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TITLE: DEVELOPMENT OF HIGH-RELIABILITY, MULTIKILOHERTZ REPETITION-RATE, FAST-DISCHARGE COMPONENTS

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DEVELOPMENT OF HIGH-RELIABILITY, MULTIKILOHERTZ REPETITION-RATE, FAST-DISCHARGE COMPONENTS

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Introduction

A pressing need has arisen for the development of very long-life, energy-transfer system components. As additional applications for fast pulse-power techniques are conceived, especially in laser technology, component specifications become more and more severe. High-repetition rates, high-peak and rms currents, and extremely high reliability are but a few of the difficult constraints. The two basic components in pulsed-power technology are capacitors and switches. In order to develop these high-voltage components, a unique laboratory has been constructed using state-of-the-art diagnostic and shielding techniques.

The laboratory is comprised of three basic systems:

Charging systems
Diagnostic systems
Grounding and shielding systems

The block diagram in Fig. 1 shows the basic system layout. It is important to note that each system may be used separately or in conjunction with the other system blocks.

In the first year of operation, approximately 24 different thyratrons, capacitors, saturable inductors, and current-viewing resistors have been characterized in the facility. A thorough investigation of polypropylene/silicon oil low-loss capacitors has been made and is discussed later.

The Charging Systems

Perhaps the most important part of pulsed-power technology is power conditioning. In the component development laboratory, both resonant and pulse transformer charging (command charging) are used to fully characterize the behavior of discharge components.

Linear resonant charge voltages of 5 to 60 kV at repetition rates to 3000 pps are available. With the use of saturating inductors, peak-charge voltages of 75 kV are achieved. Pulse-forming-network (PFN) capacitors up to 4 nF can be charged to 80 kV at 1000-pps repetition rates. At reduced operating parameters, capacitors of several microfarads can be operated in a discharge circuit.

Pulse-transformer charging extends the operating range of the facility to a maximum charge voltage of 120 kV at repetition rates of 5000 pps. Capacitor values up to 15 nF can be charged in 2 to 10 μs. Wall-plug efficiencies of 85% are achieved with present pulse-transformer charging systems, and efficiencies of greater than 90% are expected in systems under development.

Since the resonant and pulse-transformer charging systems are completely separate, a discharge circuit under investigation can be changed from one to the other in a few minutes.

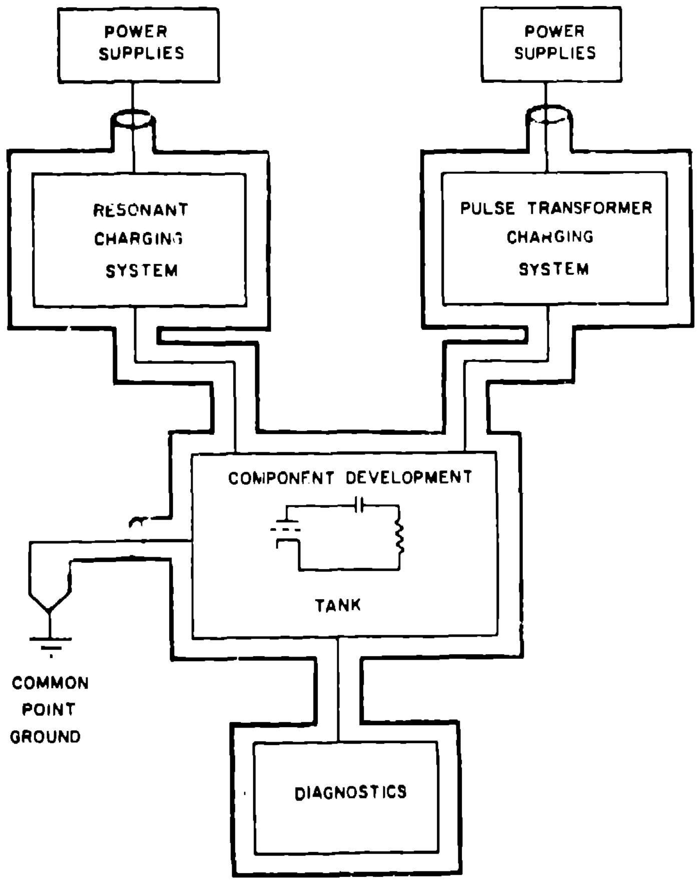

Fig. 1. High-repetition rate component-development laboratory operating system.

Diagnostics

In the field of component development, accurate and reliable diagnostic capabilities are essential. The heart of the laboratory diagnostic center is a computer-controlled two-channel transient digitizer of 500-MHz bandwidth. Pulse-current measurement capabilities of up to 50 kA at 350-MHz bandwidth are incorporated in the experimental area. A recently developed 250-kV dc to 100-MHz passive high-voltage probe and a 100-kV dc to 250-MHz probe complement the current measurement capabilities. With other in-house diagnostic techniques, such as ion microprobe, x-ray topography, and chemical analysis, a complete data base for the physics, chemistry, and metallurgy of components is being established.

A new thyratron current-viewing-resistor mounting flange assembly, shown in Fig. 2, was developed in conjunction with T & M Research, Albuquerque, New Mexico. Low-inductance design (·.40 nH) and wide range of resistance values make it suitable for almost any circuit. This new diagnostic tool has been found to be indispensible in thyratron circuits.

