PULSE GENERATORS WITH NANOSECOND LEADING EDGE DURATION BASED ON TPI-TYPE PSEUDOSPARK SWITCHES FOR FEL COMPLEX

O.V. Anchugov[1], Yu.G. Matveev[1], D.A. Shvedov[1] V.D. Bochkov[2], D.V. Bochkov[2], V.M. Dyagilev[2], V.G. Ushich[2], S.F. Mikhailov[3], V.G. Popov[3]
[1]Budker Institute of Nuclear Physics SB RAS, 630090, Novosibirsk, Russia
[2]Pulsed Technologies Ltd., 5, Jablochkova str., 390023, Ryazan, Russia
[3]FEL Laboratory, Duke University, Durham, NC, USA
E-mail: anchugov@inp.nsk.su; pulsetech@mail.ru

For FEL (Free Electron Laser) complex used in Duke University, pulse generators (kickers) of Injection, Extraction and Generator of injection into a big ring are developed and built. As fast switches TPI-type thyratrons (PSS – pseudospark switches) are employed. The thyratrons can be considered as an alternative to well-known switches, including hot cathode hydrogen thyratrons and up-to-date power solid state switches, whereas being more compact and cost-effective. Absence of hot cathode provides for turn-on time of the TPI about 3…5 ns in modes with thousands-amperes peak currents and sub-nanosecond jitter. The results of over 1.5 years of the pulse generators service are presented.

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1. INTRODUCTION

The deflector "kickers" plates with high-voltage nanosecond-width pulses applied to them are used to pass-by charged particles from one accelerator element to another [1]. Short pulse duration is necessary to kick out or in contrary to put onto the equilibrium orbit of the accelerator a single beam without touching neighboring ones.

The principal objectives for designing FEL complex generators were:

1) providing the minimum time jitter to avoid contacting adjacent beams;

2) providing the minimum rise and decay time;

3) achieving "flattop" instability not more than ±5%for long pulses (100 ns);

4) providing capability of fivefold output voltage tuning with pulse shape conservation.

The objective of development, research and operation of the generators is closely connected with application of switches. The first switches used in kickers were thyratrons with hot cathode. For high currents to achieve ultra-fast switching tetrode thyratrons are normally used. At that, grid 1 is pulsed with about 100 A and delayed trigger pulse is applied to grid 2. CX1599 thyratrons at faster 5 kV output driver with 3.5 ns rise-time into a single 50 ohm load. CX1 171 thyratrons are now employed in a variation of kickers circuit which now offers a rise time of 25 ns to 6 kA, time jitter – 1.0…5.0 ns [2].

The shortcomings of conventional thyratrons – uncontrolled prefires, substantial power losses in heating circuits - led to their replacement by solid state switches (SSS) [3, 4]. However, due to high cost of the SSS-based kickers, substantial overall dimensions and complexity of the devices, the designers of the kickers are compelled to look for alternative switches of the type. In the report the collected results of research and employment of kickers with pseudospark switches TPI-type are presented [5, 6].

2. SETUP AND RESULTS

TPI-thyratrons (Fig.1) with superdense glow and partially arc discharge form are intended for switching of up to 10^{-1} Coulombs in pulse mode at high frequency rate. In circuits with grounded cathode they offer the longest lifetime at lower cost than classical thyratrons with heated cathode.

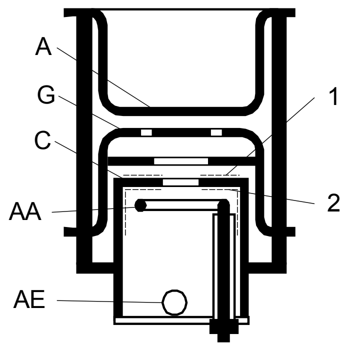

Fig.1. Schematic drawing of the TPI1-1k/20 PSS triggered with a glow discharge inside a hollow cathode. A – anode; G – grid; C – cathode; AA – auxiliary anode; AE – low-work-function element. Position 1 – erosion damages of cathode surface in microsecond mode; position 2 – in submicrosecond mode

The computer simulation of electrical fields inside the trigger region is carried out by solving the Laplace equation in absence of space charge.

