, along with the first results.

#P2-8

A 3-D ELECTROMAGNETIC ANALYSIS OF A MONOPOLAR PULSE FORMING LINE COUPLED TO AN IMPEDANCE TRANSFORMER FOR APPLICATION TO BIO-MEDICAL DOMAIN

KEYNOTE SPEAKER

IBRAHIMI Njomza[(1)], ARIZTIA Laurent[(1)], SILVESTRE DE FERRON Antoine[(1)], RIVALETTO Marc[(1)], NOVAC Bucur M.[(1,2)], BERTRAND Valérie[(3)], PECASTAING Laurent[(1)]

[(1)] Universite de Pau et des Pays de l'Adour, E2S UPPA, SIAME, Pau, France
[(2)] Wolfson School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, Loughborough, Leicestershire LE11 3TU, United Kingdom
[(3)] CISTEME – 15 rue Daniel de Cosnac, 19100 Brive-La-Gaillarde, France

ABSTRACT

A monopolar pulse forming line (M-PFL) was designed, manufactured, and tested for application to bio-medical domain. The M-PFL generates a voltage step with an amplitude up to 300 kV, a rise time of around 150 ps, and a duration of less than 1 ns on a 50 Ω matched load. Details of the design configuration are provided and validated using the CST 3-D electromagnetic analysis software. The TDR technique was also implemented to calculate the variation of the impedance in the time domain, considering both the incident and the reflected signals at the CST input port. A circuit approach for switch integration in the 3D model of CST MWS is proposed using transient co-simulation between MWS and Design Studio modules. Experimental tests were performed with an assembly composed of a Marx generator and the M-PFL combined with a 50 Ω to 3.125 Ω impedance transformer. The output of the impedance transformer is connected to a loop. This system aims at generating pulsed electric fields (PEF) of interest for bio-medical applications as cancer treatment.

#P2-9

SOLID-STATE PULSED POWER GENERATOR USING INDUCTIVE ENERGY STORAGE

KEYNOTE SPEAKER

REN Xiaojing[(1)], SUGAI Taichi[(1)], TOKUCHI Akira[(1,2)], JIANG Weihua[(1)]

[(1)] Nagaoka University of Technology, Nagaoka, Niigata, Japan
[(2)] Pulsed Power Japan Laboratory Ltd, Kusatsu, Japan

ABSTRACT

Inductive energy storage (IES) has been widely researched with its characteristic of high energy density. However, the disadvantage of its low transferring efficiency limits lots of the industrial applications. And improving the efficiency has became one of the directions that researchers are striving for. In this research, we have devised a solid state inductive pulsed power circuit, which can not only discharge high voltage, but also allow partial energy recovery. The power MOSFETs are used to operate the entire process. As the status of the power MOSFETs change, four steps can be seen as: charging the capacitor; charging the inductor; inductor discharge; energy recovery. As a result, a high voltage with a rectangular waveform can be generated on a resistant load with the opening switches, and then part of the energy of the inductor can be sent back to the primary capacitor as the discharge is terminated with the closing switches. Through this method, the efficiency of the inductive discharge circuit can be improved within a certain range. In order to evaluate the improvement, the analysis of the switching loss and the energy consumption of the inductor itself are also the key parts of this research.

#P2-10

EFFECTS OF VACUUM IMPEDANCE CHANGES ON MITL FLOW USING 3D ELECTROMAGNETIC PIC SIMULATIONS

KEYNOTE SPEAKER

GRABOWSKI Theodore

Sandia National Labs, Albuquerque, USA

ABSTRACT

Results are compared with those using QUICKSILVER, a structured EM PIC code and EMPIRE, another unstructured EM PIC/Fluid/Hybrid code. All codes agree with each other, and, more importantly, with experimental current measurements. Further evidence of electron loss in the MITL is given by strong thermoluminescent dosimeter (TLD) readings along the outer surface of the MITL anode.

The extended MITL on HERMES III has been redesigned with constant impedance and now shows considerably reduced current loss. It is shown that when delivering current to a Bremsstrahlung diode this increases the gamma dose measured on the external faceplate of the diode by at least a factor of two. As a result, doses measured at greater distances from the faceplate are also increased. Geometry choice as well as comparison between simulation and experimental performance of the redesigned MITL is reported and discussed. The new MITL has current sensors on both the anode and cathode at several locations along the MITL so the voltage can be estimated1,2 and that approximation can be compared to the simulations. Electron temperature in the MITL can have a large effect upon the estimated voltage2. The pressure was varied in simulation and compared to the experimental data to determine the approximate experimental electron temperature. These data are then correlated with the dose measurements made on the surface of the faceplate as well as at greater distances from the diode.

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#P2-11

ELECTRIC FIELD INSIDE A GAS CAVITY FORMED AT A SOLID-SOLID DIELECTRIC

KEYNOTE SPEAKER

WONG Timothy, TIMOSHKIN Igor, WILSON Mark, MACGREGOR Scott

University of Strathclyde, Glasgow, United Kingdom

ABSTRACT

Interfaces between different solid dielectric materials may exhibit lower breakdown strength as compared with bulk solid materials. A reason for such reduction in the dielectric strength is the presence of gas cavities which are formed at the interface. When the solid-solid interface is subject to impulsive electrical stress, the enhanced electric field in the cavities may result in the development of initial (partial) discharges. This may ultimately lead to the complete catastrophic breakdown across the interface, severely compromising the integrity of the entire insulation system. Therefore, it is paramount to understand the field distribution and ionisation processes in interfacial cavities, such that the behaviour and strength of the insulation system can be fully predicted.

The present paper considers a complex cavity formed between two solid dielectric (poorly conductive) materials which are characterised by their relative permittivity and electrical conductivity. In some cases, an internal surface of the gas cavity(es) may be covered with a thin layer of material with an elevated electrical conductivity, formed by partial discharges, which may impact the field distribution in and immediately surrounding the cavity. The layer within the cavity is characterised by its own relative permittivity and electrical conductivity values, which are greater than that of the surrounding bulk dielectric. The paper provides an analytical solution to the transient electric field in the cavity, the layer and in the dielectric bulk when stressed with an impulsive electric field with a specified rise and fall time. A comprehensive analysis of the transient field has been conducted, in order to investigate the effect of the various system conductivities and relative permittivities on the field magnitude and its transient behaviour.

The transient electric field will be used alongside a gas-kinetic approach to obtain the breakdown field-time characteristics of the gas cavity, within the framework of the Townsend and streamer models. The model presented in this paper will help to further the understanding of solid-solid interfacial breakdown under high voltage impulsive stress.

#P2-12

NON INVASIVE ELECTROMAGNETIC DIAGNOSTIC FOR NEW WIDE BAND GAP SEMI-CONDUCTORS

KEYNOTE SPEAKER

LARBAIG Jean-marie[(1)], RUSCASSIE Robert[(1)], DIENOT Jean-marc[(1)], RAMOS Ioav [(2)]

[(1)] Université de Pau et des Pays de l'Adour, E2S UPPA, SIAME, PAU, France
[(2)] NOVATEM S.A., Toulouse, France

ABSTRACT

The arrival and the maturity of new wide band-gap components gives the ability to reach very fast transition times (ns) by working at higher power (kW) which were, until then, inaccessible with Silicon semiconductors. Their integration in pulse generators is more and more recommended to replace mechanical switching means in order to propose significant improvements on operation frequency and switching accuracy and efficiency.

However, the improvement of these commutation speeds causes non-negligible electromagnetic constraints which, in many cases, lead to the failure of the implemented measurement means.
One of the solutions required to avoid this kind of issue is to implement non-invasive electromagnetic field probes on the solid-state switching boards in order to be able to safely measure as close as possible to the measurement source.

Consequently, in collaboration with the LabCEeM laboratory of Tarbes, we have implemented magnetic field probes developed by their competences, whose bandwidth characteristics are located between 1 MHz and 800 MHz. It has been proved that it is a convenient way to to measure the image of the high speed current flowing through power planes connected to SiC MOSFETs.

Initially designed to be placed above the components, we did, in our case, explore two different positions: one near a power plane, the other at the intersection of a via hole connection.

Comparisons of the modeling results with the obtained measurements will be discussed. Then, we did observe information's data and characteristics via these probes, in a power conversion system, of the magnetic field flowing through the electronic boards. Our main conclusions regarding this measurement technique will be presented.

#P2-13

TWO-DIMENSIONAL MEASUREMENT ON NANOSECOND PULSED DISCHARGE IN COAXIAL ELECTRODE USING SPECTROSCOPIC IMAGING

KEYNOTE SPEAKER

RYU Terumasa

Kumamoto University, Kumamoto, Japan

ABSTRACT

Non-thermal plasmas are being actively studied for industrial and environmental applications. Observations of discharged plasmas are useful in gaining a better understanding of plasma physics in this growing field. In general, a pulsed discharge of about 100 ns consists of a primary streamer phase and a secondary streamer phase. It is well known that the streamer head always has the largest electric field between electrodes and a faster propagation velocity. Furthermore, since the streamer head produces a variety of radical species with high efficiency, it is important to understand the distribution of active species between the electrodes. In the recent study, a nanosecond pulsed power generator that can generate a pulsed voltage with 5 ns of duration was developed and achieved the highest efficiency on ozone generation. However, the mechanism to achieve such high efficiency is not well understood. In this study, we focused on the acquisition of two-dimensional spectroscopic images of ns pulsed discharges in a coaxial electrode under atmospheric pressure air. In the experiments, we measured the position dependence of the reduced electric field and rotational temperature between the electrodes on ns pulsed discharges, based on the N_2^+ first negative system and N_2 second positive system.

#P2-14

FISH BARRIER PULSE GENERATING SYSTEM

KEYNOTE SPEAKER

ROTH Ian, HAWKEY Tim, GAUDREAU Marcel, ALLEN Michael, ZOGHBI George, KEMPKES Michael, SIMPSON Rebecca

Diversified Technologies, Inc., Bedford, USA

ABSTRACT

In October, 2020, Diversified Technologies, Inc. (DTI) delivered a high-power, high voltage Pulse Generating System (PGS) for the U.S. Army Corps of Engineers. This system uses short, high voltage pulses to deter fish from crossing electrodes located in a waterway. The major components of the PGS are: a 4.5 MW, +/- 3 kV DC power supply; output capacitor banks, which store energy for the pulses; and pulse switches, which produce pulses at up to 30 kA.

The PGS is part of an integrated system at the Permanent Barrier I Aquatic Nuisance Species Dispersal Barriers (PB1 Barrier or Permanent Barrier I) facility in Romeoville, Illinois, located on the Chicago Sanitary Shipping Canal (CSSC). This system provides an additional barrier to the incursion of invasive fish species (primarily Asian Carp) from the Mississippi river basin via the Canal that could potentially damage the Great Lakes ecosystem. A second PGS is scheduled for construction in 2022.

This paper will describe the design and construction of the PGS, and present results from its operation. This effort was performed under a subcontract from exp Federal.

#P2-15

DESIGN AND TESTING OF RF-ACCELERATING MODULE FOR THE IAP RAS PHOTOINJECTOR COMPLEX

KEYNOTE SPEAKER

BANDURKIN Ilya, DANILOV Yury, ILYAKOV Evgeny, KUZIKOV Sergey, MARTYANOV Ivan, PESKOV Nikolai, SAVILOV Andrey, VIKHAREV Alexander

Institute of Applied Physics RAS, Nizhny Novgorod, Russian Federation

ABSTRACT

The photoinjector complex being developed in the IAP RAS is projected to have two stages. The first one should provide electron energy of ~3-5 MeV and is to be used in experiments on undulator THz radiation. It has a classical layout and consists of an accelerator cavity powered by the microwave radiation at the frequency of 2.45 GHz, a photocathode located directly in this cavity and providing efficient electron emission, an ultraviolet laser causing photoemission of electrons from the cathode, and a system for synchronizing laser pulses with the phase of the RF accelerating cavity field. The second stage of the complex should accelerate the electron bunches to the energy of up to 20 MeV, after which they may be used in the Laser-Compton Scattering and Wakefield Plasma Acceleration setups. It is planned to use a linear accelerator in the form of a copper corrugated structure consisting of several sections with a total length of about 1 m and fed at the same frequency of 2.45 GHz as the first stage.

By present, the accelerating structure of the first stage is manufactured and tested in «cold» experiments, measured characteristics showing a good coincidence with the simulations. The following immediate steps are assembling the whole first-stage setup, conditioning of this structure at the input microwave power of up to 5 MW, and carrying out first experiments on measuring its accelerating capabilities in the low-current regime with a copper photocathode.

This work is supported by the Russian Science Foundation (grant #20-12-00378 for development of 3-5 MeV stage and grant #21-72-30027 for development of 20 MeV stage).

#P2-16

EFFECT OF GAS SPECIES ON THE PLASMA FLOW VELOCITY GENERATED IN TAPERED CONE PLASMA FOCUS DEVICE

KEYNOTE SPEAKER

WATANABE Shuto[(1)], TAKEZAKI Taichi[(2)], ITO Hiroaki[(2)], TAKAHASHI Kazumasa[(1)], SASAKI Toru[(1)], KIKUCHI Takashi[(1)]

[(1)] Nagaoka University of Technology, Niigata, Japan
[(2)] University of Toyama, Toyama, Japan

ABSTRACT

High energy particles called as cosmic rays have been observed in outer space, and collisionless shock waves play an important role in their generation process. Collisionless shock waves are formed in fast plasma flows originating from supernova remnants and stellar winds. Although collisionless shock waves are believed to generate the high energy particles, the particle acceleration mechanism is unclear.

Tapered cone plasma focus device (TCPFD), which uses a pulsed high-voltage gas discharge, can easily generate a fast plasma flow in a laboratory experiment. Experimental and numerical studies on the interaction between the plasma flow produced by the TCPFD and a perpendicular magnetic field have been carried out. Numerical simulations predicted that the plasma flow composed of multi-ion-species improves the efficiency of the particle acceleration caused by the interaction between the plasma flow and the perpendicular magnetic field.

In this study, to experimentally evaluate the response of the magnetic field to the multi-ion-species plasma flow, the effect of the gas species on the generation process of the plasma flow and its parameters such as the flow velocity, the ion number density, and the electron temperature are investigated. We measured the discharge voltage and the flow velocity as a function of the gas species in the TCPFD.

#P2-17

PRESSURE WAVE CHARACTERISTICS OF PULSED ARC ELECTROHYDRAULIC DISCHARGE VERSUS UNDERWATER ELECTRICAL WIRE EXPLOSION

KEYNOTE SPEAKER

BACQUEYRISSES Yoan[1,2], REESS Thierry[2], DE FERRON Antoine[2], TCHALLA Viviane[2], NOVAC Bucur M.[3,2], TUJAGUE Rémi[1], MORELL Alain[1]

[1] ITHPP, Thégra, France
[2] Universite de Pau et des Pays de l'Adour, E2S UPPA, SIAME, Pau, France
[3] School of Mechanical, Electrical and Manufacturing Engineering, Loughborough University, Loughborough, Leicestershire, United Kingdom

ABSTRACT

The main objective of the studies presented in this paper is to compare the characteristics of the pressure wave induced by a conventional pulsed arc electrohydraulic discharge (PAED) with that produced by an underwater electrical wire explosion (UEWE).

The experimental arrangement used is mainly composed of a high voltage capacitor bank driving a circuit connected to a pair of electrodes submerged under water with diagnostic instruments used in monitoring the electric and acoustic parameters. For these tests the bank was limited to a 3.9 µF capacitor, with a charging voltage varying between 10 kV and 50 kV.

Using capacitive energy storage, the amplitude of the pressure wave was optimized using the PAED technique, by varying the capacitor charging voltage and the distance between the two immersed electrodes.

Over the same voltage range and therefore the same initially stored energy, the characteristics of the pressure wave were also optimized using the UEWE method, by varying the length and the outer diameter of a copper exploding wire.

The results of these studies will allow quantifying the improvement brought in by the UEWE method over the conventional PAED technique in terms of peak amplitude and frequency spectrum of the pressure wave.

#P2-18

EFFECT OF PUSHER LAYER FOR RADIATION TRANSPORT IN FOAM LAYER IN HEAVY-ION INERTIAL FUSION

KEYNOTE SPEAKER

WATANABE Naoto, TAKAHASHI Kazumasa, SASAKI Toru, KIKUCHI Takashi

Nagaoka University of Technology, Niigata, Japan

ABSTRACT

Heavy-ion inertial fusion (HIF) is expected to be a promising candidate for future electric power generation because of its desirable properties, such as high energy conversion efficiency and controllability of the energy deposition of the heavy-ion beam. In the HIF system, a fuel pellet must be compressed to one thousand times solid density to reduce the input driver energy and to achieve an adequate burn fraction. To realize the higher compression ratio of the fuel is difficult due to non-uniformity for driver energy deposition be kept lower than a few percent. In the previous research, introducing a foamed metal layer into a spherical fuel pellet was proposed. The foam layer induces the active radiation transport in the azimuthal direction within the fuel pellet during the implosion process. The radiative transport in the azimuthal direction smooths the non-uniformity of the implosion. However, the radiation generated in the ablator layer heated by the irradiation of heavy-ion beam will preheat the fuel core during the implosion.

Therefore, in this study, we investigated the design of the pusher layer installed inside the foam layer. We developed a one-dimensional radiation hydrodynamics calculation code and calculated the implosion process of the fuel pellet with the changes of the pusher layer thickness and the material.