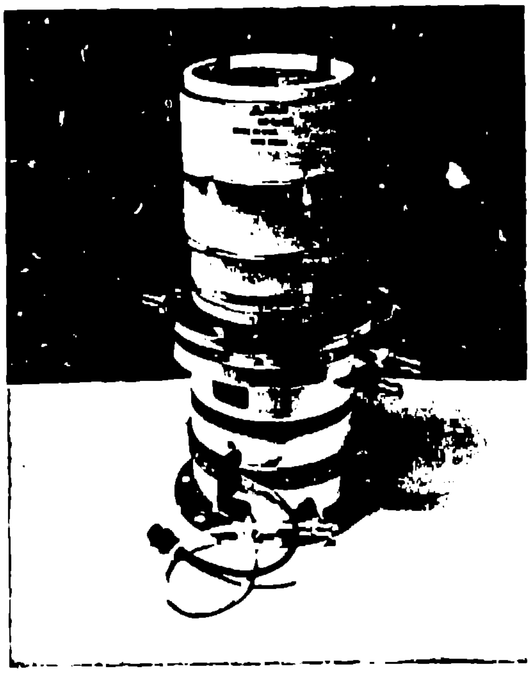

Fig. 2. Thyratron current-viewing resistor/mounting flange assembly.

Capacitors

Along with the development of various high-voltage components, the present area of prime interest is multikilohertz, long-life, low-inductance capacitors. A major program to fully characterize capacitors designed for pulse duty is in progress. The motivation for pulse-capacitor development is threefold.

- To obtain a data base to understand the physics and chemical processes affecting capacitor life.
- To develop low-loss, extremely long-life capacitors $>10^{12}$ shots.
- To interact with industry in designing capacitors in the range of 1 to 20 nF capable of 10 kA/nF peak current in a 50- to 100-ns discharge.

There are two configurations that meet the low-loss requirements, silicon oil/polypropylene and dry, reconstituted, mica-type capacitors.

The equivalent series resistance (ESR) is of prime importance in determining the loss of the capacitor during the discharge pulse. The ESR measurement was approached from several directions. The conventional method of deriving ESR from a ringing discharge was used along with phase shift, Fourier analysis, and temperature variation measurements. A direct method using circuit theory applied to nonlinear time-varying second-order circuits was also used. Results from all methods indicated an ESR of less than 100 mΩ. A 0.5% accuracy of resolution is the limit of the present laboratory diagnostics. To make high-accuracy ESR measurements at 50-kV, 1-kA pulse levels at which the capacitors operate, a 0.02% resolution of accuracy would be needed. In the polypropylene/silicon oil capacitors, dependence of lifetime on repetition rate has been determined as seen in Fig. 3. The repetition-rate dependence is due to a time-voltage stress relation seen only in high di/dt circuits.

A new in situ method has been devised to detect an imminent failure in polypropylene/silicon oil capacitors using partial-discharge detection techniques. All capacitors of this type tested have failed in the same predictable manner due to the same failure mechanism. The method of capacitor-failure prediction has thus far proved to be 100% reliable.

Thyratrons

High-average power switching is a major area in the field of pulsed power. To meet the requirements of long life, high-repetition rate, and low loss, the thyratron at present is the only viable choice. In addition to the above qualities, thyratrons require less support equipment than high repetition-rate spark gaps and are far more economical to use. Areas of thyratron investigation include efficiency, power and energy flow, and switching characteristics.

One of the major problems to date in fast-discharge, kilohertz repetition-rate spark gap switching is the large losses experienced (20 to 30%) in the switch. In long-life, high-reliability circuitry such losses are totally unacceptable. The thyratron losses during commutation in this fast-discharge circuit have been measured for the first time in this new facility. For stored energies of 1 to 1.2 J, this loss is 2.2% at an 80-ns pulse width and a peak current of 700 A. The losses were observed to decrease rapidly with increasing energy, as expected, so that low-loss switching is feasible with thyratrons, giving long economical life at high switching efficiencies.

New, compact, short-pulse thyratrons are currently under development for 50 to 100 kV multikilohertz operation at current rates of rise in excess of 10^{12} A/s at 10 to 100 kA peak current operation.

System Upgrade

The present component-development laboratory has an average power capability of 50 kW. A second facility, capable of 300-kW continuous average power, is under construction. The new facility is similar in concept to the existing laboratory with many advances in diagnostic capabilities. Two projects planned for the high-power laboratory a… development of high-energy density capacitors and PFNs for repetitive pulsed-power laser application..

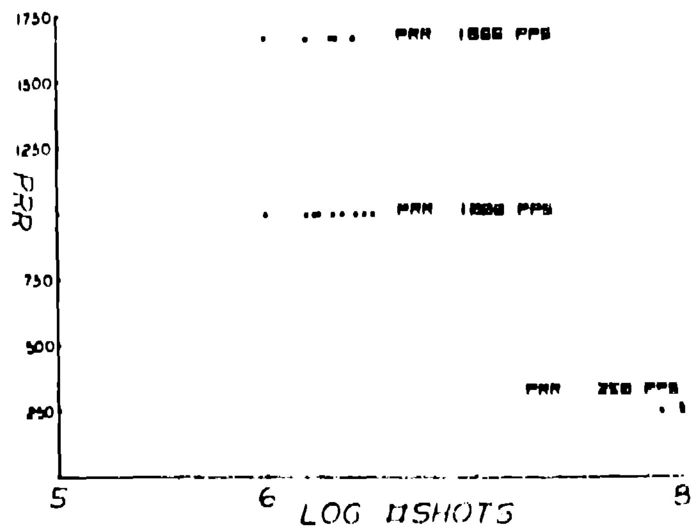

Fig. 3. Lifetime vs pulse repetition rate for silicon oil/polypropylene.

The high-repetition rate component-development laboratory has received much internal support as well as support from industry. Interaction and technology transfer between other national facilities and industry is encouraged within the Los Alamos Scientific Laboratory and are vital to the advancement of pulse-power technology.