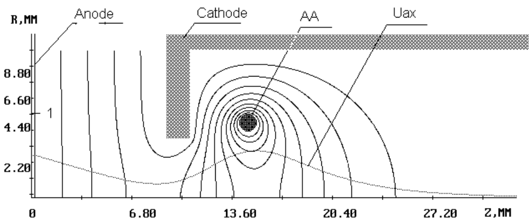

Fig.2. Equipotential contours in the cathode-trigger unit of PSS. AA - auxiliary anode, U - potential on the axis

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The pictures of fields and distribution of potential on axis of the electrode system allows to make a preliminary conclusion that there is an electrostatic trap in a cavity of the cathode of the given design (Fig.2). Such a trap at the initial stage of temporal development of the discharge can promote effective triggering of the discharge.

TPI-thyratrons were commercialized in the beginning of 2000. With the purpose to define prospective of applications of TPIs in modes with low discharge development time BINP together with Pulsed Technologies ltd, Ryazan, within 2001-2006 were conducting profound investigations of the switches and modes of triggering of the devices. We designed a driver for pulse triggering via 2 grids with constant preparatory discharge on the first grid (Fig.3). The design deficiencies are discovered, prospects of application are shown.

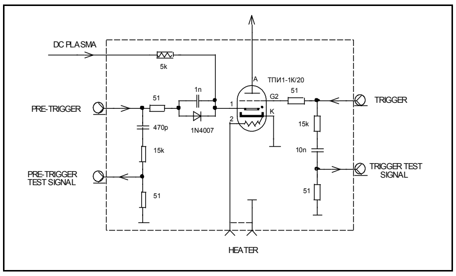

Fig.3. Principal circuit of TPI-thyratron triggering, operating in the mode with direct and pulsed auxiliary preionization current

Employing TPI-thyratrons for FEL-complex of Duke University five generators are designed and fabricated: two of them are based on TPI1-1k/20 thyratrons and three of them on TPI1-10k/20.

In the generators pulse command charging via pulse forming network (PFN) with charging time 180 and 720 μ*s* is employed.

<u>Injection generator</u> N1 (Fig.4,5) is built employing compact 150 grams TPI1-1k/20 thyratron, shaping in a load with impedance of 50 Ohm square bi-polar pulses with duration of 100 ns, pulse leading edge of 5…10 ns and "flattop" instability not greater than ±5% at the peak overall voltage on deflecting plates from 5 to 10 kV.

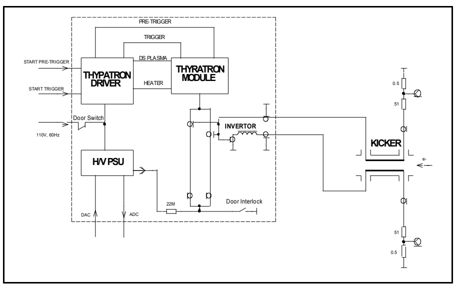

Fig.4. Injection Generator N1schematic drawing

Considering relatively low voltage of the system a circuit with single PFN is accepted. The circuit offers a minimum pulse edge limited by the response speed of thyratron only. The second deflector plate is connected via inverter to avoid two generators connection for upper and lower plates simultaneously. The inverter is performed of ferrite ring with coaxial cable PK coiled on it.

