EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

HR/lmg/afm CERN/PS/85-30 (AA)

A 400 kA PULSE GENERATOR WITH PSEUDO-SPARK SWITCHES

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(Paper presented at the 5th Pulsed Power Conference, Arlington, June 1985)

Geneva, Switzerland

July 1985

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Abstract

The development and testing of a plasma lens for the new CERN Antiproton Collector required the construction of a dedicated test pulse generator. Four capacitor banks of 27 μF charged to 20 kV are symmetrically discharged into the central common Z-pinch load. With a total pulse energy of 20 kJ current pulses of 400 kA amplitude and a half wavelength of 12 μs are passed through the plasma lens. Each bank is separately switched with the aid of a low inductance pseudo-spark switch operating at a pressure of 0.01 to 0.05 mbar helium. The modular switch design allows for the easy exchange of different trigger systems. Switching delays of 100 to 200 ns and jitter values of ±10 ns were obtained.

Introduction

The CERN proton-antiproton collider system, which has been the basic tool for the successful discovery of the W and Z bosons, will be upgraded towards at least tenfold higher antiproton intensities. A new antiproton collector ring (ACOL) will be built at CERN in 1987. A key element of ACOL is the strong focusing lens which has to collect the antiprotons emerging from the production target up to an emittance of 200π mm mrad. The devices, which seem best suited to this task, are so-called linear lenses. They are essentially rods carrying a high homogeneous axial current which generates a strong azimuthal magnetic field which bends the high energy particles towards the axis. Two developments of linear lenses are actually pursued at CERN. In the first case the current conductor is a lithium rod. Due to absorption of antiprotons the length of the lithium cylinder is limited to about 10 cm. It is more attractive to use a non-absorbing medium as current conductor like a pinched plasma column. In this case the current path can be made longer resulting in less current amplitude with the same focusing effect.

During the first development stage of a plasma lens at CERN the fundamental problems of stability and control of the plasma column contraction have been solved. Presently, the most critical aspects of long term behavior of such plasma lenses are investigated. In 1965 a plasma lens had already been installed in the AGS at BNL[1]. It failed after one day of successful operation due to high energy dissipation. Metal evaporation and erosion from the electrodes and the contamination of the insulating walls of the plasma lens vessel limit the lifetime and have to be minimized. With proper crowbaring the energy which remains in the system after reaching the peak current has to be guided away from the plasma lens.

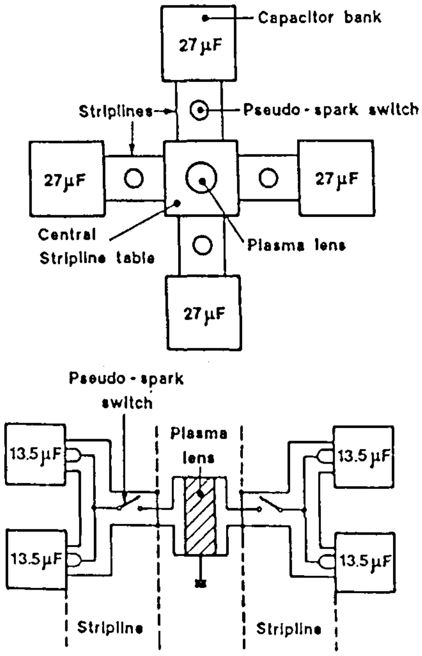
For studying the long-term behavior of plasma lenses a dedicated pulse generator has been built at CERN. It is not specifically designed to be used with a plasma lens installed at the ACOL target area, but serves as a laboratory test generator. We voluntarily built the generator without crowbar system. In this way the life tests are speeded up since the whole pulse energy will be dissipated in the lens during several current cycles.

Fig. 1 - Top view of the test pulse generator.

The energy will be switched from the capacitor banks to the plasma lens with special high current switches which have been developed at CERN. These low pressure spark gaps, called pseudo-spark switches, can switch high currents with nanosecond precision, while triggered with very low energy. Their low inductance enabled us to reach the required discharge parameters for the plasma lens with a charging voltage of less than 20 kV.

Layout of Pulse Generator

A real size plasma lens with a quartz cylinder of 250 mm length and 190 mm inner diameter and with hollow electrodes will be symmetrically placed on a quadratic stripline table in the centre of four separate capacitor banks (Figs. 1, 2a and b). The capacitor banks are linked to the centre table via 0.5 m



a) Top view

b) Side view

Fig. 2 - Scheme of the generator.

wide striplines. Each of the four striplines is switched separately by a single pseudo-spark switch. The plasma lens has to be pulsed with a current of at least 400 kA. The pinch dynamics in the lens imposes a current rise time of 6-7 μs. Taking into account the inductance of the lens and the external electrical circuit a charging voltage of almost 20 kV is required on the capacitor banks.

