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HIGH-POWER, HIGH-CURRENT PSEUDOSPARK SWITCHES

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Abstract. - A low pressure gas switch with a hollow cathode and a hollow anode (pseudospark geometry) that switches an order of magnitude higher current than commercially available thyratrons, over 100 kA, is reported. The switch is not a spark gap and does not form arcs at the electrodes. The cold cathode produces much higher emission than hot cathodes presently in use. The switch significantly extends the performance capabilities of switching technology.

Based on initial results of research into the "pseudospark" phenomena [1], it seemed interesting to use the pseudospark chamber as a high-power switch. In 1981 a first pseudospark medium-power switch had been built at CERN [2]. The good results obtained with this experimental switch were the reason for starting the study of basic pseudospark physics relevant to switching applications, the systematic development of trigger methods and the exploration of potential applications in high-voltage, high-current and high-power switching.

Several advantages of pseudospark switches compared with other high-power gas switches stem from the simple cylinder symmetrical geometry (Fig. 1). In principle it can be considered as a z-pinch structure with hollow electrodes, the holes of which are centered on the axis. However, in contrast to a z-pinch discharge where the current normally starts to flow at the insulator wall, the triggered pseudospark is always initiated on the axis. The physical processes of the discharge are not yet fully understood but it has been theoretically and experimentally shown that shortly before breakdown a significant increase of electron density appears on the axis inside the hollow cathode. Fast charge multiplication and breakdown starts from this region and extends on the axis into the main gap of the switch.

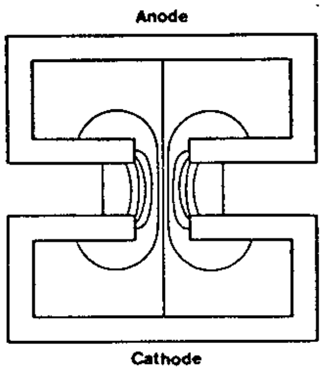

Fig. 1 - Basic geometry of a pseudospark switch.

Some tens of nanoseconds after breakdown the discharge channel expands and transforms into some kind of z-pinch. The rising azimuthal magnetic field linked to the growing current helps to confine the current channel to the axis. The insulator surfaces of the switch must be moved far away from the discharge channel and have to be protected by metallic and dielectric screens against radiation and plasma contact. Unlike in high-pressure spark gaps, the formation of craters on the electrode surfaces is totally absent.

A consequence of the longitudinal geometrical symmetry of the pseudospark switch is its capability to support full current and voltage reversals. Moreover, both charging polarities can be applied; however, triggering from the hollow cathode is most effective. Trigger systems can be positioned inside the hollow electrodes far away from the main gap and well protected against hot plasma and leakage currents from the main discharge. Very little energy is required to trigger a pseudospark switch. Low delay and jitter values are achieved even when the trigger system in the hollow cathode is not in direct contact with the main gap of the switch. Triggering methods for pseudosparks include surface discharge [2] [3] [4] [5], electron beam [4], charge injection [4] [6] [7] and optical [8] triggering.

Due to the absence of heated cathodes and due to the short distances the ions need to run through to reach an electrode wall very good hold-off capabilities, very short recovery times after discharge and high repetition rates above 100 kHz can be achieved.

The specific pseudospark breakdown properties lead to fast current-rise rates. These rates are not only observed at small amplitudes, but also at current levels above 100 kA. This means that the fast initial rise after breakdown is favourably backed up by the onset of a z-pinch like dynamics with magnetic confinement and with a fast decay of plasma resistivity.

In the early stages of high-current pseudospark switch development the prime importance of the discharge dynamics, the symmetry of the discharge and the effects of electrode erosion and insulator attack were realized. After the discharge has transformed into a dynamic high-current discharge the current flows through a hot plasma column varying strongly in diameter and interacting strongly with the wall material to which it makes contact. The objectives in the design of a high-power pseudospark switch are therefore to maintain all the advantages for the initial stages of the discharge and, on the other hand, to provide the electrode and insulator geometry appropriate for plasma confinement. Appropriate materials have to be chosen where plasma-wall interaction takes place.