#P2-19

DETECTION OF CURRENT DENSITY ASYMMETRY IN ELECTROMAGNETIC LAUNCHERS VIA CURRENT BARYCENTER METHOD

KEYNOTE SPEAKER

BANDINI Gabriele, MARRACCI Mirko, CAPOSCIUTTI Gianluca, TELLINI Bernardo

Department of Energy, Systems, Territory and Construction Engineering (DESTeC), University of Pisa, Pisa, Italy

ABSTRACT

Pulsed power applications are characterized by high peak power and usually short time transients. Linear drives such as electromagnetic launchers (EMLs) are fed by capacitor- or inductor-based pulsed power supplies (PPSs) [1]. The short transient response characterizing the operation of such devices lead to a significant influence of the current diffusion process, in which skin effect, proximity effect and velocity skin effect (VSE) play an important role [2]. Moreover, defects in the rail/armature contact during launch result current distribution (CD) inhomogeneity causing efficiency loss and localized heating. These problems highlight interest in CD characterization in pulsed power applications and, particularly, in EMLs.

In [3] Omar et al. characterize the current distribution in a flat transmission line via rectangular search loops. The simulated signal on the loops is compared with measurements, inferring the device CD by evaluating the direct problem solution. In [4] Wild et al. investigate the CD in C-shape armatures by measuring the voltage drop on the rail along the launch direction. In [5] Liebfried et al. compares colossal magnetoresistance (CMR) effect sensor measurements with data from small Rogowski coils wounded around the brush of an armature.

In [6]–[8], the signal induced in a loop array mutually coupled with brush armatures was used to solve the inverse problem and infer the current in each brush. A similar approach was used in [9], where the magnetic flux through a loop array was used to evaluate the current repartition among a set of parallel rods. The results were compared with Rogowski coil readings, with good agreement. The method was then extended to the characterization of current diffusion in EMLs by measuring the current barycenter (CB) position during the current transient. The comparison between measured CB location and 2D finite element method (FEM) simulation results gave encouraging results in analyzing the current diffusion process.

In this work we apply the CB method to the characterization of CD asymmetries due to rail/armature contact defects in EMLs. The evolution of the CB coordinates over time due to the diffusion process is observed both in the armature and in the rails, and a shift in the coordinates themselves was measured in case of controlled defect. When the loop array is affected by border effects, the same data can be used to detect asymmetries, possibly by double-weighted measurement. The latter approach takes the form of a zero-measurement method. The experimental activity is carried out on an EML developed in the laboratory of measurement techniques, University of Pisa, Italy. An uncertainty analysis performed by Monte Carlo simulation according to the GUM [10] is also provided. The presented method is applied but not limited to EML, being suitable for the characterization of current diffusion and unbalance in all straight conductors in pulsed power experiments.

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#P2-20

SUPERCONDUCTING ARMATURES FOR COILGUN APPLICATIONS

KEYNOTE SPEAKER

VERTELIS Vilius[1,2], BALEVIČIUS Saulius[2], STANKEVIC Voitech[2,3], ZURAUSKIENE Nerija[2,3], SCHNEIDER Markus[1]

[1] *French-German Research Institute of Saint-Louis, Saint Louis, France*
[2] *Center for Physical Sciences and Technology, Vilnius, Lithuania*
[3] *Faculty of Electronics, Vilnius Gediminas Technical University, Vilnius, Lithuania*

ABSTRACT

In comparison to railguns, coilguns are attractive, as their operation does not require sliding electric contacts. Synchronous wave induction coilguns accelerating metal armatures suffer from an effect called armature capture. Eddy currents in the armature decay due to the resistivity of the material and consequently the accelerating force decreases. Type II superconductors can be treated as conductors that exhibit nonlinear magnetic field diffusion. If these materials are used as coilgun armatures, their behavior differs qualitatively from that of normal conductors. In this contribution, we present our investigation of the performance of a type II superconducting armature when accelerated by a pulsed magnetic field generated by a single-stage pancake coil. The typical pulse had a duration of 160 ms and a peak amplitude in a range of 450-570 A. We performed a numerical finite element simulation and an experimental study of the magnetic field dynamics at the edge of the pancake coil when the payload was a superconducting disc made from YBa2Cu3O7-x, cooled down to 77 K. The magnetic field measurements were performed using a CMR-B-scalar sensor, which measures the magnitude of the magnetic field up to 90 T amplitude. The sensor used here was specifically designed to have an increased low field sensitivity in the range up to 500 mT. The main result of the study is that type II superconducting armatures can outperform normal metals with regard to maximum kinetic energy if the launch conditions are tailored to their electromagnetic properties.

#P2-21

DOUBLE-BEAM PLANAR MAGNETRON-INJECTION GUN FOR POWERFUL TERAHERTZ GYROTRONS

KEYNOTE SPEAKER

ZASLAVSKY Vladislav[1,2], MANUILOV Vladimir[2], KUFTIN Andrey[1], LESHCHEVA Kseniya[1]

[1] *Institute of Applied Physics of the Russian Academy of Sciences, Nizhny Novgorod, Russian Federation*

[2] *Nizhny Novgorod State University, Nizhny Novgorod, Russian Federation*

ABSTRACT

The double-beam diode planar magnetron-injection gun (MIG) forming two generating ribbon helical electron beams (HEBs) was suggested. Electron-optical system (EOS) for a 140 GHz gyrotron operating at the first harmonic of the cyclotron frequency with an accelerating voltage of 50 kV, a total beam current of 60 A, and a magnetic field compression of 36 were considered. 3D numerical simulations of the HEB properties based on the CST STUDIO SUITE code were performed to find the optimal configuration of the gun. It is shown that it is possible to form two sheet HEBs with practically equal pitch-factors and moderate values of velocity spread. The proposed two-beam EOS makes it possible to increase the total beam current and, accordingly, the generated power of the device. In addition, the considered EOS is promising from the point of view of the gyrotron operation at high cyclotron harmonics. An important difference from the conventional gyrotron circuits is qualitatively different dependence of the coupling coefficients on the transverse coordinates. In the proposed planar scheme, the coupling factors can be almost the same for both HEBs, which gives an additional advantage even for operation on the first harmonic and makes the situation much better when working on high-order modes and high gyrofrequency harmonics. A three-dimensional particle-in-cell simulation of the electron-wave interaction in 140 GHz planar gyrotron of a megawatt power level operating at the first gyrofrequency harmonic in a high-order operating mode has been carried out.

#P2-22

INVESTIGATIONS ON TWO BRANCH TOPOLOGIES FOR AN INDUCTIVE VOLTAGE ADDER BASED ON SIMULATIONS

KEYNOTE SPEAKER

RUF Johannes[1,2], BARNES Mike[1], KRAMER Thomas[1], SACK Martin[2]

[1] CERN, Meyrin, Switzerland
[2] KIT, Karlsruhe, Germany

ABSTRACT

For driving kicker magnets featuring a short circuit termination a novel approach for a pulse generator architecture based on an inductive voltage adder is currently under investigation. Short circuit termination of the magnet results in a traveling wave reflecting back from the load to the generator. Once the reflection reaches the pulse generator, it switches into freewheeling mode, so no more energy is fed into the system. Hence, initially the generator needs to inject the current and only absorb it at the end of the pulse. It is desirable that in the on-state the losses are low. Two novel circuit topologies for a branch of the inductive adder have been investigated. They have been designed for an easy implementation, but hence may involve some compromises with respect to the precision of the pulse shape: nevertheless, the pulse shape must meet the required specifications. The two topologies differ with respect to their way of handling the absorbed energy. One topology dissipates the energy which needs to be absorbed by means of a resistor. The other topology recuperates this energy back into the pulse capacitor. Circuit simulations have been performed in order to investigate the performance of both circuits and compare them to the requirements for the generator design. Selected predictions are presented and discussed in this paper. The results suggest that both topologies are in principle suitable for the intended application. At the next step both designs will be set up in hardware for further investigations.

#P2-23

NLTL FOR PICOSECOND PULSE COMPRESSION

KEYNOTE SPEAKER

ZHABIN Alexey[1], USKOV Grigory[2], RIVALETTO Marc[1], PECASTAING Laurent[1]

[1] Universite de Pau et des Pays de l'Adour, E2S UPPA, SIAME, Pau, France
[2] Voronezh State University, Department of Electronics, Voronezh, Russian Federation

ABSTRACT

Nonlinear transmission lines (NLTLs) are an effective solution to improve the parameters of an ultrashort pulse signal. NLTLs with linear inductors and reverse-biased diodes as a nonlinear capacitance have found many applications in RF/microwave fields. However, the application of these lines for picosecond pulse compression has physical limitations associated with processes in the semiconductor structure of a diode. The response of the NLTL parameters to the pulse signal has an order of its duration. This paper presents the results of Pspice simulations combined with experimental research of picosecond pulse compression by NLTL. The line was optimized to achieve the shortest duration without amplitude decrease. The pulse width and rise-time were reduced from 350 ps to 210 ps and from 244 ps to 167 ps, respectively. It is shown that the line does not allow further compression of the pulse. As appears from simulation results the efficiency of NLTL application for the pulse compression decreases with decreasing of its duration..

#P2-24

ELECTRON TEMPERATURE AND ELECTRON DENSITY MEASUREMENT OF PULSED STREAMER DISCHARGE PLASMA BETWEEN POSITIVE AND NEGATIVE VOLTAGE POLARITY DEPENDENCE BY LASER THOMSON SCATTERING DIAGNOSTICS

KEYNOTE SPEAKER

MURAKAMI Tomomasa

Kumamoto Univeristy, Kumamoto, Japan

ABSTRACT

Pulse streamer discharge plasma, a type of non-thermal equilibrium plasma, is characterized by "electron temperature higher than gas temperature," "large discharge area," and "large electric field. it is known to produce a variety of chemically active species, and it is applied to a wide range of applications such as water treatment, ozone generation, and exhaust gas decomposition. However, the appropriate electron temperature varies depending on the application. Therefore, accurate measurement of the electron temperature of the generated pulsed streamer discharge can improve the plasma treatment efficiency. Laser Thomson scattering diagnostics is considered to be a reliable method to measure electron temperature and electron density in plasma. In this study, the propagation process of a pulsed streamer discharge from a needle electrode to a cone electrode was observed by an ICCD camera, and the characteristics of the streamer discharge were investigated. In order to clarify the characteristics of the streamer discharge, LTS diagnostics was also performed. in the LTS measurement, a high voltage was applied to the needle electrode to generate a streamer discharge between the electrodes, a laser was irradiated just below the anode needle, and the scattered light that passed through the spectrometer was captured by the ICCD camera. As a result, we succeeded in obtaining Thomson scattering between positive and negative voltage dependence, and measured the electron temperature and electron density of the pulsed streamer discharge.

#P2-25

CMR-B-SCALAR SENSORS FOR MEASUREMENT OF MAGNETIC FIELD DYNAMICS DURING MAGNETIC PULSE FORMING

KEYNOTE SPEAKER

VOITECH Stankevic[1,2], NERIJA Zurauskiene[1,2], SAULIUS Balevicius[1], SKIRMANTAS Kersulis[1], JUSTAS Dilys[1], MODESTAS Ceikauskas[1], VALENTINA Plausinaitiene[1,3]

[1] Department of Functional Materials and Electronics, Center for Physical Sciences and Technology, Vilnius, Lithuania
[2] Faculty of Electronics, Vilnius Gediminas Technical University, Vilnius, Lithuania
[3] Faculty of Chemistry and Geosciences, Vilnius University, Vilnius, Lithuania

ABSTRACT

During the last decades it was demonstrated that magnetic field sensors based on nanostructured manganite films exhibiting the colossal magnetoresistance (CMR) phenomenon could be used for high pulsed magnetic field measurement in very small volumes (10-2 mm3). The output signal of these sensors doesn't depend on the magnetic field direction (CMR-B-scalar sensors). Such sensors were used for the measurement of magnetic diffusion processes in railguns and magnetic field distribution in pulsed magnets generating magnetic field pulses of 1 – 100 ms duration with amplitudes up to 60 T. However, in some applications such as Magnetic Pulse Forming (MPF) or Welding of metals the significantly shorter magnetic pulses with high amplitude are used.

In this study, we present the investigation of magnetic field dynamics measured in a narrow gap between formed (or welded) metal and magnetic field shaper during MPF of metal tubes. The specifically manufactured the CMR-B-Scalar probe, which design ensures high signal/noise ratio, and electronic measurement module with a high sampling rate were used for these measurements. The experimental results demonstrated that during the deformation of the aluminum tube, the maximum magnetic field in the gap between the field shaper and the flyer is achieved much earlier than the maximum of the current pulse of the coil. Moreover, the analysis of magnetic field dynamics using different workpieces and different charging energy of capacitors gives a useful information about the magnetic pressure acting on the deformed workpiece, deformation velocity and other features which take place during forming or welding processes.

#P2-26

EVALUATION OF A MULTI-CHANNEL FAST MARX PROTOTYPE

KEYNOTE SPEAKER

LASSALLE Benjamin[(1)], SOUSBIELLE Léo[(1,2)], RODNER Simon-Pierre[(1)]

[(1)] CEA/DAM/CEA-Gramat, GRAMAT, France
[(1)] Université de Pau et des Pays de l'Adour, E2S UPPA, SIAME, Pau, France

ABSTRACT

An original architecture for a fast Marx is proposed in this paper. This Marx is arranged in a strip-line structure and is composed of several Marx in parallel synchronized by multi-channel air gap switches. The performances of a prototype designed with off-the-shelf components and working at atmospheric pressure are shown. These experimental results are used to estimate the performances of a redesigned Marx with pressurized switches and optimized mechanical design. Specific embedded diagnostics such as current and voltage sensors on PCB and optical fiber spark detection system have been developed to measure its performances and to characterize the behavior of the switches.

#P2-27

NUMERICAL ANALYSIS ON WAVE PROPAGATION IN TAMPER FOR HEAVY-ION BEAM DRIVEN INERTIAL CONFINEMENT FUSION TARGET

KEYNOTE SPEAKER

LIN Zehao, TAKAHASHI Kazumasa, SASAKI Toru, KIKICHI Takashi

Nagaoka University of Technology, Nagaoka, Japan

ABSTRACT

Heavy-ion-beam irradiation is a hopeful way to achieve inertial confinement fusion (ICF). Heavy-ion beam deposits a significant part of its kinetic energy inside the material instead of the material surface. The target pellet consists of fuel, pusher, and tamper layers in the heavy-ion beam driven ICF scheme. The outermost shell of the fuel target structure (tamper) is sturdy enough. In that case, most of the energy deposited from the heavy-ion beam is converted into the fluid kinetic energy for the implosion of the fuel pellet. In the case of heavy-ion beam driven ICF, it is difficult to irradiate the fuel pellet uniformly because the heavy-ion beams are incident from the limited number of beams. The adjustment of fuel pellet structure is one of the critical issues to achieve uniform implosion by the nonuniform beam irradiation.

For this reason, the dynamics of the tamper in the ICF pellet becomes important. We have studied the dynamics of tamper during the ICF pellet implosion using a developed hydrodynamic simulation code. Also, we analyzed the dynamics of tamper theoretically with the wave theory of hydrodynamics. In the case for the tamper is not thick enough, outward shock from the ablator and inward isentropic wave decide the tamper dynamics. While the tamper is thick enough, the outward rarefaction wave from the ablator becomes an important factor in the tamper dynamics.

#P2-28

INVESTIGATION ON TRANSIENT CURRENT SHARING BETWEEN PARALLEL SIC MOSFETS IN HV PULSED-POWER APPLICATIONS

KEYNOTE SPEAKER

AZIZI Madhi, GEELEN Stefan, VAN OORSCHOT Jeroen, HUISKAMP Tom

Electrical Energy Systems Group of the Department of Electrical Engineering at Eindhoven University of Technology, Eindhoven, Netherlands

ABSTRACT

In this contribution, the results of our study on transient current sharing between parallel SiC MOSFETs and its effect on output pulse characteristics, mainly rise time, will be presented. Solid-state high-voltage pulsed-power supplies capable of generating flexible pulses with considerable repetition rate make them the best choice for many applications. Nonetheless, the output pulse's rise-time of MOSFET-based pulse sources, which is important in some applications like transient plasma generation [1], is longer than can be achieved with spark-gap-based pulsed-power supplies. In solid-state pulsed-power supplies, different parameters are effective on the output pulse's rise-time. One key factor is the semiconductor current which directly affects the output pulse's rise-time. Therefore, to achieve a short rise-time the switch current should be as small as possible. One solution is paralleling a couple of switches to share the output current between them. Although, in steady-state current sharing between parallel MOSFET happens automatically, transient current sharing needs to be investigated to illustrate the influence of switch paralleling on the rise time of the output pulse. Therefore, a test circuit with identical gate driving loop and high-power path is designed. The MOSFETs current is measured using the high bandwidth Rogowski coils introduced in [2]. The effect of parameters such as paralleling method (direct paralleling with same driver or indirect paralleling with separate drivers), load current level, and gate resistance on transient current sharing between parallel SiC MOSFETs and output pulse rise-time is investigated and the results will be presented.