The charging of the capacitor banks is done with two parallel high voltage regulated power supplies delivering 0.4 A each. The maximum repetition rate, at which the life tests can be run, is 0.3 Hz.

Several diagnostic tools enable us to survey the operation of the generator. Four Rogowski type current pick-ups built with printed circuit methods are incorporated into each of the striplines. A total current loop based on the same principle is wound around the plasma lens. All current derivative signals are integrated passively with negligible distortion and parasitic noise. The voltage between the plasma lens electrodes is measured with commercial high voltage probes. The intensive light output of the plasma lens is measured as function of time via a fiber optic cable with a photodiode. The correct charging of each capacitor bank and the correct operation of the high current switches will be observed on the signals from high voltage dividers installed at each bank and on the charging current waveforms obtained from the high voltage power supplies. A small microcomputer system with CAMAC interface fulfils a number of surveying and measuring tasks.

High Current Pseudo-Spark Switches

The pseudo-spark chamber was invented at the Physical Institute of the University of Erlangen in 1979[2]. This device is becoming increasingly important in applications as pulsed intensive electron and ion source[3-4], as well as sources of microwave[5] and laser[6] radiation. The pseudo-spark geometry (Fig. 3) is particularly well suited for switching high currents and voltages at high peak and average power with high precision. The principles of the pseudo-spark discharge and its switching features have been described earlier[3,7]. The position of the pseudo-spark during discharge is predictable and reproducible unlike in the case of a high pressure spark. The current transition to the electrodes is spread over a rather large surface area around, inside and behind the centre holes (Fig. 3). The reduced current density decreases the energy deposition on the electrodes compared with a high pressure spark. Between the electrodes the plasma channel is confined to the axis of the switch by the forces of the azimuthal magnetic field.

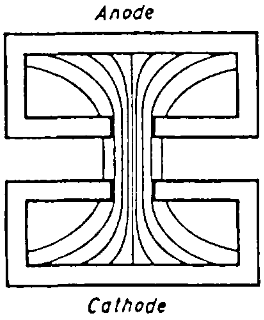


Fig. 3 - Pseudo-spark structure and current flow.

The pseudo-spark chamber can be triggered with very low energy from the interior of the hollow cathode leaving the main discharge gap free from elements like grids, trigger pins, baffles, etc. Pseudo-spark switches have been developed for medium power switching in laser applications. Voltages of 20 kV and currents up to 10 kA have been switched at repetition rates up to 100 kHz with subnanosecond precision and current rise-times of 2.5 kA/ns[8-9].

In our plasma lens test generator we require four 20 kV switches carrying 100 to 150 kA each with an inductance below 10 nH and a precision of better than 100 ns. The switches have to withstand reverse current amplitudes of almost hundred percent. Since commercially available switches cannot do this job, we developed special high current pseudo-spark switches (Figs 4 and 5). The switch and its trigger system have to be well taylored to meet the severe conditions of electrode erosion and metal vapor contamination of the insulators. The principal insulator is protected against the discharge plasma by dielectric and metallic screens. Both electrodes are water cooled. The coaxial structure leads to plasma confinement in the centre region. The switch is maintained at a pressure of 0.01 to 0.05 mb with helium as filling gas.

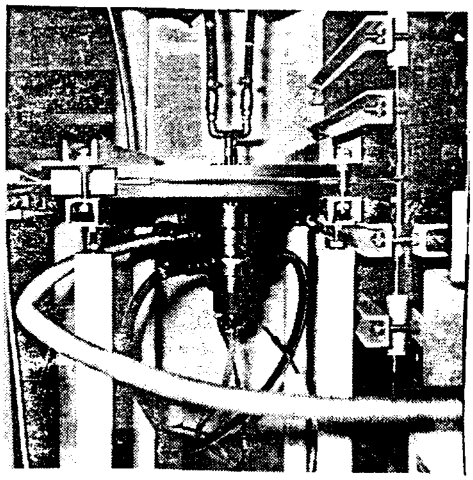


Fig. 4 - High current pseudo-spark switch mounted into the stripline of the test pulse generator.