The mechanical layout scheme of a high-current pseudospark switch is given in Fig. 2. The size of the metallic screens has to be chosen such that the hot plasma cannot reach the main insulator region. At the same time the electrode distance has to be kept to the same value all over the whole gap.

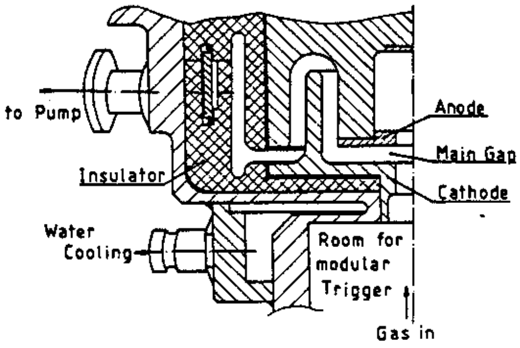

Fig. 2. - Scheme of the mechanical layout of the CERN high-current pseudospark switch.

The high-power switches are generally filled with helium at a pressure of 0.01 to 0.1 mbar during operation, but have been tested also with nitrogen and hydrogen. During each pulse a considerable part of the switched energy is dissipated inside the switch when the total pulse generator impedance is in the milliohm region. The centre parts of both electrodes are therefore strongly heated and must be water cooled. The cooling water must be taken as near as possible towards the centre holes.

Two trigger systems have been successfully tested in the high-current pseudospark switches. The principle of the surface discharge trigger is given in Fig. 3. A charge injection trigger system which is more complex but less prone to degradation is shown in Fig. 4.

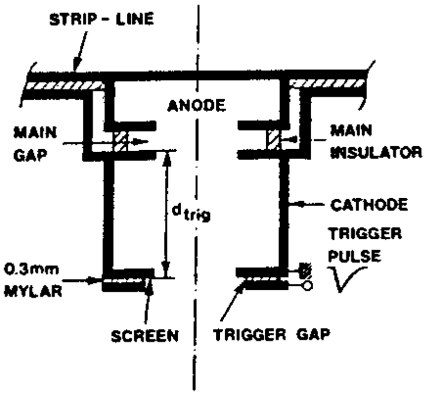

Fig. 3. - Scheme of surface discharge trigger. Ignitron spark across higher surface.

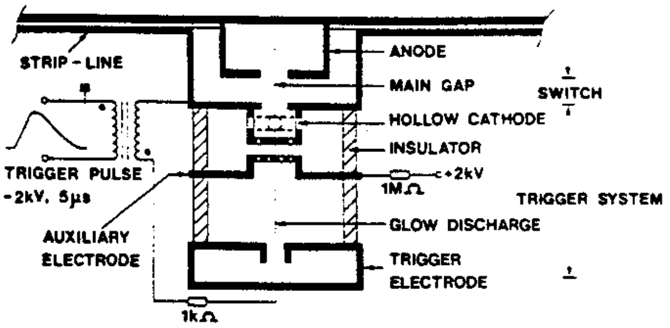

Fig. 4. - Scheme of simple charge injection trigger.

Table I summarizes the main characteristics of the high-current switches. For their application in a plasma lens pulse generator [4] an essential requirement is the simultaneous switching of four pseudospark gaps, which can only be achieved when the breakdown delay of all four units can be made equal and when the jitter is smaller than the voltage decay time on the individual switch.