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#P2-29

PULSED CORONA DISCHARGE ABATING AQUEOUS AND AIRBORNE ORGANIC COMPOUNDS: FINDINGS IN ENERGY EFFICIENCY ENHANCEMENT

KEYNOTE SPEAKER

PREIS Sergei[(1)], TIKKER Priit[(1)], ONG Liina[(1)], KASK, Maarja[(1)], DULOVA Niina[(1)], KRICHEVSKAYA Marina[(1)], BOLOBAJEV Juri[(1)], KORNEV Iakov[(2)]

[(1)] Tallinn University of Technology, Tallinn, Estonia
[(2)] National Research Tomsk Polytechnic University, Tomsk, Russian Federation

ABSTRACT

Gas-phase pulsed corona discharge (PCD) in the gas-liquid mixtures, where aqueous media are dispersed in an oxygen-containing gas, exhibits energy efficiency and practicability in oxidation of aqueous and airborne organic compounds unequalled among other advanced oxidation processes. This statement is confirmed in laboratory and pilot scale experiments described earlier [1-4] with various volatile and non-volatile compounds. The search for the ways of further enhancement of the PCD energy efficiency was found in extended gas-liquid interface [5], application of extrinsic oxidants addition [6], and addition of a surfactant [7, 8]. The presence of aqueous surface accelerates oxidation of airborne volatile organic compounds (VOCs) in PCD [9]. None of the approaches with the only exception of the VOCs abatement, is of universal character requiring detailed explanations.

Extension of gas-liquid interface in an aqueous media showered to the discharge zone results, at its initial stage, growth in oxidation energy efficiency with subsequent gradual saturation dependent on oxidation reaction kinetics, when oxidation rate becomes determined by the applied discharge power. Optimization of the treated solution spray density presents a task for future studies.

Unlike hydrogen peroxide, addition of persulfate to the acidic solutions profoundly accelerates oxidation of dissolved organic compounds providing noticeable economic benefits. Neither persulfate, nor peroxide showed any impact to PCD treatment in neutral or alkaline solutions leaving unassisted PCD the most feasible solution.

Addition of moderate amounts of sodium dodecyl sulfate (SDS) to aqueous solutions of an organic compound, as a rule, dramatically reduce the oxidation energy efficiency, but sometimes results in up to tripled oxidation rate. The behaviour of SDS as the oxidation rate regulator was explained using the model of molecular interaction screening the target pollutant from the surface-borne hydroxyl radicals or, in opposite, exposing the target molecules to the surface radical attack. The model predictions were confirmed experimentally, providing additional proof for the surface reaction hypothesis.

Oxidation of VOCs in the air-water mixture proceed with an oxidation rate surpassing all other results reported for electric discharge applications towards, for example, airborne toluene for at least an order of magnitude due to massive formation of hydroxyl radicals at the air-water interface.

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#P2-30

INVESTIGATION OF ANNULAR EXPLOSIVE EMISSION CATHODES OF CONDUCTOR-INSULATOR CONSTRUCTION

KEYNOTE SPEAKER

CHEPUSOV Alexander, KOMARSKIY Alexander, KORZHENEVSKIY Sergey

Institute of electrophysics UB RAS, Ekaterinburg, Russian Federation

ABSTRACT

Research is devoted to investigation of properties of pulsed explosive emission cathodes for X-ray tubes. Three types of annular explosive emission cathodes were examined: metal-ceramic with slits (of a comb-shaped kind), metal-ceramic and carbon-ceramic. A pulsed high-voltage generator used in experiments is characterized with the following parameters: voltage pulse full width at half maximum is about 20 ns, pulse voltage amplitude is up to 150 kV, pulse frequency is up to 200 Hz. The installation makes it possible to study demountable models of pulsed X-ray tubes of different designs. Current and voltage waveforms corresponding to different operation modes, rates of rise of X-ray tube anode voltage are obtained. Current pulse duration for the ring carbon-ceramic cathode is considerably lower than for the other cathodes. Investigation of radiation dose rates demonstrates better irradiation ability of carbon-ceramic cathode: its dose rate is considerably higher than for the others.

#P2-31

HIGH PRECISION MAGNETIC MEASUREMENT ON SOLENOIDS FOR HIGH CURRENT ELECTRON LINAC

KEYNOTE SPEAKER

CASSANY Bruno, CASTAGNET Nicolas

CEA, Le Barp, France

ABSTRACT

In particle accelerators, the beam is transported, guided and focused with the help of magnetic fields. The beam quality and stability is highly affected by mechanical and magnetic alignments. In high current electron LINAC's, the solenoids cannot be aligned independently of acceleration cells. A key performance issue in solenoids characterization is the accurate determination of the magnetic axis. It is defined as the path where the integral over the radial field components takes its minimum. The aim is to measure both axial and transverse magnetic components on the mechanical axis. For each Z position, the ratio between the Br radial and the Bz axial components determines the quality of the solenoid. The measurement is performed by two Hall probes mounted on a rotating arm coupled with a laser telemeter. The proposed methodology is able to take into account the mechanical imperfection of the system.

The experiment presented is carried out on solenoids dedicated to linear induction accelerator: the third axis of EPURE facility at CEA.

#P2-32

INVESTIGATION OF MECHANICAL STRESSES AND HEATING OF A QUASI-FORCE-FREE MAGNET WITH INERTIAL RETENTION OF THE END PART OF THE WINDING

KEYNOTE SPEAKER

SHNEERSON German, KRIVOSHEEV Sergey, LAGUTKINA Anna, NEMOV Alexander, NEMASHEV Aleksey, SHIMANSKIY Sergey, PARFENTIEV Anatoliy, TITKOV Vassiliy

Peter the Great St. Petersburg Polytechnic University, St. Petersburg, Russian Federation

ABSTRACT

A small-volume magnetic system with a quasi-force-free winding, aimed at generating a magnetic field with pulse duration of several microseconds, is studied. Three-dimensional simulations revealed specifics of the distribution of mechanical stresses, temperature, and current in the winding turns. The possibility of unloading the end parts of the winding by means of using a massive screen, which virtually does not move during the discharge, is demonstrated. A configuration of the magnet in which the ratio of the von Mises stress to the magnetic pressure of the field does not exceed 0.235 was developed.

#P2-33

COMPTON SASE FEL BASED ON SECTIONED RF UNDULATOR SYSTEMS

KEYNOTE SPEAKER

SAVILOV Andrei, PESKOV Nikolai, KUZIKOV Sergey, VIKHAREV Alexander

Insitute of Applied Physics, Russian Academy of Sciences, Nizhny Novgorod, Russian Federation

ABSTRACT

A key problems in realization of shore-wavelength free-electron lasers (FELs) is a small efficiency at the saturated stage of the electron-wave interaction. The averaged radiation loss in the relativistic Lorentz-factor is determined by the so-called FEL parameter, which is typically very small. A similar condition limits the admissible quality of the operating electron bunch (spread in initial energy).

Recently, the regime of multi-stage trapping was proposed for FELs. We develop the idea of the "non-resonant" trapping regime , which can provide an effective trapping in a beam with a great energy spread. In the multistage system, the non-resonant trapping is provided several times in several consecutive sections, where the energy corresponding to the exact electron-wave resonance gres is decreased with the axial coordinate. In each section, only a relatively small fraction of the beam is trapped and pass their energy to the wave. However, repetition of this process from section to section involves in the electron-wave interaction almost all particles of the beam. As a result, an great electron efficiency can be achieved for a beam with a big energy spread .

An important feature of this multi-stage regime is that the phase correlation between undulator sections is not needed. This feature can be especially important in FELs based on the use of rf-wave undulators. Thus, a system of separated tapered rf undulator sections (either cavities or waveguides) can be used. Since the synchronization between undulator sections is not needed, these sections can be fed by separated and independent pulsed powerful rf sources. In this work, we describe our activities in simulations of FELs based on the use of the regime of the multi-stage trapping, as well as in development and testing of prototypes of profiled microwave systems of rf-wave undulators.

This work is supported by the Russian Foundation for Basic Research grant 18-02-40009 and the IAP RAS State Task Project 0035-2019-0001.

#P2-34

A MULTIPHASE RAIL LAUNCHER WITH CIRCULAR GEOMETRY AND MODULAR DESIGN: DEVELOPMENT, CONSTRUCTION AND FIRST EXPERIMENTS

KEYNOTE SPEAKER

ZELLMER Florian[1,2,3], LÖFFLER Markus[2], SCHNEIDER Markus[1], KREISCHER Christian[3]

[1] ISL Saint Louis, Saint Louis, France
[2] High Voltage and Pulsed Power Laboratory, Westphalian University, Gelsenkirchen, Germany
[3] Chair of Electrical Machines and Drive Systems, Helmut Schmidt University, Hamburg, Germany

ABSTRACT

The idea to use multiphase alternating current instead of direct current to drive a rail launcher has been brought up quite a while ago. An interesting but not obvious feature of such an approach is that a constant acceleration force can be realized [1].

However, in comparison to conventional launchers, the whole system has to be re-designed. The launcher becomes more complex as more than two rails are required and an appropriate power supply has to be developed.

In this contribution, the development of a multiphase launcher prototype working at low power levels is described. If up-scaled, a potential application could be the launch of satellites because in contrast to military applications, a compact design would not be required. On the other hand, the launch of satellites may require high initial speeds. Therefore, a modular setup allowing for more than one acceleration stage is considered. Indeed, the analysis of the electric behavior of a multiphase launcher does also lead to the conclusion that a modular setup is to be preferred.

As the passage of the armature between the modules is expected to be a critical point, the idea came up to build a 6 phase circular geometry meaning that the armature leaves at the "muzzle" and re-enters at the "breech" of the launcher. This also allows using an electric motor for a pre-acceleration in order to minimize sliding contact problems during start. As power supply served a re-designed 100 kW high-current transformer which could be connected it directly to the local power grid.
Experimental data including electrical parameters (e.g. armature current of 20 kA) are presented and discussed.

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#P2-35

MODIFIED LIF-DIP SPECTROSCOPY OF RYDBERG STATES OF XENON FOR ELECTRIC FIELD MEASUREMENT IN PLASMA

KEYNOTE SPEAKER

AN Wladimir, WANG Zhen, WEISENBURGER Alfons, MULLER Georg

Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany

ABSTRACT

Based on the LIF-Dip diagnostics principle and the use of a wide-band excitation laser, we developed a method that enables the measurements of weak electric fields in plasmas with poor microscale pulse to pulse reproducibility. The new measurement technique not only allows the entire Stark spectrum of a point to be recorded in just one measurement process, but also provides the complete image of the one-dimensional electric field distribution, stretched to macroscopic plasma areas of a few cm.

#P2-36

DIFFERENT EXTRACTION STRUCTURES APPLICATION IN HIGH EFFICIENCY RELATIVISTIC MAGNETRON SIMULATION

KEYNOTE SPEAKER

FAN Yuwei, LIU Zeyang

National University of Defense Technology, Changsha, China

ABSTRACT

In our recent research, different relativistic magnetron extraction structures including diffraction output (DO) and all-cavity extraction are designed to adapt to a same high power capacity electromagnetic structure.Typical optimized simulation results are as follows: For DO, working at an applied voltage of 563 kV and a magnetic field of 0.34 T, the relativistic magnetron with diffraction output (MDO) radiates microwave of 2.13 GW at 1.59 GHz, and the corresponding power conversion efficiency is 75.5%. For all-cavity extraction, high-power microwave of transverse electromagnetic (TEM) mode is generated with average power of 1.56 GW, frequency of 1.593 GHz and power efficiency of 75.8%, when the voltage is 586 kV and the current is 3.59 kA. There final numerical value of efficiency are similar.

#P2-37

PLANAR RELATIVISTIC SUB-TERAHERTZ SURFACE-WAVE OSCILLATORS AND AMPLIFIERS WITH TRANSVERSE ENERGY OUTPUT AND INPUT: CONCEPT, THEORY, AND SIMULATIONS

KEYNOTE SPEAKER

MALKIN Andrey, FEDOTOV Alexey, ZASLASKY Vladislas, SERGEEV Alenxander, GINZBURG Naum

Institute of Applied Physics RAS, Nizhny Novgorod, Russian Federation

ABSTRACT

Relativistic high-current Cherenkov surface-wave oscillators and amplifiers provide a possibility of using oversized electrodynamic systems with much larger transverse dimensions comparing to conventional relativistic BWOs operating at low-index bulk modes of corrugated waveguide.

Here we consider a planar configuration based on sheet relativistic electron beams. The advantage of this layout, as compared to cylindrical variants, is the possibility of using transversely open waveguides. This provides an additional mode selection mechanism allowing the operating current to be increased by means of applying wider cathodes. This configuration regularizes the transverse structure of radiation inside the interaction region of oversized planar waveguides with a single corrugated wall.

However, a problem of the radiation outcoupling into a regular waveguide mode should be solved. Besides, a significant part of the generated radiation would go to the cathode side reducing the output power or requiring an additional cathode reflector. In order to solve both of these problems, we propose using the transverse output of radiation so that the output energy flow (Poynting vector) is directed normally to the corrugated structure. For π-mode operation, transverse output may be organized by means of subharmonic corrugation with a period twice longer than the period of the main corrugation supporting the surface wave.

Additional subharmonic corrugations can also be used as a radiation input and output in a klystron-type surface-wave amplifier. We demonstrate the efficiency of both schemes in sub-THz range based on the quasi-optical theory and PIC simulations for radiation generation and amplification at the power level of 10-100MW.

#P2-38

COUPLING OF HIGH VOLTAGE, HIGH POWER MODULES FOR LIGHTNING STRIKES EXPERIMENTAL SIMULATION

KEYNOTE SPEAKER

ZAEPFFEL Clement, ANDRAUD Vincent, SOUSA MARTINS Rafael

(1) DPHY, ONERA, Université Paris-Saclay, F-91123 Palaiseau, France

ABSTRACT

To ascertain the safety of aircraft against lightning; materials, components and structures are tested against this threat. Standards define several current waveforms occurring in series during a lightning event. A lightning generator inject those current waveforms in the device under test through a 10 cm electric arc. In this work, we present the design and the performance of three modules developed at ONERA to study lightning strikes respecting the standards of the domain. Compactness and innovation are the main objectives of these designs to allow research in a small laboratory without the infrastructure usually needed for this kind of generator.

Three modules coupled together composed the GRIFON generator. Two high voltage modules produce biexponential waveform up to 100 kA. The last low voltage module produces a 400 A continuous current waveform using a buck converter scheme. Firstly, aim and design choices are discussed and the obtained results are presented for each module. Secondly, the coupling of the three modules is described with emphasis on the necessary filtering components between each of them. Finally, we present a comparison between the resulted current waveform and spice simulation as well as some examples of lightning test performed with this generator.

#P2-39

MEASURE OF ELECTRICAL PARAMETERS OF NANOSECOND DIELECTRIC BARRIER DISCHARGES (NSDBD) IN AIR AT ATMOSPHERIC PRESSURE

KEYNOTE SPEAKER

DOBBELAAR Martinus [1], BESSIÈRES Delphine [1], ARNAUD-CORMOS Delia [2], LÉVÊQUE Philippe [2], PAILLOL Jean [1]

[1] *Universite de Pau et des Pays de l'Adour, E2S UPPA, SIAME, Pau, France*
[2] *XLIM University of Limoges CNRS, Limoges, France*

ABSTRACT

Nanosecond pulsed electric fields (nsPEF) is increasingly used in cancer treatment. nsPEF consists in high voltage pulses with durations of a few nanoseconds and high electric field. Biological samples can be exposed to nsPEF without direct contact when they are placed into a guided transverse electromagnetic (TEM) structures. On the other hand non-thermal plasma techniques are explored for similar biomedical purposes, on the same nanosecond time scale. New developments in DBD operating under high voltage nanosecond pulses (nsDBD) are now a promising technique for cancer therapy. In this context, the purpose of this study is to propose an experimental technique allowing generate both nsPEF and nsDBD in combination. The work presented here focuses on the generation of nsDBD, associated measurement techniques in order to obtain an electrical characterization of the discharge.

An electrical setup is proposed for generating nsDBD over large frequency bandwidth. The classical DBD equivalent circuit has been extended to high frequencies. A synchronization procedure of currents with voltages pulses is based a comparison with circuit simulation results. Discharge current pulses with amplitudes up to 50 A and rise times less than 1 ns and are measured. The energy deposited in the plasma channel of the discharge is presented as a function of time. Note that circuit simulation support experiments : the discharge resistance is then modeled by two resistances in series, one following a Rompe and Weitzel formulation and the other of constant value, in series with a capacitor which stands for the charging of the sheaths.

#P2-41

ANALYSIS OF THE SECONDARY EMISSION OF ELECTRONS IN COLLECTOR SYSTEMS OF MODERN GYRODEVICES

KEYNOTE SPEAKER

MOROZKIN Mikhail, MANUILOV Vladimir

IAP RAS, Nizhny Novgorod, Russian Federation

ABSTRACT

We have developed a physical model and an algorithm for calculating the specific power density dissipated on the collector of gyrodevices, taking into account the reflection and secondary emission of electrons from the collector surface. The features of the energy and angular distribution of secondary electrons are taken into account when the electron beam is obliquely incident on the surface.
The electron trajectories and the corresponding power density distributions were found for several typical collector systems of gyrodevices: a relativistic pulsed powerful gyroklystron, a 170 GHz / 1 MW gyrotron for the ITER project, a 28 GHz / 10 kW gyrotron for technological applications, and a 263 GHz / 1 kW gyrotron for spectroscopic applications.