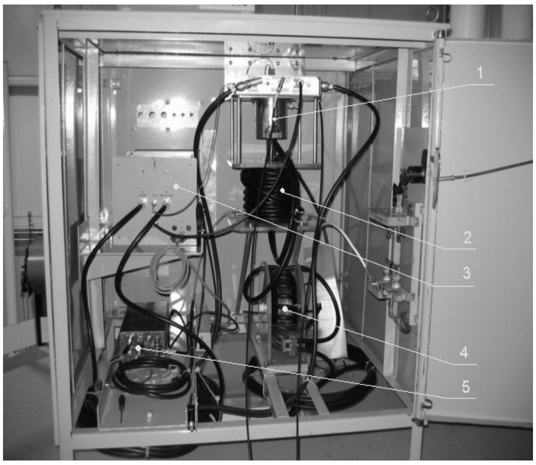

Fig.5. Injection Generator N1. Outline.
1 - thyratron in screen; 2 - PFN; 3 - driver;
4 - inverter; 5 - high-voltage DC generator

Two PK cables constitute the PFN. It is discovered by experiment that the matching is optimum if impedance (ρ) of one cable is 75 Ohm. At that, impedance of PFN is 30 Ohm, and internal impedance of thyratron in the given configuration is 5 Ohm (Fig.6).

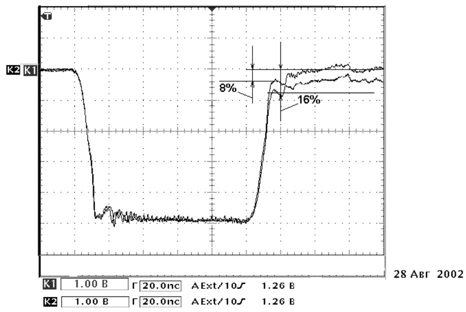

Fig.6. On the oscillogram the change of flattop after pulse in PFN from ρ = 25 и 30 Ohm

It is worth specifying that the pulses presented on the oscillograms were taken not from generators output, but from kickers matching terminators, when the pulses are distorted by transport cables, plates and unmatched loads. In the 1-st injection generator output pulse had a leading edge of 5 ns.

<u>Extraction generator</u> is built also on TPI1-1k/20 thyratron. It provides in a load with impedance of 50 Ohm, high-voltage pulses with duration at level 0.1 not greater than 15 ns at the peak overall voltage on plates from 8 to 40 kV.

For the project realization we chose a circuit with separated supply of every plate from separate generator.

Both generators are based on double coaxial PFN (Blumlein line), since providing output voltage of a single generator up to 20 kV on one PFN, employing TPI1-1k/20 thyratrons as the fastest switches ever used, is not possible due to the fact, that in this case the PFN charging voltage and, hence, anode voltage of the thyratron, will be increased up to over 45 kV. Both generators are identical except for one of the plates is connected to inverter, offering positive supply polarity (Fig.7,8).

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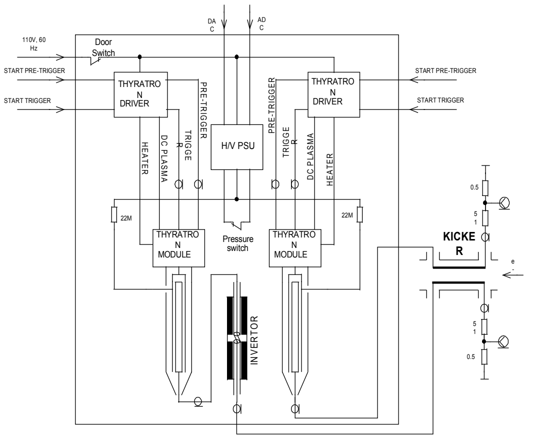

Fig.7. Extraction Generator schematic drawing

It is worth mentioning, that in extraction generator pulse rise time did not change in a range of 4…20 kV (i.e. at current change via the switch from 240 up to 1200 A), whereas in big ring injection generator from 5 to 25 kV (800…4000 A).