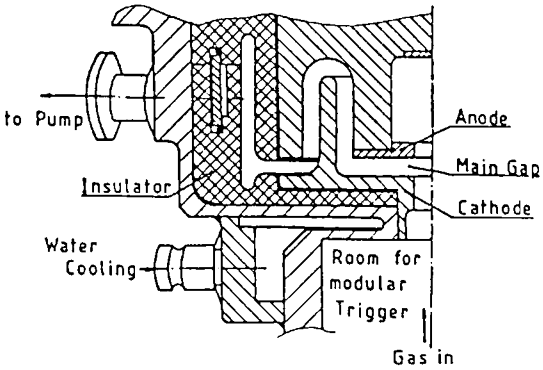


Fig. 5 - High current switch geometry.

Two trigger systems have been developed for the high current switch. Both are mechanically compatible and can be modularly plugged into the switch from below. The first type is a so-called surface discharge trigger (Figs 6 and 7). A trigger pulse of 2 kV amplitude initiates a small spark across a tiny dielectric layer 35 mm away from the main gap. The local plasma leads to rapid charge carrier multiplication in the hollow cathode space which immediately provokes break-

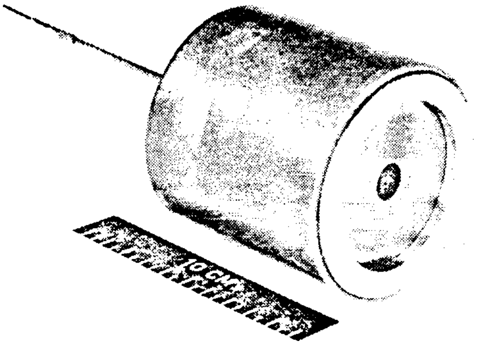


Fig. 6 - Modular surface discharge trigger for high current switch.

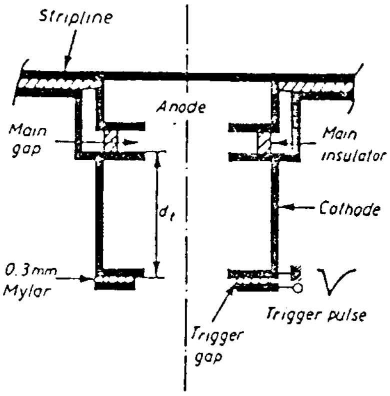


Fig. 7 - Principle of surface discharge trigger system for high current pseudo-spark switches.

down of the main gap. Under these circumstances trigger delays below 200 ns and jitter values of ±10 ns are obtained.

The second trigger type is based on a low d.c. voltage preionization of the rear cathode space[7-9]. Ignition is started with a superimposed current pulse of 0.1 to 0.5 A amplitude (Fig. 9) injecting additional charges into the hollow cathode space. With this charge injection trigger subnanosecond precision can be achieved at low pulse energies. However, at a current level of 100 kA, the jitter increases to several nanoseconds.

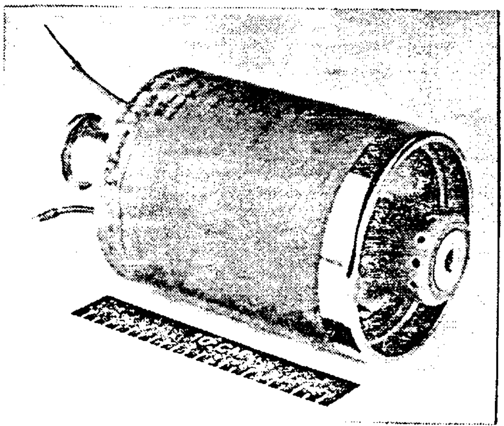


Fig. 8 - Modular charge injection trigger for high current switch.

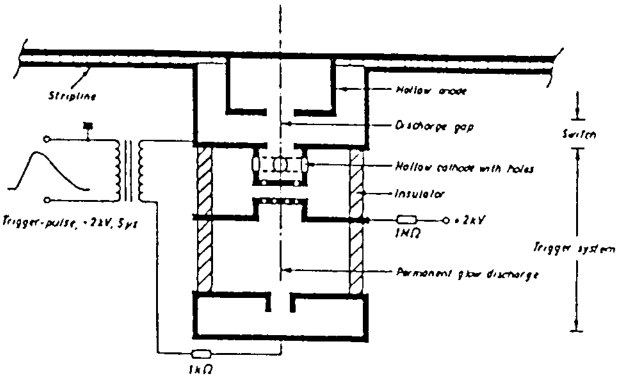
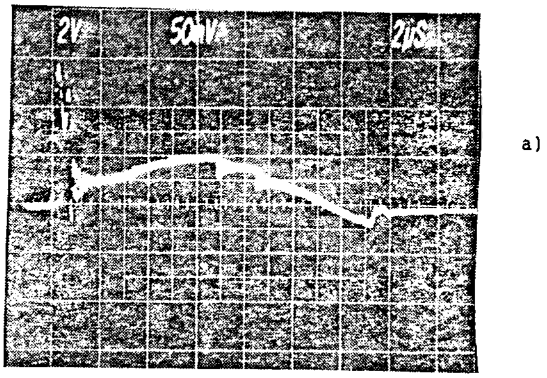