The calculations were performed independently using two software packages: a two-dimensional EPOS code and a three-dimensional code based on the IBSimu library. The transition to three-dimensional calculation methods is relevant for calculating axially asymmetric helical electron beams, for example, in gyrotrons with quasi-optical multi-mirror resonators, as well as in planar gyrotrons.

The generalized results of calculations show that electron re-reflections significantly expand the instantaneous trace of the electron beam. This requires a significant lengthening of both the entire collector and its cooling zone. In this case, the distribution of the power density of the deposited beam changes, accompanied by a significant decrease in the peak value of the scattered power density, which opens up the possibility of using collectors of a much smaller diameter in powerful gyrodevices.

This work was supported by RSF, grant 21-19-00884.

#P2-42

DURABILITY STUDY OF STEEL LAYERED STRUCTURES OBTAINED BY POWDER APPROACH IN HIGH MAGNETIC FIELDS OF MICROSECOND DURATION

KEYNOTE SPEAKER

SPIRIN Alexey, PARANIN Sergey, KRUTIKOV Vasiliy, ZAYTSEV Evgeniy, KHRUSTOV Vladimir, ZAYATS Sergey, KOLEUKH Dianna

Institute of Electrophysics UB of RAS, Yekaterinburg, Russian Federation

ABSTRACT

The work focuses on the development of steel-based materials and approaches for engineering reliable tool coils (inductors) employed in the magnetic pulse welding (MPW) technique. This application requires the generation of high, 40–50 T, pulsed magnetic fields (HMF) of microsecond duration. At such conditions, inductors made of many pure metals and alloys have poor durability. This significantly reduces the economic attractiveness of the MPW technique. An inductor failure usually starts from the working surface where the inductor material is subjected to intense thermo-mechanical stresses due to magnetic pressure and especially ohmic heating [1]. A promising and theoretically justified approach to reduce the thermal stresses and the deformations is the creation of a conductor surface layer with higher resistivity, which decreases with depth continuously or stepwise [1,2]. Steels are considered promising materials for the production of massive coils due to their low cost, high strength, and the possibility of modification by different methods. Our results on the creation of continuously changed conductivity in structural steels by different diffusion treatment: ion nitriding and diffusion pack chromizing, and study the effects under HMF generation are presented in [3,4].

In the present work steel conductors of uniform materials and with layered structures were obtained by powder approach and studied. This allows for a stepwise conductivity change with the layers of different resistivity and thickness. In perspective, such structures can be realized by modern additive technologies. To create a massive support layer, powder of medium-carbon structural steel of 30KhGSA grade (0.3C, 1.0Cr, 1.0Mn, 1.1Si) with a low resistivity value among alloyed steels was used. For the formation of resistive layers, the base powder with an addition of 5, 7, and 10 wt.% of chromium and alternative powder from austenitic resistive alloy 36NKhTYu (0.03C, 12.7Cr, 36.3Ni, 3.1Ti, 1.1Al, 1.1Mn, 0.4Si) were studied. The powders were obtained by steel ball milling the metal shavings in argon which were obtained by machining the cast steels. The chromium adding as a micron-sized powder was performed by milling as well. The powders were then pressed into pellets 32 mm in dia and 2.5–3 mm thick by magnetic pulsed compaction in vacuum (pressure pulse – up to 1.5 GPa in amplitude, preheating at 430°C) followed by sintering in vacuum at 1200°C to obtain the uniform and bi-layered samples with a relative density 95–99%. The sintering kinetics and CTE of compact materials were studied. The structural, microstructural, and mechanical properties, as well as the resistivity of as-obtained and sintered samples, were investigated depending on the material type and porosity. The influence of the

1/2

porosity is of interest since it usually presents in the articles obtained by additive technologies.

For testing the materials in HMFs, an inductor system with a field shaper was used. Some uniform and bi-layered compact samples of 32 mm in dia were cut into rectangular plates. The plates were then welded to one part of a duplex field shaper (DFS), the other one was used as reference material. Further, the DFS was placed inside a capacitor-driven single-turn inductor. Replaceable DFSs and the inductor were made of 30KhGSA steel as well. Prior to testing the DFSs with the samples being tested were subjected to hardening. The testing conditions were: magnetic field amplitude – 50 T, half-period – 15 μs, discharged current amplitude – 1.00±0.05 MA. The samples were prepared for comparative metallographic analysis after 20 pulses. It was observed that the mechanism of destruction of the uniform and bi-layered (with 0.8mm layer containing 7%Cr) powder samples was different from that one of cast steel (the reference material). The detailed results will be given and discussed in the extended paper.

The work was partly financed by RFBR, RFBR and BRFBR, RFBR and ROSATOM grants (Nos. 19-08-00931, 20-58-00029, and 20-21-00050).

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#P2-43

IMPULSE GENERATOR FOR TESTING THE EFFECTS OF INDIRECT LIGHTNING ON ELECTRONIC DEVICES

KEYNOTE SPEAKER

PARK Su-Mi, JEONG Woo-Cheol, RYOO Hong-Je

Chung-Ang University, Seoul, Republic of Korea

ABSTRACT

This paper deals with an impulse generator to test the reliability of electronic equipment against the indirect lightning effect. The designed impulse generator consists of a single high voltage capacitor charging power supply (CCPS) to charge the storage capacitor and the pulse forming network (PFN) and injection transformer. When designing PFN circuits, detailed parameter tuning is performed to meet the specifications of the output waveform such as voltage/current level, rising/falling time, repetition rate, and so on, and as a result, a storage capacitor with a minimum of 1 nF and a maximum of 150 μF is used as a load of the high voltage CCPS. However, in order to use a single high voltage CCPS for all PFN loads, a large charging current for repeatedly charging a 150 μF capacitor up to few kV within a few ms is required while a small 1 nF capacitor must be charged with high precision. From these requirements, the CCPS in this paper is designed with two types of converters in parallel: one has relatively low output current and the other has large one. Through the experiments of the developed CCPS, the maximum specification for charging voltage of 11 kV and a repetition rate of 10 kHz was confirmed. Finally the impulse generator was developed by connecting the CCPS, PFN, and an injection transformer, and was verified to generate various waveforms for simulating indirect lightning effect.

#P2-44

THE EFFECT OF IMPULSE RISE-TIME ON THE BREAKDOWN OF COMPOSITE ESTER-POLYMER INSULATION

KEYNOTE SPEAKER

Williamson Chris[(1)], Timoshkin Igor[(1)], MacGregor Scott[(1)], Wilson Mark[(1)], Given Martin[(1)], Sinclair Mark[(2)], Jones Aled[(2)]

[(1)] University of Strathclyde, Glasgow, United Kingdom
[(2)] AWE Plc, Aldermaston, United Kingdom

ABSTRACT

Environmentally friendly ester dielectric fluids have been the subject of active research within the power industry for over 80yrs [1]. Given the nature of such research, focusing on ester fluids as an alternative to conventional transformer oil, test methodologies were developed which are based on a standard 1.2/50ms lighting impulse, which represents the transient electrical stress which insulating liquid may experience within a typical power transformer [2-4]. While such an approach may yield suitable data for power operators, it does not fully extend to pulsed power technology. For example, large pulsed power machines [5] typically generate impulsive voltages with nominal parameters (rise-time, fall-time, rise method) which are not reflected within standard tests, IEC 60897. Representation of pulsed power systems is also lacking in published research surrounding breakdown of interfaces between liquid and solid dielectrics. As with bulk liquid breakdown, work in this area has focused on breakdown of interfaces formed with typical dielectrics used in power transformers: mineral oil and kraft paper, [6-8]. However, kraft paper is not commonly used with pulsed power machines, typically different solid polymers are employed in such HV apparatus. Consequently, efforts must be made to increase understanding of the dielectric behaviour of solid polymer-insulating fluid interfaces stressed with non-standard high voltage impulses.

It is therefore the intention of this work to provide experimental data on the breakdown of ester fluids, both natural and synthetic, under testing conditions more representative of the stresses experienced within a pulsed power machine. To that end, an investigation was conducted into the breakdown of composite insulating systems formed of synthetic ester fluid, MIDEL 7131 (M&I Materials, UK) and natural ester fluid, EnviroTemp FR3, (Cargill, USA) and solid polymers under a number of discrete voltage impulses of wave-shapes with rise time of 0.4μs, 1.2μs and 7μs; with all data measured against a benchmark of the same interfaces formed with transformer oil (SHELL Diala S4 ZX). Obtained breakdown parameters (breakdown voltage and time to breakdown) will yield important information to increase confidence in the use of environmentally friendly ester fluids within the pulsed power industry.

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#P3-1

PROJECT OF POWERFUL LONG-PULSE THZ-BAND FEL DRIVEN BY LINEAR INDUCTION ACCELERATOR

KEYNOTE SPEAKER

PESKOV Nikolai[1,2], ARZHANNIKOV Andrey[1], BELOUSOV Vladimir[2], GINZBURG Naum[1,2], NIKIFOROV Danila[1], SANDALOV Evgeny[1], SINITSKY Stanislav[1], SOBOLEV Dmitry[2], ZASLAVSKY Vladislav[2], ZHIVANKOV Kirill[1]

[1] Budker Institute of Nuclear Physics RAS, Novosibirsk, Russian Federation
[2] Institute of Applied Physics RAS, Nizhny Novgorod, Russian Federation

ABSTRACT

Project of high-power long-pulse THz-band FEL is under development in collaboration between BINP (Novosibirsk) and IAP RAS (N.Novgorod) driven by the linac "LIU" 5 - 20 MeV / 2 kA / 200 ns of the new generation. The aim of this project is to achieve a record sub-GW power level and pulse energy content up to 10 - 100 J at THz frequencies. Principal problems in realization of this generator include: formation of the electron beam with parameters acceptable for operation in the short-wavelength ranges, development of undulator for pumping operating transverse oscillations in the beam, and elaboration of electrodynamic system that can provide stable narrow-band oscillation regime in a strongly oversized interaction space.

Initial proof-of-principle experiments are planned to start at the "LIU-5" accelerator in the 0.3 THz frequency range, with prospects of transition to 0.6 THz range and higher frequencies after positive results would be demonstrated. In the report, the design parameters of the FEL project are discussed. Results of electron-optical experiments on the beam formation are presented. Structural elements of the FEL magnetic system based on helical undulator and a guide solenoid that provides intense beam transportation were elaborated. An electrodynamic system was proposed exploiting a new modification of oversized Bragg structures, so-called advanced Bragg structures, which have significantly improved selective properties. Structures of such type were designed with the diameter of 20 and 40 wavelengths for operation in specified frequency ranges.

This work is supported by the Russian Science Foundation (grant #19-12-00212).

#P3-2

SERIES GATE DRIVING SYSTEM FOR SOLID-STATE BIPOLAR PULSED POWER MODULATOR BASED ON MODULAR CELL STRUCTURE

KEYNOTE SPEAKER

SONG Seung-Ho, RYOO Hong-Je

Chung-Ang University, Seoul, Republic of Korea

ABSTRACT

This paper presents a series gate driving system for a high voltage bipolar pulsed power modulator. A solid-state bipolar pulsed power modulator with a multi-stage structure requires two to four times more switching componants than a unipolar pulsed power modulator. The proposed gate system can implement not only the supply of isolated signals and power required for a gate circuit for driving each switch, but also the operating of complex logic for generating bipolar pulses with a simple structure. The system consists of a pair of inverters with high voltage cables that generate signals and small transformers in the gate circuits. Two high voltage cables are connected in series with the small transformers in the gate circuit to deliver synchronized signals and isolated power to all gate circuits. The designed gate driving system is applied to a 10-kV bipolar pulsed power modulator consisting of 12 modular cells and drives 48 solid-state switches. The modulator can freely control the pulse width and repetition rate through the simple system. The modulator can freely adjust the pulse width and repetition rate through a simple gate system. Experiments were conducted with a pulse width of 1 to 10 us and a repetition rate of 1 to 3 kHz under resistance load conditions. Finally, the proposed gate system with bipolar pulsed power modulator is verified with plasma application tests.

#P3-3

INVESTIGATION OF DIELECTRIC STRENGTH OF MINERAL OIL BASED NANOFLUIDS UNDER HIGH PULSED VOLTAGE

KEYNOTE SPEAKER

PETRE Anca [1], ALLOUCHE Joachim [2], EL-KHATTABI Mohamed [1], DE FERRON Antoine [1], PECASTAING Laurent [1]

[1] *Universite de Pau et des Pays de l'Adour, E2S UPPA, SIAME, Pau, France*
[2] *Universite de Pau et des Pays de l'Adour, E2S UPPA, IPREM, CNRS, Pau, France*

ABSTRACT

Within the recent years, dielectric breakdown of oil-based nanofluids was widely studied, by modifying different parameters like type of nanoparticles, temperature, moisture content %, oil nature, DC or AC voltage.

In this context, the originality of our study lies in the application of fast pulsed high voltages, and the influence of the rise time and fall time has been studied.

In order to highlight the influence of these parameters, tests were performed first on the genuine mineral oil. Besides, the influence of the gap spacing was carried out.

Furthermore, this study has been extended to nanofluids. Nanofluid was made by adding different magnetite concentrations to the mineral oil. Magnetite was synthetized by a Massart method and its average diameter was of 20 nm.

Tests were made on 6 samples, 5 with different magnetite concentrations of 0.2 to 1 g/l and one control sample without magnetite. The waveforms used for nanofluid tests had first a constant rise time and the fall time was varying, and then the fall time was kept constant and the rise time was modified. The obtained results will be shown and discussed in this article.

#P3-4

MICROSCOPIC SCHLIEREN AND ACOUSTIC INVESTIGATION OF SUPERSONIC UNDERWATER ELECTRICAL DISCHARGE PHENOMENA

KEYNOTE SPEAKER

STOBBS Jessica, NOVAC Bucur, SENIOR Peter, WOODYARD Matthew

Loughborough University, Loughborough, United Kingdom

ABSTRACT

A custom made Schlieren system featuring an ultrahigh-speed camera is used to investigate the pressure disturbances generated by supersonic underwater discharge. Hydrophone data are used to corroborate the pressure disturbances identified optically, and further analyse their acoustic properties, including frequency content, pulse duration, and acoustic power. The efficiency of this process can be determined by comparing acoustic data and electrical data, which reveals the electrical power. The possibility of producing pressure disturbances without breakdown is also investigated, by electrically insulating one electrode the formation of a conducting plasma column is prevented.

#P3-5

ELECTROMAGNETIC LAUNCHER SPEED CONTROL WITH A MULTILEVEL FAST TRIGGERING TIME ALGORITHM (MFTTA)

KEYNOTE SPEAKER

TOSUN Nail, KEYSAN Ozan

Middle East Technical University, Ankara, Turkey

ABSTRACT

Electromagnetic launchers (EMLs) can provide accurate speed control of a projectile compared to gun-powder-based alternatives. However large-caliber launchers have several pulse power supply (PPS) modules connected in parallel to reach the required current levels. Determination of the triggering instants of these parallel PPS modules is a crucial part of the launch mechanism. The triggering instants do not only affect the exit velocity but also the forces on the armature which can lead to transition i.e. separation of the armature from the rails. In this study, a triggering sequence optimization method is faster than other alternatives in the literature and takes into account speed-dependent parasitic masses and transition phenomena. Real-coded genetic algorithm (RCGA) and Particle Swarm Optimization (PSO) are used to create benchmarks. 32 capacitive PPS modules with 8 MJ total energy are used. With the achieved accuracy and speed, this study offer: An effective speed control algorithm with several physical constraints.

#P3-6

A PORTABLE X-PINCH AS A SOURCE FOR DISPERSIVE SPECTROSCOPY IN HIGH ENERGY DENSITY PHYSICS

KEYNOTE SPEAKER

STRUCKA Jergus, HALLIDAY Jack, BLAND Simon

Imperial College London, London, United Kingdom

ABSTRACT

Dynamic compression experiments on pulsed-power machines produce more uniform extreme states of matter that can reach mm in size. Commonly, these experiments suffer from the lack of availability of x-ray diagnostics. It is of interest to material, planetary, and fusion science to study the state variables, phase transitions, and long-range structure in these extreme states. Recent advances in pulsed power technology - including low inductance capacitors and dry air switches - enabled development of portable pulsed x-ray drivers with extremely high fluence. Our next generation portable X-pinch driver - Dry Pinch 1 - is only 30cm x 30cm x 70cm, weights @50kg and produces ~ 150kA pulse in 300ns. The X-pinch emits ~ 70mJ of radiation between 1-10KeV in approximately 1ns, directly comparable to a 3rd generation synchrotron at a distance of <20cm from the pinch. Dry pinch 1 is ideally suited as a portable x-ray source for optimization of experimental setups where x-ray diagnostics are currently unavailable or before high-precision campaigns at large facilities. I will present the recent developments, results, and future milestones in our portable diagnostics campaign.