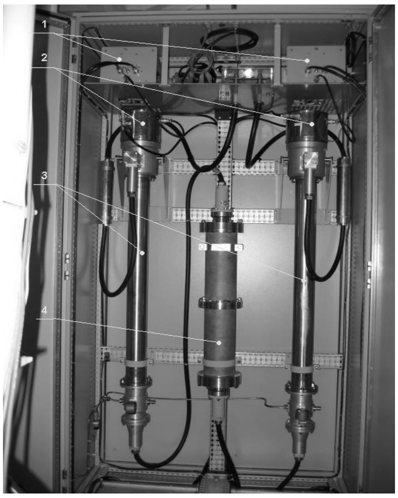

Fig.8. Extraction Generator. General view. 1 - driver, 2 - thyratron unit, 3 - pulse forming network, 4 - inverter

The generator built by the scheme (see Fig.7) has an advantage by offering output voltage close to charging one, however we have a problem connected with a feature of Blumlein line to increase output pulse leading edge approximately as much as twice in respect to response time of the switch. However, increasing PFN charging voltage up to 30 kV we obtained acceptable parameters of the output pulses for the given thyratrons.

Pulses from the matching loads are identical; one of them is presented in Fig.9. Time jitter was less than 0.8 ns. Unlike previous generator in the presented one we used pulse command charging of PFN via high-voltage step-up transformer with capacitor discharged onto a primary winding. PFN charging time was 180 μs.

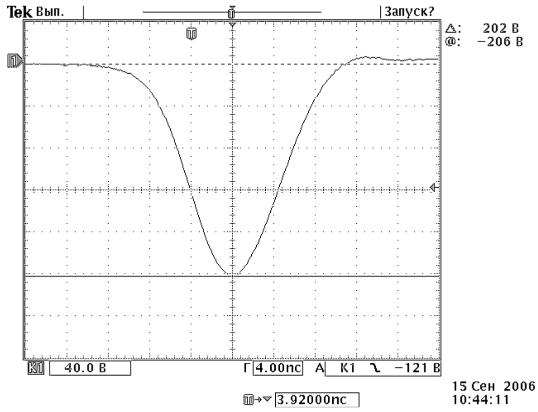

Fig.9. Pulse from the matching loads

<u>Generator of injection into a big ring</u> is built on TPI1-10k/20 thyratrons. With plate impedance of 25 Ohm it provides for pulse duration at level 0.1 not greater than 100 ns at the peak overall voltage on plates from 10 to 50 kV. In this case it was decided to employ Blumlein line, since the requirements to the pulse shapes are less tough and voltage is sufficiently higher.

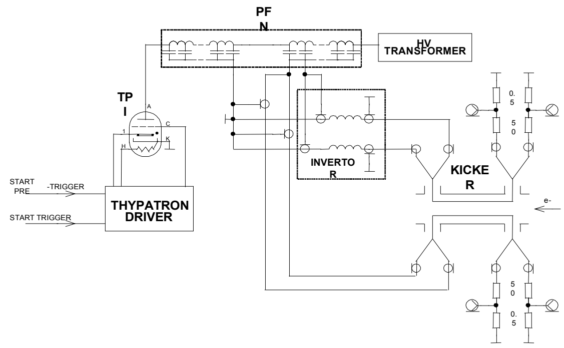

Fig.10. Scheme of the generator of injection into a big ring

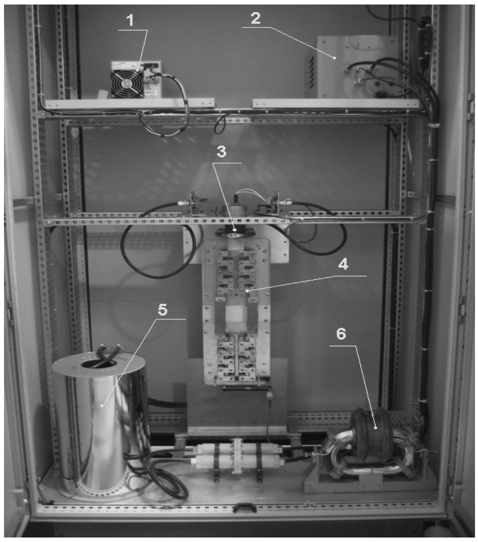

Fig.11. Generator injector into a big ring.
1 – charging source; 2 – driver; 3 – thyrtron; 4 – PFN; 5 – inverter; 6 – h/v transformer

Both plates are supplied from a single generator but since their impedance is 25 Ohm they must be connected via two parallel cables PK50. That is why PFN impedance was to be 6 Ohm. The choice of the switch was conditioned by that reason and it was a high-current thyratron TPI1-10k/20. In the given circuit at charging voltage of 25 kV switching current is about 4 kA.