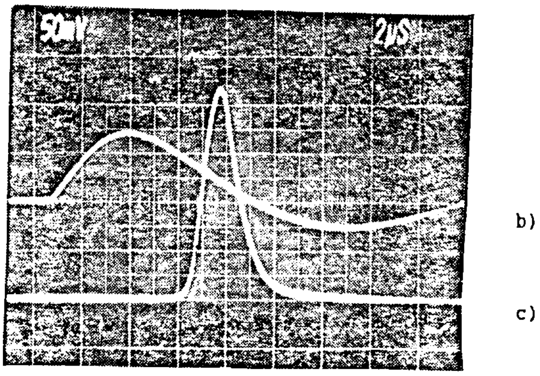
Fig. 9 - Principle of charge injection trigger for high current pseudo-spark switches.

Pulse Generator Performance

The maximum current amplitude which can be achieved with 20 kV charging voltage depends on the pinch dynamics in the plasma lens. The contracting plasma column represents an increasing inductance. Figures 10a and 10b show the measured voltage and current waveforms for a charging voltage of 13 kV and a minimum pinch radius of 40 mm. Figure 10c shows the light intensity measured on the plasma lens axis as function of time. The generator is able to deliver 1 MA pulses when



1 kV/Volt



5,8 kA/mV; i_{peak} = 400 kA

Fig. 10 - Voltage a) total current b) and light intensity c) waveforms of the plasma lens.

a 50 nH short-circuit is mounted into the central stripline table instead of the plasma lens (Fig. 11). The long term behavior of plasma lens and high current switches is subject of a life test which is just now going on. In future we intend to use better materials like steatite insulators and thoriated tungsten electrodes for the switches[10]. These improvements should multiply the lifetime by a factor between 3 and 10.

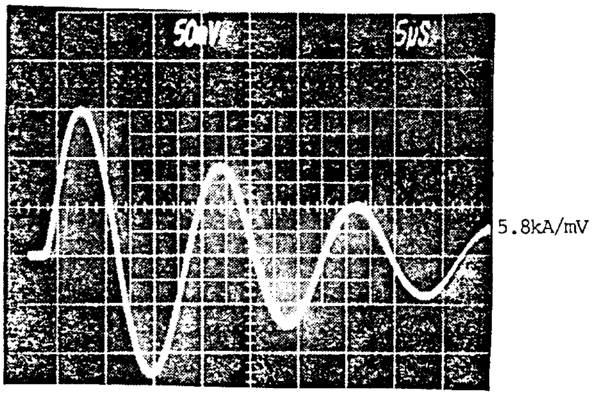


Fig. 11 - Current waveform with a 50 nH short-circuit.

Conclusion

Due to space and radiation restrictions the pulse generator cannot be installed in the ACOL target area in its present form. The plasma lens requirements concerning peak current and pulse length will remain unchanged. We, therefore, intend to use a two-cell circuit with two capacitor banks each heaving the same type of capacitor and the same value of capacity as the present four banks together. The energy will be stored in the first bank and switched via several pseudo-spark switches and striplines to the second bank near the plasma lens. From the second bank the pulse is transferred to the plasma lens via a short stripline by a magnetic switch. The first circuit cell will contain an efficient crowbar system, also with pseudo-spark switches.

The features of the high current pseudo-spark switches developed for this application are far superior to those of commercial ignitrons. The modular design allows for an easy and fast change of components like insulators and electrodes. The trigger system can be typically exchanged within a few minutes. Like the promising developments of pseudo-spark switches in the thyratron range, this is another example of successful application of the general pseudo-spark principle to high power switching.

Acknowledgements

We have to mention the very valuable active help of the CERN EF Division, especially of R. Grüb, during the design phase of the pulse generator. We are grateful to P. Billault, G. Fort, Y. Thebault and M. van Gulik who intensively took part in the design and installation of the test pulse generator. We acknowledge the competent design work of G. Dietz from the company Messerschmitt-Bölkow-Blohm, where the switches have been built. The authors also like to thank all their colleagues and the management of the CERN PS Division for their support to these developments in advanced accelerator technology.

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