#P3-7

A 9×9 SUB-MICROSECOND PULSED PLASMA JET ARRAY FOR DISINFECTION AND STERILIZATION

KEYNOTE SPEAKER

CHEN Hongyu, RONG Zhang, LIU Zhen, YAN Keping

Zhejiang University, Hangzhou, China

ABSTRACT

In recent years, with the advancement of atmospheric pressure non-thermal plasma technology in the field of biomedical applications, it has shown many advantages in disinfection and sterilization. In terms of application, the key lies in how to easily generate a large-area, uniform and stable plasma. In this work, a unipolar microsecond pulse power source is developed to excite an array plasma jet under atmospheric pressure, thereby performing a large-area disinfection and sterilization treatment. The source can produce high-votlage pusles with a peak voltage up to 28kV, a pulse width of about 700ns, and a repetition rate up to 20kHz. The effects of parameters such as voltage, gas flow rate, pulse frequency, treatment distance and treatment time on the sterilization effect were studied. The results show that the sterilization rate is positively correlated with voltage, gas flow rate, pulse frequency, and treatment time, and negatively correlated with the treatment distance. Better sterilization effects can be achieved under helium atmosphere. The array plasma jet sterilizes Bacillus subtilis spores up to 100% in a circular range of 48 cm^2 at a voltage of 20 kV and a frequency of 15 kHz.

#P3-8

GENERATION OF SUB-TERAHERTZ CHERENKOV SUPERRADIANCE PULSES IN STRONGLY OVERSIZED 1D AND 2D PERIODICAL SURFACE-WAVE STRUCTURES

KEYNOTE SPEAKER

MALKIN Andrey[(1)], GRINZBURG Naum[(1)], ZASLASKY Vladislav[(1)], SERGEEV Alexander[(1)], ZOTOVA Irina[(1)], BOLTACHEV Grey[(2)], SHARYPOV Konstantin[(2)], SHUNAILOV Sergey[(2)], UL'MASKULOV Marat[(2)], YALANDIN Mikhail [(2)]

[(1)] Institute of Applied Physics RAS, NIzhny Novgorod, Russian Federation
[(2)] Institute of Electrophysics UB RAS, Ekaterinburg, Russian Federation

ABSTRACT

Significant progress was achieved lately in generation of high-power microwave pulses based on superradiance (SR) of extended electron bunches, which occurs due to the development of microbunching and slippage of the wave with respect to electrons. SR pulses with the peak power exceeding 1 GW were obtained in X- and K-bands using the Cherenkov mechanism when electrons interact with the backward wave in a slow-wave structure (SWS) with an oversize factor (diameter-to-wavelength ratio) of ~1.

In shorter wavelength bands, the use of single-mode SWSs is hindered due to requirements for transportation of the electron beams and increase of the Ohmic losses. A promising solution of the specified problems is operation at evanescent (surface) waves in oversized SWSs. Experiments conducted based on the RADAN accelerator demonstrate that the azimuthally coherent radiation is generated at an oversize factor about 3. The peak power at a frequency of 0.15 THz reached 50-70 MW. For further increasing of the oversize factor up to 5-6, SWS with double periodical corrugation was suggested. In experiments, an SR pulse at 0.09 THz with a duration of 0.7 ns and an output power of ~ 150 MW was generated. These experiments are in line with the quasi-optical theory describing the excitation of surface waves by relativistic electron beams.

The work is supported by RSF grant No. 21-19-00260.

#P3-9

INFLUENCE OF ELECTRICAL CONDUCTIVITY ON ELECTRICAL DISCHARGES MODE IN LIQUIDS

KEYNOTE SPEAKER

IMBERT Tony[(1)], REESS Thierry[(2)], DE FERRON Antoine[(2)], PECASTAING Laurent[(2)], DEMOL Gauthier[(1)], GUEGAN Baptiste[(1)]

[(1)] ITHPP, Thegra, France
[(2)] Universite de Pau et des Pays de l'Adour, E2S UPPA, SIAME, Pau, France

ABSTRACT

Depending on practical applications in the field of electrical discharges in liquids, the controlling of the propagation mode of the electrical discharge is key. It is now well know that the breakdown voltage in tap water under atmospheric conditions is affected by the duration of the applied voltage. In one hand, pulses shorter than a microsecond induce supersonic propagation mode and breakdown fields can increase up to a few MV/cm. On the other hand, voltage impulses longer than a microsecond lead to a decrease breakdown field values (from 100kV/cm to a few tens of kV/cm) and to the subsonic propagation mode.

It is important to understand the influence of electrical conductivity on the transition between the two discharge modes.

This paper presents an experimental study of a water gap voltage breakdown as a function of water conductivity and particularly focused on the propagation time of the discharge phenomena in liquid in order to estimate the transition between modes. This transition between modes is directly linked to the electric field between electrodes, which is estimated by electrostatic simulations. While the value of the electric transition field is known around 300 kV / cm for tap water, the study determined this threshold when the liquid conductivity is higher. Tests were performed with different coaxial geometry electrodes and several storage capacitive benches. An energy balance of the discharge formation is obtained from this experimental data.

This presentation is complementary with a second one entitled "Influence of fluid static pressure and temperature on electrical discharges mode in liquids".

#P3-10

EXPERIMENTAL MEASUREMENTS, NUMERICAL SIMULATIONS, AND ANALYTICAL CALCULATIONS OF INTENSE RELATIVISTIC ELECTRON BEAM PARAMETERS ON THE SINUS-6 HIGH-CURRENT ELECTRON-BEAM ACCELERATOR

KEYNOTE SPEAKER

ISLAM K. Nusrat, ANDREEV Andrey D., SCHAMILOGLU Edl

The University of New Mexico, Albuquerque, USA

ABSTRACT

The aim of this study is to validate experimental results obtained on the high-current electron-beam accelerator SINUS-6 by direct measurements of (i) the current of a thin annular electron beam generated from a cylindrical explosive emission cathode in a smooth cylindrical waveguide (SCW) immersed into a strong magnetic field and propagating downstream of the cathode, and (ii) accelerating voltage applied to the cathode, with results of analytical calculations and computer simulations of the problem. The experimental results show current-voltage characteristic of the SINUS-6 accelerator by comparing (i) the maximum in the pulsed electron-beam current measured at some distance from the cylindrical explosive emission cathode to (ii) the maximum in the pulsed accelerating voltage applied to the cathode. The simulation results are obtained using the particle-in-cell (PIC) code MAGIC for the experimental geometry of the problem, as well as the experimentally measured accelerating voltage pulses. The analytical results are obtained by calculating two different space-charge limited (SCL) electron-beam currents available to be transported in an SCW without forming a virtual cathode: (1) SCL current of the first kind (a.k.a. Brejzman-Ruytov SCL current) for an electron beam injected into an SCW with non-zero initial kinetic energy of electrons, and (2) SCL current of the second kind (a.k.a. Fedosov-Belomytsev SCL current) for an electron beam generated from the cathode just inside an SCW and accelerated downstream of the problem from zero initial kinetic energy of electrons at the cathode. Comparison of experimental measurements, computer PIC simulation, and analytical calculations show relatively good agreement of the results.

This work is supported by AFOSR MURI Grant FA9550-20-1-0409.

#P3-11

DEVELOPMENT OF A LOW VOLTAGE RAILGUN IN THE CONTEXT OF LIGHTNING RESTRIKE

KEYNOTE SPEAKER

ANDRAUD Vincent [(1)], SOUSA-MARTINS Rafael [(1)], ZAEPFFEL Clément [(1)], TESTE Philippe [(2)], LANDFRIED Romaric [(2)]

[(1)] DPHY, ONERA, Université Paris-Saclay, F-91123 Palaiseau, France
[(2)] Geeps, CentraleSupelec, 91190 Gif-Sur-Yvette, France

ABSTRACT

In the context of lightning strikes to aircraft, there is a relative motion between the static lightning channel and the airplane that flights at velocities faster than 100 m/s. Thus, the attachment point is displacing through the fuselage and is able to impact any part of the aircraft. The complex physical phenomenon that drives this displacement remains a high challenge for computational simulations, mainly because there is a lack of reliable experimental measurements.

To accurately reproduce this experiment in a laboratory and then obtain physical measurements based on reliable diagnostics, a low voltage Railgun is designed and realized. It aims to propel aeronautical material plates of few hundreds of grams up to 100 m/s within 2 meters, performing an acceleration of a hundred of g's before being hit by a lightning electric arc produced from an electric current generator.

Whereas common Railgun applications operate at thousands of Volts to provide current intensities up to the mega Amperes during a few milliseconds to reach thousands of g's of acceleration, the designed Railgun operates under 30 V for safety reasons and to smooth the acceleration profile. A maximum current of 25 kA is reached thanks to the use of a supercapacitor bank made of 144 supercapacitors for a total equivalent capacitance of 3000 F. The speed of the railgun is enhanced by Neodymium NdFeB magnets providing augmented magnetic field. As the gliding contact is the main problem in this kind of application since a bad electric contact might prevent the generator to provide power to the projectile, different configurations of projectile are tested as well as its geometry and its material.

#P3-13

INVESTIGATING THE BENEFIT OF SOLID-STATE ARCHITECTURES TO IMPROVE PERFORMANCES OF PULSED POWER GENERATOR FOR MULTI-PULSE FLASH RADIOGRAPHY APPLICATIONS

KEYNOTE SPEAKER

LARBAIG Jean-Marie [(1)], PECASTAING Laurent [(1)], REESS Thierry [(1)], SILVESTRE de Ferron Antoine [(1)], RIVALETTO Marc [(1)], RUSCASSIE Robert [(1)], CARON Michel [(2)], CADHILON Baptiste [(2)], COURTOIS Laurent [(3)], CASSANY Bruno [(3)], GOEURY Alexandre [(3)]

[(1)] Universite de Pau et des Pays de l'Adour, E2S UPPA, SIAME, PAU, France
[(2)] French Atomic Energy and Alternative Energies Commission, GRAMAT, France
[(3)] French Atomic Energy and Alternative Energies Commission, CESTA, France

ABSTRACT

CEA is investigating pulsed power for multi-pulse flash X-ray radiography. In this way, CEA CESTA is developing a high-voltage generator able to produce up to 3 consecutive 200kV pulses in a microsecond range. This generator will be dedicated either to drive an IVA (induction cells in an Inductive Voltage Adder) for the generation of electron beams, or to drive a LIA (induction cells in a Linear Induction Accelerator) to accelerate those consecutive beams. Due to the very short delay between pulses, dispersions created by the first pulses will degrade the voltage plateaus of the following pulses, thus questioning the quality of the radiography.

The aim of the HiVoSS (High Voltage Solid Switch) project conducted within the SAGE laboratory is to find a way to improve the flatness of these high power pulses To address this issue, two solutions are proposed. The first one focuses on absorbing this parasitic oscillations by loss (semi-conductor loaded) cables between the multi-pulse generator and the cells (IVA or LIA). The advantage of these cables is clearly located on the HF dispersion that they will allow to obtain. However, their low maturation doesn't allow to have ones with the same characteristics, calling into question their design reproducibility. The second research axis deals with the use of the new large band gap solid state components in the field of high pulsed power Generally used to replace mechanical switches, we will bias them as a dynamic resistor that will vary, according to the voltage image of dispersions, and compensate them.

Only work engaged on this topic will be presented at the conference.

#P3-14

NUMERICAL MODELING OF DYNAMICS A PROTON BEAM IN AN ACCELERATING STRUCTURE WITH A RADIO FREQUENCY QUADRUPOLE

KEYNOTE SPEAKER

BORISKOV A.S., ZAVYALOV N.V., TELNOV A.V., SMETANIN M.L., OPEKUNOV A.M., POLYAKOV L.E.

VNIIEF, Sarov, Russian Federation

ABSTRACT

Calculation of the dynamic parameters of accelerated beams in linear resonance accelerators is actual problem in the design of new installations. In this paper, we consider the possibility of using numerical methods for calculating the dynamics of protons in a linear resonant accelerator RFQ. This type of accelerating structure is of interest for its efficiency at a low initial particle velocity, which is a necessary requirement to ensure a high capture coefficient. In the accelerator there is a simultaneous focusing, grouping and acceleration of charged particles by a high-frequency electromagnetic field, which accelerates particles from several tens of keV to several MeV.

To determine the RFQ parameters, a program for calculating the dynamics of the proton beam has been developed.

A change in the geometry of the beam due to its motion and the loss of charged particles on the elements of the accelerating structure leads to a change in the function of the beam charge density. The presence of the Coulomb interaction between its particles also affects the function of the beam charge density. To estimate the effect of the space charge of the beam, the PIC (Particle in Cell) calculation method was used, in which each simulated particle is placed in a virtual cell, at the nodes of which the value of the Coulomb field is calculated. The advantage of this method in comparison with others is a significantly higher counting rate.

On the basis of a physical and mathematical model describing the behaviour of a beam of charged particles in the accelerating structure RFQ, a program was implemented in the C ++ programming language. The model makes it possible to describe the process of acceleration of protons in the accelerator channel.

Numerical simulations were used to calculate the dynamic parameters of the beam during the entire acceleration time, and the results of numerical calculations of the dynamics of proton bunches taking into account the space charge are presented.

#P3-15

LONGITUDINAL ELECTROMAGNETIC (EM) FORCE INVESTIGATION

KEYNOTE SPEAKER

GRANEAU Neal

AWE, Aldermaston, United Kingdom

ABSTRACT

A full understanding of ponderomotive electromagnetic force on metallic conductors is required to improve the performance of Pulsed Power Electromagnetic mass accelerators. Currently unresolved controversy concerning the possible existence of longitudinal electrodynamic force components, in line with the direction of current flow, remains to be resolved by experiment despite almost 200 years of attempts. A new experiment called the Split-Top Recoil Experiment (STRE) using DC currents is proposed here. It consists of copper conductors and a liquid metal pool in which a mobile copper section is submerged and on which the applied force in the longitudinal direction can be measured. The mobile armature should not receive any longitudinal force as a result of modern EM theory. However a longitudinal component is predicted by the force law proposed by Ampère in 1822. Since then, a variety of experiments have indicated the existence of this force, but it has proven to be very difficult to achieve an unambiguous demonstration. The suggested experimental circuit is modelled using Ampère's force law and the predictions shown here will be compared to the experimental results. Details are discussed regarding the circuit design and other ancillary components and a strategy devised to determine whether the EM force laws on metal conductors require revision. At low currents, the longitudinal force component may be insignificant and this is why it has remained unexplored for such a long time. However if a longitudinal force component is found to be a real phenomenon, it will have to be built into the modelling of all future high current pulsed EM mass drivers as these forces will affect sliding contact as well as solid conductor motion, distortion and fracture as well as high energy density plasmas.

#P3-16

MULTI-PULSE HIGH PULSED POWER GENERATOR FOR FUTURE X-RAY FLASH RADIOGRAPHY APPLICATIONS

KEYNOTE SPEAKER

CADILHON Baptiste[1], VERMARE Christophe[1]

[1] CEA, Le Barp, France

ABSTRACT

Short pulse (flash) x-ray sources continue to be an important diagnostic for the evaluation of hydrodynamic phenomena. Future flash radiographic machines will be able to deliver multiple (2 or more) radiographic images along a single axis in a short time scale.

Based on a LIA (Linear Induction Accelerator) architecture, this facility implements many induction cells to generate voltage which are added in series in the electron injector (inductive voltage adder), or accelerate the electron beam along its propagation in the vacuum section.

The x-ray spot quality depends greatly on the high energy electron beam quality when it interacts with the x-converter target. In a multi-pulse scale, we care about the reproducibility of these successive high-quality electron beams at a MHz repetition rate. Then, particular efforts have to be made on voltage pulse applied to the induction cells either for the emission of the electron bunches or their acceleration.

In this context, we are developing a multi-pulse modular high voltage generator to produce 200kV short pulses. Inspired by the single pulse version made for EPURE third axis, this generator uses lasers to trig air-pressurized spark-gap switches. We present here the detailed design of this specific laser triggering switches.

#P3-17

EFFECTS OF HIGH SWITCHING FREQUENCY AND DIELECTRIC BARRIER DISCHARGES ON ENAMEL INSULATION DEGRADATION OF MOTORS FED BY SIC-BASED INVERTERS

KEYNOTE SPEAKER

GRAVILENKO Veronika[1,2,3], KOLESNIKOV Stanislav[2], LEONOV Andrey[1], HLIOUI Sami[2], LEFEBVRE Stéphane[2]

[1] National Research Tomsk Polytechnic University, Tomsk, Russian Federation
[2] ENS Paris-Saclay, CNAM, SATIE, UMR 8029, CNRS, Paris, France.
[3] Universite de Pau et des Pays de l'Adour, E2S UPPA, SIAME, Pau, France

ABSTRACT

Electric motors powered by inverters are subjected to repetitive surges due to fast changing voltage pulses and reflection phenomena. These surges may lead to partial discharge (PD) inception accelerating winding insulation degradation and its premature failure that is especially critical for the enamel insulation of low voltage motors. The use of wide bandgap semiconductors, such as Silicone Carbide (SiC), in power electronic devices offers better performances than demonstrated by Silicon-based ones. However, the impulse voltage generated by SiC-based inverters has high dV/dt intensifying the electric stresses in motor drives. Works intended to PD phenomenon in inverter fed motors are often focused on PD features such as partial discharge inception voltage (PDIV), magnitude and repetition rate. However, a destruction mechanism of motor winding insulation also needs a profound investigation. This research focuses on PD characterization and related degradation of winding wires' enamel insulation when subjected to high dV/dt impulse voltage generated by a lab-designed SiC inverter.