Table I : High-current pseudospark switch features

Maximum hold-off voltage	20 kV
Maximum peak current	200 kA
Nominal hold-off voltage	16 kV
Pulse length	15 µs
Nominal peak current	100 kA
Charge transfer/pulse	0.43 Cb
Reverse current	100%
Maximum dI/dt at 16 kV	$1.5 \cdot 10^{11}$ A.s^{-1}
Switching delay	100-600 ns
Jitter (pulse energy = 1 J)	±10 ns
Jitter (pulse energy = 3.5 kJ)	<100 ns
Inductance	40 nH
Repetition period	3 s
Filling gas	Helium
Gas pressure	10^{-2}-10^{-1} mbar
Electrode material	Densimet 18 (95% W)
Insulator material	Araldite
Lifetime (at 3.5 kJ/pulse)	>500,000 pulses

Depending on gas pressure the switches are operated with breakdown delays of 100 to 600 ns. The jitter of the high-current switch at high-pulse power amounts to ±50 to ±100 ns. This is an increase by more than one order of magnitude compared to the jitter at low-pulse power. For avoiding spurious breakdown the switches are operated far from the breakdown curve.

The current amplitude in each switch is normally about 100 kA, when pulsing into the plasma lens load [8] [9]. Occasionally currents up to 200 kA per switch have been switched with the same pulse generator through a low inductance short-circuit load. In this case current reversals of almost 100% are observed. A number of tests were performed to determine average values of internal resistance and inductance. The typical average resistance at 100 kA is less than 1 mΩ (Fig. 5). Average dissipated energies in a single switch may reach 0.5 kJ per pulse. An average internal inductance of less than 40 nH was derived from tests with different low-inductance short circuits.

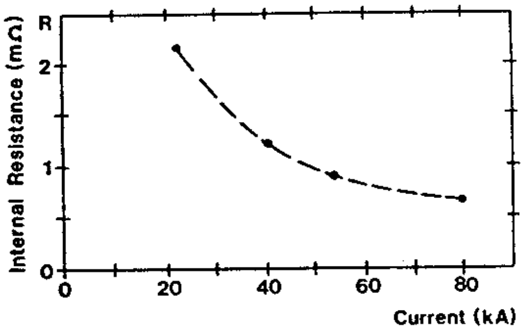

Fig. 5. - Internal resistance at peak current ($dI/dt = 0$) plotted as a function of current.

Maximum current rise rates of 1.5×10^{11} A/s were observed at a capacitor-bank charging voltage of 16 kV. Though this is the maximum rate of pseudospark switches observed at such high-current levels, the limitation of current rise is still given by the pulse generator circuit characteristics.

Many hundred thousands of pulses of 100 kA amplitude have been switched at 16 kV charging voltage every 3 seconds without any substantial deterioration of the switching properties. Inspection of one switch after 10^5 pulses revealed slight traces of erosion on the central electrode parts and on the metallic screen surface which is directly exposed to the strong radiation from the plasma column on the axis. The electrode surface was smoothly and symmetrically eroded showing no single crater or asymmetry of discharge. The insulator, though composed only of organic components was not attacked by the discharge.

Pseudospark switches cover a very wide range of applications including high-voltage switching and high-frequency operation at subnanosecond precision. The capabilities of switching high current, high-power and high-pulse energy have been clearly demonstrated here.

Pseudospark switches combine the advantages of different gas switches into one system. The low trigger energy results in high-repetition rates at high precision. The geometry leads to a high-current density discharge with low erosion enabling the handling of high peak and average power in strongly oscillating, low-inductance circuits.

Improvements of the high-power pseudospark switches are mainly expected by the application of better electrode and insulator materials. The use of thoriated tungsten at the heaviest loaded electrode areas will result in an even smoother current distribution due to the reduced electron-work function and therefore in less erosion. Inorganic insulator material with less outgasing rate will enhance the peak and average power switching capability and will reduce the spurious breakdown rate. Better performance is also expected from an optimization of the switch geometry, e.g. from a systematic matching of gap spacing, centre hole diameter, hollow electrode volume, cathode thickness and screen diameter. Better trigger systems may lead to megampere switching with nanosecond precision.

The application of pseudospark switches is particularly promising in switched high-power induction linacs for inertial confinement fusion and free-electron lasers, for high-energy physics research, for high-power laser pulse generators, and also in standard technology as a replacement for conventional switches.

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