The pulse forming network consists of discrete elements – two parallel lines of 11 cells with 3 series ceramic capacitors 470pF xl6 кВ, 470 pF (Fig.10,11).

CONCLUSIONS

TPI-thyratrons offer parameters fitting the principle requirements to the generators: time jitter not greater than 0.8 ns, rise and decay time of 4…5 ns, flattop instability for long-width pulse (100 ns) not greater than 5%, capability of fivefold output voltage tuning with pulse shape consevation.

Also:

- design of the generator is significantly simplified at the expense of employment of one switch for supply of both kicker plates and higher switching current (up to 10 kA)

- reliability of the generators is sufficiently higher as well as manufacturability of fabrication and assembling, in the accelerator system there is no evidence of self-breakdowns.

It is worth mentioning that since in this configuration fabricated cabinets were used, there was a lot of free space in them. As a matter of fact the design could be made much more compact.

The generators have been employed at FEL Laboratory Duke University since 2005. From the beginning of periodic operation the system has been working over 2000 hours. During this time the major problems were connected with reliable operation of high-voltage drivers, by this time the problems are almost eliminated. After 2000 hours increase of voltage drop through the thyra-tron on preionization electrode due to occurrence of direct current was observed. In order to reduce the tendency, a "quaziconstant" preionization must be introduced with applying of low-current trigger pulse with delay to the moment of thyratron firing not greater than 1 ms.

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ИМПУЛЬСНЫЕ ГЕНЕРАТОРЫ С НАНОСЕКУНДНЫМИ ФРОНТАМИ НА ОСНОВЕ ПСЕВДОИСКРОВЫХ КОММУТАТОРОВ ТПИ-ТИПА ДЛЯ КОМПЛЕКСА ЛСЭ

О.В. Анчугов, Ю.Г. Матвеев, Д.А. Шведов, В.Д. Бочков, Д.В. Бочков, В.М.Дягилев, В.Г. Ушич, С.Ф. Михайлов, В.Г. Попов

Для комплекса ЛСЭ, созданного в университете Duke, разработаны и изготовлены пять генераторов-«кикеров»: генератор инжекции, генератор экстракции и генератор инжекции в большое кольцо. В качестве быстрых коммутаторов использованы тиратроны ТПИ-типа, называемые также pseudospark switches – PSS. Отсутствие накаливаемого катода позволяет ТПИ обеспечить в режимах с килоамперными пиковыми токами большие, чем классическим тиратронам, сроки службы, уменьшенное время включения и субнаносекундный джиттер. Представлены результаты эксплуатации импульсных генераторов в течение более 1,5 лет.

ІМПУЛЬСНІ ГЕНЕРАТОРИ З НАНОСЕКУНДНИМИ ФРОНТАМИ НА ОСНОВІ ПСЕВДОІСКРОВИХ КОМУТАТОРІВ ТПІ-ТИПУ ДЛЯ КОМПЛЕКСУ ЛСЕ

О.В. Анчугов, Ю.Г. Матвеєв, Д.А. Шведов, В.Д. Бочков, Д.В. Бочков, В.М.Дягилєв, В.Г. Ушич, С.Ф.Михайлов, В.Г. Попов

Для комплексу ЛСЕ, створеного в університеті Duke, розроблено і виготовлено п’ять генераторів-"кікерів": генератор інжекції, генератор екстракції і генератор інжекції у велике кільце. Як швидкі комутатори використано тиратрони ТПІ-типу, які називаються також pseudospark switches – PSS. Відсутність розжарюваного катоду дозволяє ТПІ забезпечити в режимах з кілоамперними піковими струмами більші, ніж класичним тиратронам, терміни служби, зменшений час включення і субнаносекундний джиттер. Представлено результати експлуатації імпульсних генераторів на протязі більше 1,5 року.