Experimental study is conducted on twisted pair specimens made of enameled copper wire having external diameter of 0.8 mm and insulation radial thickness of 30 µm. The test bench acts as a pulse generator performed with SiC MOSFET 1700V transistors producing impulse voltage with dV/dt ≥ 50 kV/µs and switching frequency up to 125 kHz. The generated impulse voltage is measured by means of the differential probe Tektronix THDP0100 and the oscilloscope Tektronix MDO3024. A full bridge inverter topology is used to generate bipolar pulses. The tested specimen is connected to inverter's midpoints. To measure the specimen's current, a designed shunt is placed in one of the inverter's leg and the oscilloscope is powered via an isolation transformer. During these measurements, the voltage on the specimen is recorded using a designed RC-divider.

With the objective to investigate the effects of switching frequency and impulse voltage amplitude with steep dV/dt on discharges characteristics and resulting insulation destruction, we have measured currents (shunt), light emission spectra (Ocean optics USB2000 Spectrometer) and temperatures (infrared camera Fluke Ti100). Firstly, we have recorded current pulses waveforms on the rising rates of impulse voltage. The analysis of current pulses' peaks shows that the twisted pair's current rises significantly above the DC bus voltage of 1 kV that explains by the start of a PD activity when the total

1/2

current includes capacitive one and PD pulse current. The effect of switching frequency is not so pronounced. As an important part of PD energy transforms into a heat, the discharges intensity can be evaluated by temperature monitoring. The temperature values demonstrate the influence of both voltage amplitude and switching frequency variations on specimens' heating by discharges. Considering that the studied partial discharges arise in air gaps between two conductors separated by enamel insulation, we can classify it as dielectric barrier discharges (DBD). It allows us to apply common aspects in ozone generation for understanding of discharge phenomenon and insulation destruction mechanism. As mentioned above, the main part of discharge energy transforms into heat, the rest of it consumes for chemical reactions and dissipates in light and sound. Basing on that, one of the methods for study DBD characteristics is the optical emission spectroscopy. Thus, this experimental study includes the analysis of light emission spectra of barrier discharges in the tested twisted pair. The higher switching frequency leads to the higher emission intensity. Furthermore, microscopic images have been made with the purpose to link the discharges arising between enameled wires and erosion on their surface. The photographs have been taken through an optical microscope demonstrating DBD between two enameled wires in the twisted pair under high dV/dt pulses. The enamel erosion craters observed on the tested wires' surface corresponds to tracks of observed DBD filaments. The rise in switching frequency leads to increasing of the filaments' propagation zone.

Based on the experimental study, several results have been highlighted. The impulse voltage having steep dV/dt and switching frequency from 20 to 70 kHz provokes higher air volume ionization favoring filamentary discharge mode. It leads to an erosion craters formation on enamel insulation as result of filaments' tracks. The same light emission spectrum's peaks but of different intensity have been observed on various frequencies. In presence of DBD the increase of frequency results in higher discharge repetition rate and higher energy as seen from temperature and spectrum measurements. The heating of tested specimen increases capacitive currents, intensifying the electric field that enlarges filaments, acting on the insulation surface that accelerates insulation destruction.

#P3-18

ULTRAFAST 30-KV NANOSECOND SOLID-STATE IMPEDANCE-MATCHED MARX GENERATOR FOR TRANSIENT PLASMA GENERATION

KEYNOTE SPEAKER

AZIZI Mahdi, VAN OORSCHOT Jeroen, HUISKAMP Tom

Electrical Energy Systems Group of the Department of Electrical Engineering at Eindhoven University of Technology, Eindhoven, Netherlands

ABSTRACT

In this contribution, a novel solid-state impedance-matched Marx generator (IMG) based on SiC MOSFETs and a modified gate-boosting gate driver circuit will be presented [1, 2]. The modified gate-boosting circuit can drive SiC MOSFETs extremely fast which is very important for applications such as transient plasma generation. The proposed IMG is built using twelve 2.5-kV series-connected stages. The stages can be controlled separately, therefore the output pulse is flexible in amplitude and waveform shape. The rise time of the output pulse can be adjusted by changing the turn-on delay of the stages, with a fastest achievable rise time of 4 ns. In addition, the low- and high-voltage power required for each stage is supplied through magnetically isolated high-frequency modules. Each stage has a low-voltage and a high-voltage isolated supply module which are connected to a high-frequency low-voltage bus and high-voltage bus respectively. This charging method reduces the output capacitance of the stages and thereby improves the rise time of the output pulses. To assess the proposed IMG in a real application, a 30-kV prototype was developed and tested with a corona plasma reactor. The test results will be presented to verify its performance in different working conditions.

[1] T. Huiskamp and J. J. Van Oorschot, “Fast pulsed power generation with a solid-state impedance-matched Marx generator: Concept, design, and first implementation,” IEEE Transactions on Plasma Science, vol. 47, no. 9, pp. 4350–4360, Sep. 2019.

[2] M Azizi, J. J. van Oorschot, T Huiskamp, “Ultrafast Switching of SiC MOSFETs for High-Voltage Pulsed-Power Circuits”, IEEE Transactions on Plasma Science, vol. 48, no. 12, 2020.

#P3-19

NANOCRYSTALLINE MAGNETIC CORES UNDER FAST PULSE MAGNETIZATION

KEYNOTE SPEAKER

PECASTAING Laurent [1], NOVAC Bucur[1,3], BARNES Michael[4], SENAJ Viliam[4], KRAMER Thomas[4], DAULHAC Gaëtan[2], BARANOV Aleksandr[2], BOISNE Sébastien[2]

[1] Université de Pau et des Pays de l'Adour, E2S UPPA, SIAME, Pau, France
[2] ITHPP ALCEN, Thégra, France
[3] Loughborough University, Loughborough, United Kingdom
[4] CERN, Geneva, Switzerland

ABSTRACT

In recent decades, repetitive pulsed power has found more and more applications in industrial and research domains. One of them is injection and extraction systems employed in the state-of-the-art particle accelerator facilities [1], where, besides the main voltage-current specifications, the lifetime and reliability of pulsed power generators are of great importance. Solid-state pulsed power generators based on magnetic elements and semiconductor switches suits these stringent requirements.

A pulse generator based on a semiconductor opening switch (SOS) is also an example of such a repetitive pulsed power system. A circuit containing a single magnetic element – a saturating pulse transformer – is the most efficient design of an SOS generator with an efficiency of up to 0.7 [2]. Soft magnetic materials with a rectangular hysteresis loop are traditionally used in magnetic switches. However, a saturating pulse transformer combines the two functions of both a step-up transformer and a magnetic switch. Therefore, to reduce hysteresis losses, we use materials with a flat hysteresis loop. Besides, it allows avoiding an active reset circuit, but at the price of the total swing flux reduction. Strip-wound amorphous nanocrystalline Fe-based alloy is a modern magnetic material which, according to its datasheet, offers many advantages such as high saturation magnetic flux density, low losses, low magnetostriction and high inter-laminar insulation.

In this study, several types of nanocrystalline cores made by different manufacturers were tested in a step-up saturating pulse transformer. A time before saturation of ~500 ns and transferred energy of up to ~10 J were setup in the experiments. After core saturation, a reverse current with an amplitude of up to several kA and pulse duration of ~100 ns flowed through the secondary winding. Core losses, overall transformer efficiency and influence of DC biasing on transformer operation were investigated.

[1] M. J. Barnes et al., “Future circular collider injection and extraction kicker topologies and solid-state generators,” Phys. Rev. Accel. Beams, vol. 22, no. 7, p. 071001, Jul. 2019.
[2] S. N. Rukin, “Pulsed power technology based on semiconductor opening switches: A review,” Rev. Sci. Instrum., vol. 91, no. 1, p. 011501, Jan. 2020.

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#P3-20

REVERSE VORTEX FLOW GLIDING ARC PLASMA FOR NITROGEN FIXATION IN WATER

KEYNOTE SPEAKER

JIN Yun-Sik, CHO Chuhyun, SHON Chae-Hwa, KIM Daejong, HAN Seong-Tae

Korea Electrotechnology Research Institute, Changwon, Korea, Republic of

ABSTRACT

The reverse vortex flow (RVF) gliding arc (GA) plasma generator operating at atmospheric pressure has been used for various gas treatments such as CH_4 reforming, CO_2 conversion, and VOC decomposition. In this study, the devices was applied for preparing plasma activated water (PAW), and the nitrogen fixation characteristics in the water were investigated. Several types of RVF discharge configuration were examined, and PAW production characteristics according to the operating conditions of RVF were evaluated. This study demonstrates RVF discharge is very effective in improving the nitrogen fixation in the plasma activated water, and the production efficiency of NO_3^- ions is higher than 20 g/kWh.

#P3-21

UPDATE ON MARX GENERATOR CIRCUIT FOR ACCELERATORS BASED ON SIC MOSFETS

KEYNOTE SPEAKER

REDONDO Luis [1], KANDRATSYEU Aleh [2], BARNES Mike [3],

[1] Lisbon Engineer Superior Institute, GIAAPP/ISEL, Lisbon, Portugal
[2] EnergyPulse Systems, Lisbon, Portugal
[3] ABT Group, SY Department, CERN, Geneva, Switzerland

ABSTRACT

This work describes the updated design strategy for a new Marx generator, based on SiC Metal Oxide Semiconductor Field-Effect Transistors (MOSFETs), proposed for accelerator applications, such as replacement of Thyratrons and Pulse Forming Lines (PFLs) in kicker system pulse generators. The use of semiconductor switches in areas that were traditionally dominated by hard tubes, such as Thyratrons, can be explained by the vertiginous progress of semiconductor devices and associated electronics, driven by the irresistible need for more economic equipment with lower maintenance costs and with increased flexibility and reliability. This paper presents new design strategies and test results for a Marx generator, for possible replacement of a Thyratron and PFL in an existing kicker system at CERN (European Organization for Nuclear Research), with specifications of 16 kV, 2.5 kA, 2 microseconds pulse width, 70 ns rise and fall time, and 1 Hz repetition rate. The novelty presented in this work is the use of off-the-shelf components, such as SiC MOSFETs, in a low inductance Marx topology. Tests using 1000V/90A pulse MOSFETs in an optimized four-stage Marx generator, producing about 3100 V/2740 A, 0.6 microsecond pulses, are described and the concept is evaluated, considering scale up to 16 kV.

#P3-22

ELECTROMAGNETIC PARTICLE-IN-CELL MODELLING OF THE MERLIN IVA USING THE MEASURED PULSE-FORMING LINE DRIVE

KEYNOTE SPEAKER

MEADOWCROFT Anthony, SINCLAIR Mark, JONES Aled, THOMAS Ken, HUGHES Adrian, HINES Carl, GOUDE David, THREADGOLD Jim

AWE Aldermaston, Reading, United Kingdom

ABSTRACT

The Multi-mEgavolt Radiographic Linear INductive voltage adder (MERLIN) is a pulsed power machine developed for flash X-ray radiography of future AWE hydrotrials. The MERLIN pulsed power system outputs a ≈ -8 MV, ≈ 200 kA drive through the use of a single Marx generator, which charges a series of ten Pulse-Forming Lines (PFLs). The PFLs discharge into associated induction cells that collectively form an Induction Voltage Adder (IVA).

The electromagnetic Particle-In-Cell (PIC) code Large-Scale Plasma (LSP) is used to underwrite the physics modelling of the MERLIN pulsed power machine performance. LSP modelling of the IVA section of MERLIN originally used a PFL drive based on initial characterisation tests of the PFL, transmission line modelling and the assumption of ideal machine operation. In practise, however, shot-to-shot machine operation is not ideal and there may be faults with diagnostic monitors, the machine, or differences in the timings used during the PFL firing sequence. In order to more accurately model MERLIN operation for each shot, the PFL drive for the LSP model of the IVA has been updated to include measurements of PFL voltages and currents obtained during machine commissioning, based on corrected diagnostic calibrations and the transmission line impedance. The model has been validated against previous modelling work and commissioning measurements covering the different configurations used for machine operation.

Advantages of the updated PFL drive simulations over the original PFL drive simulations are improved reproducibility of machine measurements of the pulse timings, pulse widths, rise times and less skewed forward machine drive voltages. The simulated amplitudes for cell voltages and the Magnetically Insulated Transmission Line (MITL) anode currents are comparable for both PFL drive setups, with the cell voltage amplitudes ≈ 10% to 15% higher than measurements. This discrepancy is likely due to differences between the diagnostic measurements and the simulation monitors, as well as the use of a 2D modelling geometry as opposed to a 3D one. Further commissioning analysis has shown calibration corrections were necessary for the MITL voltage diagnostics. These corrections significantly improve the agreement between measured and simulated MITL voltages and the recorded dose (a function of the MITL voltage) in Self-Magnetic Pinch (SMP) diode shots. Results for the simulated diode currents are also compared to the measured currents at different angular positions around the stalk.

#P3-23

DUAL PULSE GENERATION FROM A VELVET COLD CATHODE WITH A NEW INDUCTIVE VOLTAGE ADDER "MI2" FOR X-RAY FLASH RADIOGRAPHY APPLICATIONS

KEYNOTE SPEAKER

DELAUNAY Rudy[1], CADILHON Baptiste[2], COURTOIS Laurent[2], MOUSSEAU Isia[2], PLEWA Jérémie-Marie[3], ALVINERIE Clara-Marie[1], CASSANY Bruno[2], VERMARE Christophe[2], D'ALMEIDA Thierry[1], RIBIERE Maxime[1], MAISONNY Rémi[1]
[1]

[1] CEA/GRAMAT, Gramat, France.
[2] CEA/CESTA, Le Barp, France
[3] TRAD Tests & Radiations, Labège, France

ABSTRACT

Radiographic sources based on Linear Induction Accelerators (LIA) have successfully demonstrated multi-pulse radiography capabilities in order to achieve multi-frame measurement. "Mi2" is a new IVA designed and built at CEA/CESTA as a test bed induction injector in the framework of future multi-pulse electron LIA for flash radiography. This IVA is composed of a dual pulse driver [1] and four induction cells. Two 700 kV high power pulses are applied across the diode gap in order to produce twice a 2.5 kA electron pulse of 80 ns FWHM from a velvet cold cathode. The delay between the two pulses can be adjusted from tens of nanoseconds up to few microseconds.

The evolution of the two intense pulsed electron beams is presented in a coupling of experimental and simulation studies. For this purpose, a multidimensional particle-in-cell simulation model is used to provide a numerical analysis in order to quantify the influence of velvet plasma dynamics on the second pulse, which represents an important parameter from the beam transport point of view. Analysis of the experimental results indicates that the motion of the electron extraction zone within the expanding plasma remains lower than 1 mm for 3 µs delay inducing an increase in the order of 10% of the current extracted from the second pulse which is consistent with LIA injector parameters for multiple pulse use.

[1] B. Cassany et al., *2015 IEEE Pulsed Power Conference (PPC)*, Austin, TX, 2015, pp. 1-4.

#P3-24

THE INFLUENCE OF SHAPE AND TIMING OF APPLIED PULSED VOLTAGE ON ACTIVE SPECIES PRODUCTION IN ELECTRIC DISCHARGE WATER TREATMENT EQUIPMENT

KEYNOTE SPEAKER

PHUNG Nhat-Thanh, SUGAI Taichi, AKIRA Tokuchi, JIANG Weihua

Nagaoka University of Technology, Nagaoka, Japan

ABSTRACT

The influence of waveform control of atmospheric pulse discharge on producing active species (OH radical and Ozone) in water treatment equipment was investigated in this study. Due to high oxidation potential, OH radical and ozone play main role in decomposing organic compound in water. According to the previous studies, when the pulse width is lengthened, energy yield of active species decreases. In addition, if the interval between two pulses is shorter than lifetime of OH radical, it is predicted that more OH radicals produced from the primary pulse discharge are recombined with OH radicals from the second pulse and lead to more loss of radical since OH radical have strong reaction rate each other. To confirm those experimentally, ozone and OH radical were measured with applying various complicated pulsed high voltage, e.g., voltage with lower peak at a latter part of a pulse or burst pulse with microsecond pulse interval, which were able to be generated by our solid-state linear transformer driver (LTD) system. In case of ozone production, shortening pulse width and lengthening the interval resulted in high energy yield. In this presentation, it is discussed how the difference of applied pulse affects production and reaction of ozone and OH radical based on the experimental results including OH radical measurement.

#P3-25

DEVELOPMENT OF SINGLE-TURN COIL FOR MULTIPLE GENERATION OF 40T MAGNETIC FIELD IN MICROSECOND RANGE

KEYNOTE SPEAKER

KHRUSTOV Vladimir, PARANIN Sergey, SPIRIN Alexey

Institute of Electrophysics UB of RAS, Yekaterinburg, Russian Federation

ABSTRACT

The technologies of magnetic pulse treatment find their use in the automotive industry, aviation, and nuclear industry. Magnetic pulse welding gives high-quality joining of fuel pin cladding in fast nuclear reactors [1]. The main parts of a magnetic pulse setup include an energy storage device, a switching device, and an inductor (coil). The inductor operates under the most stressful conditions, which affects its capabilities and lifetime. In magnetic pulse welding of a few millimeter-sized parts made of high strength steel such as fuel pin cladding tubes, it is required to create a pulsed magnetic field in the coil with an amplitude of 40 T and a half-period of 10–20 μs. Since the pulsed current of high frequency is required, single-turn coils with or without field shapers are the main instruments for this operation. The currents which are being commutated to the inductor working area may be as high as 700 kA, thus, it is required to lower the current density in the contacts in order to prevent the contact erosion. During the high current pulses, the coil inner surface is exposed to magnetic field pressures of 0.6–0.7 GPa with Joule heating up to 600°C. Such an impact destructs the surface of conventional beryllium bronze in 5–10 pulses of 40 T magnetic field.

Two approaches are being practiced to enhance coil durability: material research and design optimization. The first approach considers the usage of high-strength steels [2] and composite materials for the coil working area. This work is aimed to realize the second approach – the optimization of the coil design in order to maximize the number of parts welded in one coil. Analytical calculations, finite element modeling, and experimental tests were carried out for four designs of single-turn coils, which differ in the method of supplying current to the working area and in the number of working bores. The main parameters calculated and measured were the coil inductance and resistance, and the magnetic field between the coil and the workpiece with respect to the discharged current, B/I.

The inductors were made of hardened structural steel (0.3% C, 1% Si, 1% Mn) while the current leads were made of carbon steel (0.06% C, 0.35% Mn). Their working bores were 8 mm in diameter and 12 mm in length. High current contacts passed from 380 to 85 kA/cm depending on their width (or the size lateral to current direction) and the coil efficiency in order to generate a 40 T peak field. The magnetic field was measured by a pick-up coil installed between the inductor bore inner surface and a fixed copper tube (the same tube that is used as a “driver” in magnetic pulse welding of thin-walled steel tubes). The efficiency B/I varied from 34 T/MA for an inductor with a field shaper to 63 T/MA for the most effective

inductor with “direct” current flow from the contacts to the working bore. The coils lifetime was gradually increased from 25 to 50 samples of magnetic pulse welded tubes with plugs in fuel pin end geometry.

The calculated and manufactured single-turn coils are capable of generating several tens of magnetic field pulses with an amplitude of 40 T and a half-period of 10–18 μs. The calculations were in good agreement with the experimental results. As a result, the inductors were capable of processing two and more samples in one pulse with increasing the efficiency of converting the discharge current into the magnetic field.

The work was partly financed by RFBR, RFBR and BRFBR, RFBR and ROSATOM grants (Nos. 19-08-00931, 20-58-00029, and 20-21-00050).

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[2] A.V. Spirin, P.A. Russkikh, V.I. Krutikov et al., J. Phys. Conf. Ser. 830 (2017) 012080.
DOI: 10.1088/1742-6596/830/1/012080.

#P3-26

ELECTRONIC EMISSION OF A COLD VELVET CATHODE IN MULTI-PULSE REGIME

KEYNOTE SPEAKER

MOUSSEAU Isia[1], COURTOIS Laurent[1], VERMARE Christophe[1], REESS Thierry[2]

[1] CEA CESTA, LE BARP, France
[2] Université de Pau et des Pays de l'Adour, E2S UPPA, SIAME, PAU, France

ABSTRACT

LIA (Linear Induction Accelerator) Flash X-ray radiography uses electron beams, produced from an injector, accelerated and focused on a high Z material target. Spot size of the focused beam strongly depends on its emittance, and so, depends on the emittance of the injector's beam.

In the context of the development of a multi-pulse injector, the CEA is conducting experiments with a dual-pulse generator, Mi2 (700 kV, 2-3 kA). The two pulses, applied on a cold velvet cathode, generate two electron beams trough the gap. To characterize cathode emission emittance, the beam interacts with a few mm Silice convertor (radiator) after crossing the anode foil. Light is produced by Cerenkov Effect and its amplitude is a function of the beam current. Previous experiments, conducted with a single camera, capturing either the first or the second beam, showed two different beam profiles. It is assumed that this difference is the consequence of a plasma sheath, generated during the first beam emission and still present 1 µs after the pulse, which modifies the effective AK gap.

The main objectives of those new experiments are to improve our understanding of the emission phenomena and to be able to estimate the emittance measurements based on beam Cerenkov images.

The experimental setup is composed of two Pi-max cameras, which collect the light produced by the Cerenkov Effect, Rogowski coils and capacitive dividers. The AK gap can vary from 5 to 50 mm. Different cathode geometries and different velvet types will be tested.

#P3-27

CONSTRUCTION OF REPEATABLE PULSED POWER LOAD USING LIQUID METAL WITH ELECTRODE COVERED NOZZLE

KEYNOTE SPEAKER

NARITA Yuki, ISHIKAWA Hiroki, KUMAGAI Yuki, TAKAHASHI Kazumasa, SASAKI Toru, KIKUCHI Takashi

Nagaoka University of Technology, Niigata, Japan

ABSTRACT

A liquid metal load supplying by a nozzle has been proposed instead of thin metal wires in a repeatable plasma source for pulsed-power discharge.
In the previous study, the nozzle was damaged by the discharge with continuous operation. To prevent the damage due to the discharge, we propose an electrode-covered nozzle. We demonstrated the discharge experiments using a magnetic pulse compression power supply to investigate the effect of the discharge damage on the designed electrode-covered nozzle. The experiments were conducted to measure the voltage-current characteristics and we observed the time evolution of optical emission from plasma generated by the discharge. From these experiments, we obtained the similar results as the case without the electrode-covered nozzle.
Finally, damages of the nozzle were observed after several discharge experiments. Compared with the nozzle hole diameter in each experiment, the proposed structure was effective for protecting the nozzle.

#P3-28

A SOLID-STATE PULSED POWER MODULATOR WITH HIGH STABILITYFOR HARD X-RAY FREE ELECTRON LASER

KEYNOTE SPEAKER

GONG Long [1], XU Huan [2]

[1] *Micovey, Wuhu, China*
[2] *Micovey, Chengdu, China*

ABSTRACT

High-voltage pulsed power modulator is an important component for high-power microwave systems and various accelerator applications. In free electron laser applications, the requirement for the stability of a pulsed power modulator is extremely high. This paper introduces a highly stable solid-state pulsed power modulator. The scheme takes advantage of techniques such as capacitive energy storage, solid-state switch discharge, matrix transformer boost, et, al. Through theoretical analysis of the scheme, circuit simulation and prototype circuit test, key parameters of the modulator are verified and optimized. The final product achieved 430kV/310A pulse output with adjustable pulse width. The maximum half width is greater than 4us. The pulse rising and falling time is about 0.9us, rising edge jitter is within 5.9ns(rms) . The pulse top flatness is about ±0.6%, the pulse stability is 48ppm(rms), and the repetition rate can be adjusted from 1Hz up to 50Hz. This work provides a strong technical support for China's high-power light source applications, and will greatly promote the progress of pulsed power applications including high power microwave and accelerators.

#P3-29

STRUCTURE DESIGN OF INDUCTOR WITH LARGE CURRENT-CARRYING CAPACITY BASED ON TAGUCHI METHOD

KEYNOTE SPEAKER

SU Xiang, LIN Fuchang, ZHANG Qin

Huazhong University of Science and Technology, Wuhan, China

ABSTRACT

The wave-modulating inductor is an important components of the pulse power supply. It needs to meet the requirements of small size and high energy density. For this reason, a semi-analytical expression of the electromagnetic stress in the current-carrying coil is derived. And it was verified by finite element simulation. The expression shows that the stress and maximum current-carrying capacity of the coil are affected by multiple parameters such as coil radius, wire diameter, and number of turns. Taguchi method is an optimized calculation method with high efficiency and high stability. Taguchi method is applied to the structure design of the coil. Taking the maximum energy per unit volume as the goal, the sensitivity of each parameter can be analyzed and the ideal parameter combination can be determined. The weakening effect of the insulation encapsulation on the coil stress is studied by finite element simulation. Finally, a double-layer inductor is designed and manufactured, and several pulse discharge tests are carried out. The test results show that the inductor is in good condition and has sufficient mechanical structure strength at the peak current of 110kA.

#P3-30

EVALUATION OF TEMPORAL BEHAVIOR OF 200 KEV PROTON BUNCHES WITH PROMPT Γ SPECTROMETRY

KEYNOTE SPEAKER

RYZHKOV Vladislav, STEPANOV Andrei, PYATKOV Igor, REMNEV Gennady

Tomsk Polytechnic University, Tomsk, Russian Federation

ABSTRACT

Here we examine a possibility to control energy and number of protons in bunches directly accelerated in the external magnetic isolation diode TEMP-4M to average energies of 200 keV by use of two nuclear reactions 10B(p,αγ)7Be and 11B(p,γ)12C emitting prompt γ rays with energies of 429 and 4439 keV, respectively. Two organic scintillation detectors having the time resolution at the FWHM of 2.5 ns were axially oriented towards the target center, observing its front surface from equal distances of 30 cm. The IPIB shots were captured by h BN plate, covering the front side of a Collimated Faraday Cylinder (CFC) which was placed at different distances from the cathode. An opening was provided in the plates for the IPIB to come inside the CFC to determine the time of flight (TOF) of protons and C ions. It was found that γ signals averaged for the whole series of 25 shots conformally reflected all the proton current peaks. Average energies of the proton and 12C ion components were determined as being 187±18 and 192±32 keV, respectively. The TOF experimental results were in good agreement with the prompt γ spectrometry, which, in turn was in good agreement with theoretical expectations for the yield of γ rays for proton energy and number of about 200 keV and 1015 per shot. The examined prompt γ spectrometry technique can be used to control individual proton bunches accelerated to energies of up to 300 keV.

#P3-31

INDUCTANCE CALCULATIONS OF A TOROIDAL COIL AND POSSIBILITIES TO CONVERT IT TO A PULSE TRANSFORMER

KEYNOTE SPEAKER

BERARD Maxime, LIEBFRIED Oliver, BROMMER Volker

French-German Research Institute of Saint-Louis, Saint-Louis, France

ABSTRACT

Inductive pulsed power supplies are seen as a compact alternative for bulky capacitor banks as railgun power supply. Electrical circuits called the XRAM generator, pulse transformer or the meat grinder are the most popular topologies. Among them, the XRAM generator is based on a single but segmented coil whose coil segments are switched from serial to parallel connection for current multiplication. The pulse transformer and the meat grinder are based on a transformer with a primary to secondary winding ratio smaller than 1. High values of current amplification are achieved in this case by a rapid decrease of the primary current with corresponding opening switches. The magnitude of the leakage inductance of the transformer has a significant influence on the voltage across the opening switch. Thus, a good magnetic coupling between primary and secondary has to be ensured.

Recently, a demonstrator of a 1 MJ XRAM generator was successfully used to supply the ISL railgun RAFIRA [1, 2]. Its core element is the toroidal magnetic storage made from 180 copper discs [3]. The coil was designed to store an energy of more than 1 MJ at an inductance of 1 mH and was stress tested with a pulsed current up to 50 kA. Its modular design based on copper discs and screw connection allows versatile reconfigurations. Thus, the inductive storage can be converted to a transformer with primary and secondary coils having a different number of turns. In this work, we investigate the possibility to convert the XRAM generator's magnetic storage to a transformer by means of FEM simulations with Comsol Multiphysics. The major goal was the prediction of the self and mutual inductances between the transformer coils at different winding configurations and to find an optimum setup. A matrix including the self and mutual inductances between each disc was generated and allows the calculation of the magnetic coupling properties of any configuration. Simulation results for different frequencies were confirmed by measurements with a RCL-meter of the 1 MJ XRAM generator's toroidal coil in its present configuration.

[1] O. Liebfried and V. Brommer, "XRAM generator investigations with a 1 MJ demonstrator", this conference
[2] O. Liebfried and V. Brommer, "Demonstration of a 1 MJ XRAM Generator Supplying a Medium Caliber Railgun," in IEEE Access, vol. 8, pp. 225018-225031, 2020, doi: 10.1109/ACCESS.2020.3044441.
[3] O. Liebfried, V. Brommer, H. Scharf, M. Schacherer and P. Frings, "Modular Toroidal Copper Coil for the Investigation of Inductive Pulsed Power Generators in the MJ-Range," in IEEE Transactions on Applied Superconductivity, vol. 30, no. 4, pp. 1-6, June 2020, Art no. 0500206, doi: 10.1109/TASC.2020.2971205.

#P3-32

STUDY ON ACOUSTIC CHARACTERISTIC OF UNDERWATER MULTI-ELECTRODE PULSE DISCHARGE

KEYNOTE SPEAKER

LV Haonan

Zhejiang University, Hangzhou, China

ABSTRACT

A large number of gas hydrates exist in the seabed, and the exploration of their distribution requires high resolution seismic source devices. At present, most marine exploration uses acoustic detection. Using the hydroelectric effect of underwater pulse discharge, the acoustic signal obtained by bubble vibration has been widely used in seismic source design because of its high repeatability and stability. The sub-wave properties of plasma sources largely depend on the electrode structure. Previous studies have found that increasing the number of electrodes can improve the initial bubble ratio, which can make the exploration results more accurate. In this paper, by increasing the number of electrodes, the electrode structure can be similar to that in the actual seismic source, and the initial bubble ratio can be improved effectively. This can guide the design and improvement of the actual plasma source.

#P3-33

FPGA BASED PROGRAMMABLE PULSE GENERATOR FOR SOLID-STATE MARX GENERATORS

KEYNOTE SPEAKER

VAN OORSCHOT Jeoreen, AZIZI Madhi, HUISKAMP Tom

Electrical Energy Systems, Eindhoven University of Technology, Eindhoven, Netherlands

ABSTRACT

In this contribution, we present an FPGA control system to generate the control signals needed for our Flexible Solid-State Marx generator (see [1]). The control system generates (at least) 20 individual control signals with 2.5ns precision and up to seconds in length. It is implemented on a Pynq-Z2, a cheap FPGA development board with embedded ARM SoC. The system is live-reprogrammable, so the Marx output pulse shape can be changed multiple times per second. Furthermore, bursts of pulses can be made by repeating a pulse shape. An interface in Python takes care of translating Marx pulse shape to control signals, including calculating deadtime. This interface can be combined with any measurement system to create a feedback loop. For instance, an oscilloscope can measure the Marx output pulse and tune the control signals to improve the measured waveform. Alternatively, the system can be connected to a plasma diagnostics system and change the pulse shape based on the plasma behavior. Finally, we present some preliminary results on future improvements, including a delay system using programmable delay lines in the FPGA to reduce the time precision from 2.5 ns to about 20ps.

[1] J.J. v. Oorschot, M. Azizi, A.J.M. Pemen and T. Huiskamp “Fast & Flexible Impedance-Matched Solid-State Marx Generator for PAW Generation”, EAPPC 2020, Aug. 29 – Sep. 02 2021, Biarritz, France.

#P3-34

INVESTIGATING THE BEAM TRANSPORT IN A LINEAR INDUCTION ACCELERATOR FOR MULTI-PULSE X-RAY FLASH RADIOGRAPHY

KEYNOTE SPEAKER

DELAUNAY Rudy[1], ALVINERIE Clara-Marie[1], ROUSSEAU Patrick[2], MAISONNY Rémi[1]

[1] CEA/GRAMAT, Gramat, France.
[2] Université Caen Normandie, Caen, France

ABSTRACT

Radiographic sources based on Linear Induction Accelerators have successfully demonstrated multi-pulse radiography capabilities in order to achieve multi-frame measurement. In this framework, a new IVA "Mi2" was designed and built at CEA. This IVA delivers two 700 kV high power pulses across the diode gap in order to produce twice a 2.5 kA electron pulse of 80 ns FWHM from a velvet cold cathode. The delay between the two pulses was adjusted from tens of nanoseconds up to few microseconds. A multidimensional particle-in-cell simulation model was developed in order to quantify the influence of velvet plasma dynamics on the second pulse.

Based on this model, a new multi-pulse velvet diode was designed at 2.5 MV relevant to produce high quality intense beams. In this work, we simulate the beam properties (current, emittance, profile…) within the injector and their evolution with the delay between pulses. In addition, particle-in-cell and envelope codes were used in order to investigate the beam transport through the accelerator.

#P3-35

ANALYSIS OF SHOCK AND ACOUSTIC PRESSURE IMPULSES GENERATED BY AN UNDERWATER EXPLODING WIRE

KEYNOTE SPEAKER

FROST hanasi[(1)], NOVAC Bucur[(1)], SENIOR Peter[(1)], BLAND Simon[(2)], SAVVA Theocharous[(2)]

[(1)] Loughborough University, Loughborough, United Kingdom
[(2)] Imperial College, London, United Kingdom

ABSTRACT

The paper presents measurements of both shock and acoustic pressures generated by an underwater exploding wire. Shock waves have been measured using a bespoke probe connected to a multipoint Heterodyne Velocimetry (HET-V) system while the acoustic waves were detected using needle-type hydrophones. Thus, the phenomenon of the shock wave to acoustic conversion could be highlighted. This work is part of an effort to demonstrate a repetitive underwater exploding pressure source.

#P3-36

XRAM GENRATOR INVESTIGATION WITH A 1MJ DEMONSTRATOR

KEYNOTE SPEAKER

BERARD Maxime, BROMMER Volker

French-German Research Institute of Saint-Louis, Saint-Louis, France

ABSTRACT

The electric power supply for an electromagnetic launcher has to provide energy in the mega-joule range within an acceleration time which only lasts for milliseconds. Today's giga-watt pulsed power generators are based on large capacitor banks and are therefore unsuitable for most mobile applications. Thus, power supply research focuses on size reduction by means of alternative technologies like inductive storage. The XRAM topology, in which several inductors are charged in a series connection and discharged in a parallel connection, is a concept for inductive current multiplication. This technique requires simultaneous switching of closing and opening switches and was realized by using thyristors which are turned off by a counter-current pulse (inverse current commutation with semiconductor devices - ICCOS). At the French-German Research Institute of Saint-Louis, several aspects of this technology have been investigated and several demonstrators for different energies have been developed. Nowadays, the development of inductive pulsed power generators advances towards energy levels relevant for future applications. This contribution presents the development of a 1 MJ XRAM generator which demonstrates the suitability of this technology by supplying the medium-caliber ISL railgun RAFIRA during dynamic experiments. Experimental results are presented, where the XRAM generator was charged to 842 kJ with a current of 40 kA. This current was successfully commutated and 10 times multiplied by the ICCOS opening switches. An 80 g brush projectile was accelerated to 1120 m/s within the ISL's railgun RAFIRA. The railgun current was switched off at the time of the projectile's bore-exit, thus approximating a rectangular current pulse shape. Those results are compared to data recordings of Experiments with capacitor banks as railgun power supply.

#P3-37

REMEDIATION OF HCH CONTAMINATED SOIL USING DIELECTRIC BARRIER DISCHARGE

KEYNOTE SPEAKER

ZHANG Shuo, TU Xuan, LIU Zhen, YAN Keping

Zhejiang University, Hangzhou, China

ABSTRACT

Non-thermal plasma technology has shown promising results in terms of soil remediation polluted by persistent organic pollutants. In this work, the wire-tube dielectric barrier discharge (DBD) was applied to generate the non-thermal plasma for hexachlorocyclohexane (HCH) degradation at atmospheric pressure. The effects of input power, soil moisture, gas flow, and concentration on HCH degradation were investigated, and the soil samples before and after DBD treatment were characterized by XRD, SEM, and BET. The results showed that the HCH degradation was positively related to input power, while negatively with gas flow, and concentration. The HCH removal efficiency increased and then decreased as the moisture enhancement, with the maximum at 10% soil moisture. That attributed to the reason that appropriate moisture was beneficial for the generation of active species, like OH, but too much water wrapped the soil which is not conducive to the contact between active particles and HCH. Furthermore, 3,4,5,6-tetrachlorocyclohexene (3,4,5,6-TeCH), and 1,2-dichlorobenzene (1,2-DCB) as the main products after the DBD treatment were detected by GCMS, and the potential pathway was given in this study.

Non-thermal plasma technology has shown promising results in terms of soil remediation polluted by persistent organic pollutants. In this work, the wire-tube dielectric barrier discharge (DBD) was applied to generate the non-thermal plasma for hexachlorocyclohexane (HCH) degradation at atmospheric pressure. The effects of input power, soil moisture, gas flow, and concentration on HCH degradation were investigated, and the soil samples before and after DBD treatment were characterized by XRD, SEM, and BET. The results showed that the HCH degradation was positively related to input power, while negatively with gas flow, and concentration. The HCH removal efficiency increased and then decreased as the moisture enhancement, with the maximum at 10% soil moisture. That attributed to the reason that appropriate moisture was beneficial for the generation of active species, like OH, but

#P3-38

80KW HIGH VOLTAGE POWER SUPPLY FOR X-RAY GENERATOR

KEYNOTE SPEAKER

SON Seongho[(1)], BAE Jung-Soo[(1)], KIM Tae-Hyun[(1)], KWON Chang-Hyun[(1)], YU Chan-Hun[(2)], JANG Sung-Roc[(2,1)], KIM Hyoung-Suk[(2,1)]

[(1)] University of Science & Technology, Changwon, Republic of Korea
[(2)] Korea Electrotechnology Research Institute, Changwon, Republic of Korea

ABSTRACT

This paper describes design and implementation of an 80kW and 200kV power supply for driving a X-ray generator. Since the developed power supply is based on a LCC resonant converter, it can achieve high efficiency and power density by soft switching and utilization of parasitic components. In addition, 200kV output voltage is achieved while the voltage stress on the devices are minimized because the proposed circuit adopts symmetrical bipolar voltage multiplier which has low voltage imbalance among stages. Furthermore, by applying half of the output voltage to the core and adopting a new transformer bobbin structure, the disadvantage of voltage multiplier, which requires a high voltage insulation of the transformer, is effectively overcome. In order to verify the reliability and insulation performance of the developed power supply, a 200kV no-load experiment and an arc test were performed. Also, 80kW rated power operation was confirmed through an inverter rated power experiment using a series resonance circuit.

#P3-39

HIGH POWER MICROWAVE COUPLER WITH HIGH POWER HANDLING AND OPTIMIZED ELECTROMAGNETIC MODE CONVERSION

KEYNOTE SPEAKER

DIOT Jean-Christophe, CHAULOUX Antoine, CHANCONIE Thierry, DELVERT Yannick

CEA, Gramat, France

ABSTRACT

In the context of high power microwave (HPM), the CEA Gramat has developed various vacuum electronic sources. Different technics can be employed when evaluating the performances of such microwave generators. High power handling couplers can be situated very close to the HPM source which tends to increase the measurement accuracy (compared to radiated measurements as an example). However they have to handle HPM magnitudes and ensure electromagnetic mode compatibility both with the source and the measurement setup. A new design of coupler is here proposed with a high coupling surface, dimensioned in order to decrease the power density hence increase the power handling. It operates in C/X frequency bands and provides TM01 electromagnetic mode compatibility with HPM sources. Measurement is achieved thanks to a TE10 waveguide which is convenient for analysers (like vector network analyzers). The coupling between the two electromagnetic mode waveguides is achieved thanks to multiples vias, which lengths are individually optimized to enhance TM01 to TE10 mode conversion.

Simulated S-parameters results are firstly exposed, and maximum power handling is secondly detailed.

#P3-40

DESIGN OF BIPOLAR PULSED POWER SUPPLY FOR PRODUCTION OF PLASMA ACTIVATED WATER

KEYNOTE SPEAKER

KIM Tae-Hyun[(1)], BAE Jung-Soo[(1)], SON Seong-Ho[(1)], KWON Chang-Hyun[(1)] , KIM Hyoung-Suk[(1,2)], YU Chan-Hun[(2)], JANG Sung-Roc[(1,2)]

[(1)] University of Science and Technology, Daejeon, Korea, Republic of.
[(2)] Korea Electrotechnology Research Institute, Changwon, Korea, Republic of

ABSTRACT

This paper describes a design of bipolar pulsed power supply to operate a DBD reactor for production of plasma activated water (PAW). Developed power supply consists of a front-end converter and an inverter. Both the converter and the inverter are based on resonant converter and resonant inverter respectively, which have an advantage of soft switching. Reduced switching loss enables to achieve high frequency operation and high efficiency. A simple analysis on an equivalent circuit of the DBD reactor for the inverter design is conducted. Parameter design of the resonant inverter with the analyzed load is introduced. Resonance period increases according to power consumption of the DBD reactor gives hardship to maintain soft switching of the inverter. So as to overcome this problem, a variable gate pulse width for switches of the inverter is applied. Implementation and experimental result of the developed power supply are introduced. With 10kW input power and input power factor of 0.96, power consumption of 8.8kW is measured by lissajous of the DBD reactor.

#P3-41

PHASE TRANSITIONS INDUCED BY MEGAGAUSS FIELDS IN CONDENSED MATTER

KEYNOTE SPEAKER

YASUHIRO Matsuda

University of Tokyo, Kashiwa, Chiba, Japan

ABSTRACT

In 1000 T class magnetic fields, the spin Zeeman energy exceeds characteristic energy scale in matter that determines their properties and results in the phase transitions where the nature of matter is dramatically changes. Several magnetic field induced phase transitions have been observed in strongly correlated electron systems such as V1-xWxO2[1], FeSi and LaCoO3 using the electromagnetic flux compression at The Institute for Solid State Physics, The University of Tokyo.[2]

Recent experimental results of the field-induced phase transitions will be introduced along with the current status of the electromagnetic flux compression megagauss generator.

[1] Y. H. Matsuda, D. Nakamura, A. Ikeda, S. Takeyama, Y. Suga, H. Nakahara, and Y. Muraoka, "Magnetic-field-induced insulator-metal transition in W-doped VO2 at 500 T" , Nat. Commun. 11, 3591 (2020).

[2] D. Nakamura, A. Ikeda, H. Sawabe, Y. H. Matsuda, and S. Takeyama "Record indoor magnetic field of 1200 T generated by electromagnetic flux- compression", Review of Scientific Instruments 89, 095106 (2018).

#P3-42

FOCUSING AN INTENSE RELATIVISTIC ELECTRON BEAM FOR FLASH RADIOGRAPHY

KEYNOTE SPEAKER

DUDES Adrien[1], FOURMENT Claude[1], DORCHIES Fabien[2]

[1] CEA, LeBarp, France.
[2] CELIA, Talence, France

ABSTRACT

Flash radiography is an imaging technique used at CEA and aimed to study dense objects in fast hydrodynamic evolution. In order to produce the X-rays required by the technique, a high energy (~ 20MeV) short duration (< 100ns) electron beam interacts with a high atomic number target foil. The radiation are produced thanks to Bremsstrahlung effect in the foil. Focusing the electron beam on the target leads to a better resolution of the flash radiography image.

This work consists to study the focus of a relativistic electron beam (3.3MeV ; 60ns ; 1.9kA) thanks to a preformed plasma. This work is the continuation of the thesis of Thomas Lahens who has studied the propagation of an electron beam in a cylindrical glass full of helium gas and plasma. He has shown that helium gas (10^-1 - 10^-2 mbar) had an influence on the propagation of the electron beam comparing to vacuum (~10^-6 mbar), due to the ionization of atoms by the beam.

In order to study the beam propagation in a preformed plasma, a high enough ionization degree is required to overcome the ionization of neutrals by the beam. Here we report how to produce a pulsed, low density plasma with ionization rate reaching ~1%. A plasma at low pressure (10^-4 - 10^-3 mbar) is seeded by a high-voltage spark and further ionized by inductive heating in order to pre-ionize the gas before the propagation of the beam.

#P3-43

LUMPED PARAMETER WIDE FREQUENCY BAND CHARACTERIZATION, APPLIED TO SI AND SIC POWER DEVICES USED IN POWER ELECTRONICS TOPOLOGIES

KEYNOTE SPEAKER

GOPISHETTI Anusha[1], VIDAL Paul-Etienne[2,3,1]
BAFFREAU Stéphane[3]

[1] Université de Pau et des Pays de l'Adour UPPA, Pau, France
[2] Université de Toulouse, INP, Toulouse, France.
[3] 3INP-ENIT, Tarbes, France. 4IUT-Tarbes GEII, Tarbes, France

ABSTRACT

Context and challenges

Embedded power systems in modern electric drivetrains use SiC and GaN semiconductors technologies to increase the power by volume ratio. For mobility applications, such as aerospace, automotive and railway transport, high voltage and power converters are developed. The integration of new Wide Band Gap (WBG) technologies allows to increase the switching frequency and the operating temperature. A higher power/mass or power/volume ratio or new technology integration involves two main challenges:

- How to assess the reliability and the lifetime of such a device [1]. Thus, aging tests are generally set up to reveal identified failure mechanisms and characterize their probability of occurrence [2];
- How to accurately model the broadband behavior of a power module. Indeed, each parasitic component R, L, C, G of the integrated WBG package plays a role in overvoltage and current experienced [3].

For equipment predictive maintenance objectives, it is of interest to get information about the damage status of these devices while operating, using a comparative model-based simulation. The purpose of the following study is to establish the initial characterization of lumped elements for WBG power switches, both discrete and homemade packages.

The assumption is that the failure mechanism propagation is identified by the change in impedance behavior of the power switch package. The homemade power package designer is interested in characterizing the initial values of both WBG die and package parasitic elements. On the other hand, the power converter designer is aiming to get initial values of the discrete package parasitic elements. In both cases, challenges are related to the number of measurements to perform and their accuracy. The proposed methodology is based on S-parameter measurement and simulation, as studied in [4] for industrial packages. Simulations and measurements are compared, thanks to several different methods and devices.

Discrete device characterization

The purpose is to characterize the initial parasitic element values of discrete power devices. As the inner geometry is unknown, the characterization process is based on measurement. An S-parameter measurement is achieved by connecting the Device Under Test (DUT) built on adapted Printed Circuit Board (PCB), with Subminiature – A connectors to Vector Network Analyzer (VNA).

The equivalent electrical scheme of the discrete power device is assumed to be a circuit, distributed at every DUT pin: gate G, drain D, and source S. As developed in [4], the accuracy is increased when the third pin is grounded. Then, S-parameter can be transformed in impedance matrix, such as, where and. Index and are respectively related to VNA ports 1 and 2. The impedance representation is related to the equivalent circuit. The capacitive and inductive behaviors are recovered at low and high frequencies, respectively. The peak resonant frequency is related to the series resistance value. From that identification, an equivalent electrical circuit simulation is performed in LTSPICE. The results are in good agreement with the measurements.

The method is applied to MOSFET SiC and Si IGBT. In addition, parasitic capacitances are also characterized thanks to a B1505A Power Device Analyzer / Curve Tracer. These new data are also compared to datasheet results. The studied method presents accurate results.

Homemade power device characterization

The previous method is applied to a homemade power device. Here, parasitic element values can be computed using Ansys Q3D, a 3D and 2D quasi-static electromagnetic field simulator, as the inner geometry and material constitution are mastered. The equivalent electrical circuit simulation and measurement results are in good agreement.

Conclusions

The paper illustrates a method to obtain the parasitic elements for power devices. Based on S-parameter measurement for its accuracy, it is highlighted how to apply it for SiC and Si technologies. Following the technologies, the simulation and measurements results are in good agreement. Conclusions can also be made regarding the values indicated in the datasheet.

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[4] T. Liu, et al., “A New Characterization Technique for Extracting Parasitic Inductances of SiC Power MOSFETs in Discrete and Module Packages Based on Two-Port S-Parameters Measurement” IEEE Trans. on Power Electronics, vol. 33, n° 11, Nov. 2018

#P3-44

PRELIMINARY STUDY OF DUAL ANNULAR MULTI-BEAM CATHODE FOR A TM03 MODE V-BAND RTTO

KEYNOTE SPEAKER

ZENG Fanbo, ZHANG Jiande, HE Juntao, LING Junpu

National University of Defense Technology, Changsha, China

ABSTRACT

With the development of the millimeter-wave technology and the application prospects of millimeter wave, the research of high-power millimeter-wave generator is an important field in high power microwave (HPM). However, there are many restrictions in the development of HPM to high frequency band, such as power handling capacity and energy density of the electron beam. To achieve high power handling capacity, overmoded operation or oversized structures are applied in the design of the HPM generation.

To increase the power handling capacity of a relativistic transition time oscillator (RTTO) of V band, a TM03 mode cavity is introduced to settle the problem of RF breakdown in this paper, and the dual annular multi-beam cathodes is used to excite the TM03 mode. This RTTO includes dual annular multi-beam cathodes, a five-gap modulation cavity, and a three-gap extractor cavity. The multi-beam diode contains twelve cathode poles in inner circle and twelve cathode poles in outer circle.

It was found that there is a mutual electric field shielding effect of inner and outer cathodes, which has a strong dependence on the relative length and the transverse distance between them. In concrete, the relative length has a significant effect on the shielding effect of the space charge of the beam from each other, and so does the transverse distance. For example, when the inner cathode is shorter than the outer cathode, the electric field thus concentrates on the outer annular cathode, and the electric field on the inner cathode is therefore not strong enough for the explosive emission on the inner cathode, and vice versa.

As a result, the transmission of both the inner and outer beams is investigated to guarantee the consistency and uniformity of current. In the future, power handling capacity enhancement of a coaxial V-Band RTTO operating in TM03 mode by use of dual annular multi-beam cathodes will be carried out.

#P3-45

EXPERIMENTAL INVESTIGATION OF ONE METER SCALE MILLISECOND DURATION GUIDED DISCHARGE

KEYNOTE SPEAKER

ARANTCHOUK Leonid, MYSYROWICZ André, HOUARD Aurélien

Laboratoire d'Optique Appliquée - ENSTA Paris, Ecole Polytechnique, CNRS, Institut Polytechnique de Paris, Palaiseau Cedex, France

ABSTRACT

The so-called guided discharge (GD) is distinguished among the others discharges by its straight line form as it is presented in Fig.1. In our experiments the GD is generated by using the femtosecond laser beam and the Tesla coil HV generator. The laser beam creates a plasma channel which prepares a way for breakdown followed by discharge. Some applications of GDs request its fairly long life-time. To solve this problem we use an additional LC circuit which allows injecting a current into the plasma channel created by HV breakdown of 1-m scale inter-electrode gap. In this way we generate a GD which is observed as long as about 10ms.

With the help of high speed camera we observe the laser guided breakdown dynamics. We visualized the propagation of breakdown head along the laser prepared plasma channel. Our experimental data well correspond to streamer - leader breakdown conception, based on translation of high voltage potential from a HV source to the breakdown plasma channel. The progression of the channel has a stepwise character, as it was observed in negatively charged leaders in natural lightning (so-called stepping). The maximal rapid elongation happens under the negative polarity of the Tesla voltage; its speed can reach the value of 350 km/s.

With the treatment of the camera video images we study two main characteristics of the GD: its average diameter and total luminosity. It was found that the visible discharge diameter evolution has stepwise behaviors as well.

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