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Pseudospark Switch Development for the LHC Extraction Kicker Pulse Generator

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G.H. Schröder(*), E. Vossenberg(*)

Abstract

CERN, the European Laboratory for Particle Physics, has started construction of the Large Hadron Collider (LHC), a superconducting accelerator that will collide protons at a center of mass energy of 14 TeV from the year 2005 onwards. The kicker magnet pulse generators of the LHC beam extraction system require fast high power switches. One possible type is the pseudospark switch (PSS) which has several advantages for this application. A PSS fulfilling most of the requirements has been developed in the past years. Two outstanding problems, prefiring at high operating voltages and sudden current interruptions (quenching) at low voltage could be solved recently. Prefiring can be avoided for this special application by conditioning the switch at two times the nominal voltage after each power pulse. Quenching can be suppressed by choosing an appropriate electrode geometry and by mixing Krypton to the D_2 gas atmosphere. One remaining problem, related to the required large dynamic voltage range (1.7 kV to 30 kV) is under active investigation: steps in forward voltage during conduction, occurring at low operation voltage at irregular time instants and causing a pulse to pulse jitter of the peak current.

This paper presents results of electrical measurements concerning prefiring and quenching and explains how these problems have been solved. Furthermore the plans to cure the forward voltage step problem will be discussed.

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Abstract

CERN, the European Laboratory for Particle Physics, has started construction of the Large Hadron Collider (LHC), a superconducting accelerator that will collide protons at a center of mass energy of 14 TeV from the year 2005 onwards. The kicker magnet pulse generators of the LHC beam extraction system require fast high power switches. One possible type is the pseudospark switch (PSS) which has several advantages for this application. A PSS fulfilling most of the requirements has been developed in the past years. Two outstanding problems, prefiring at high operating voltages and sudden current interruptions (quenching) at low voltage could be solved recently. Prefiring can be avoided for this special application by conditioning the switch at two times the nominal voltage after each power pulse. Quenching can be suppressed by choosing an appropriate electrode geometry and by mixing Krypton to the D_2 gas atmosphere. One remaining problem, related to the required large dynamic voltage range (1.7 kV to 30 kV) is under active investigation: steps in forward voltage during conduction, occurring at low operation voltage at irregular time instants and causing a pulse to pulse jitter of the peak current.

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Introduction

During the last years the fast power switches for the LHC beam extraction system [1] have been the subject of intense R&D effort. Three different types of switches have been studied. Thyratrons, modified gate-turn-off thyristors (GTO's) and pseudospark switches (PSS's). Their relative merits were discussed in [2] while the development work on GTO thyristors is described in an accompanying paper at this symposium.

Switch Requirements

The basic requirements on the switch are listed in Table 1. The low spontaneous conduction rate and the large working range are particularly difficult to meet for gas switches, whereas semiconductor switches can more readily support them. For thyratrons the remedies to these requirements are vice versa exclusive. While a low spontaneous conduction rate can be achieved by employing 3-stage tubes, reliable triggering of such valves at the injection voltage of 1.5 kV is difficult. For pseudospark switches an acceptably low spontaneous conduction rate can be achieved, even for a 2-stage valve, by a special conditioning process, described below, and a large trigger range is obtained by equipping both stages of the tube with trigger systems. However, other problems, related to the fact that the PSS is a cold cathode tube, appear at low working voltage: current quenching and arc voltage steps. Remedies for these phenomena will be discussed in the corresponding chapters below.

Charging voltage range	1.7/30	kV
Peak current	+20/-10	kA
Current rate of rise	~10	kA/µs
Current conduction time	8-9	µs
Charge transfer pos./neg.	60/15	mC
Repetition time minimum	30	s
typical	5-20	h
Lifetime at peak current	10^5	pulses
Spontaneous conduction rate	$< 10^{-4}$	

Table 1

The LHC Pseudospark Switch

A cross-section of a 2-stage LHC pseudospark switch is shown in Fig. 1. A more detailed description is given in [2]. Its main technological characteristics are: a metal/ceramic construction with an incorporated D_2 gas reservoir, large stainless steel electrode chicanes for protection of the main insulator against metal vapour deposition, a ferroelectric trigger in each stage and a ring gap electrode geometry [3]. The latter replaces the usual axially aligned discharge holes. It consists of a central disc of diameter dc (6 mm ≤ dc ≤ 19 mm) separated by a coaxial annular discharge gap of 2.5 mm width from an outer ring electrode (Fig.1).

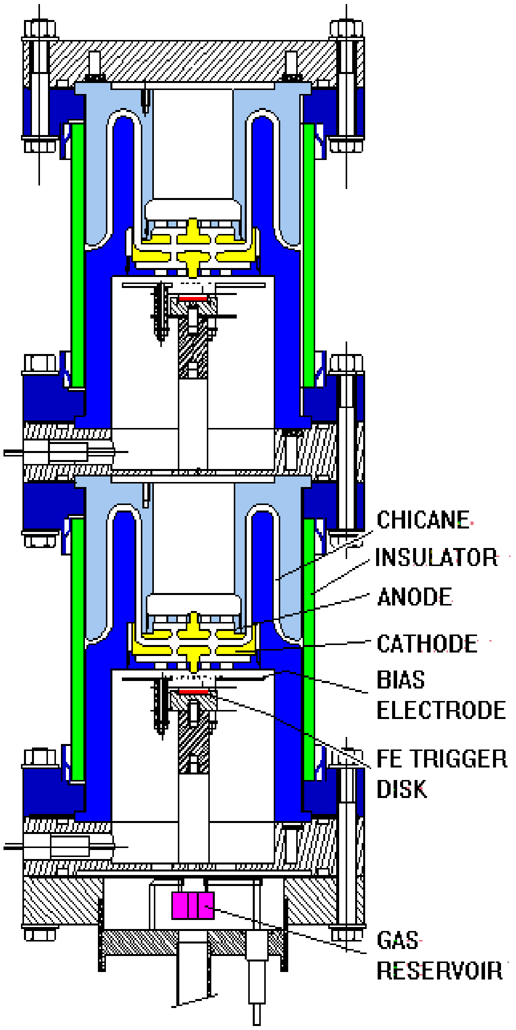

Fig. 1 Cross section of the LHC pseudo spark switch

For most of the tests described here several 1-gap versions of the switch have been used and electrode material, ring gap diameter and gas composition have been varied. For the electrode conditioning tests a 2-stage configuration as in Fig. 1 has been employed.

Electrode Conditioning

The LHC beam extraction system is composed of 2 x 14 kicker magnets, each powered by its own pulse generator. The rise of the magnetic field is synchronised with a gap of about 3 μs in the quasi continuous beam, to avoid uncontrolled deflection of particles during the kick rise. In case of spontaneous conduction of one of the switches the deflection is strong enough to kick the beam out of the vacuum chamber. Therefore in this case all systems must be powered within <500 ns to deflect the beam onto its nominal extraction trajectory. The trigger can then however no longer be synchronised with the gap in the beam and the uncontrolled deflection during the rise time may cause quenching of superconducting magnets. Spontaneous conduction of a power switch must therefore be avoided.

To improve the voltage holding an automatic program has been devised that will condition the switch electrodes after each operation cycle. The cycle consists of a 6 h to 12 h period at full energy during which the beams collide for physics experiments, preceded and followed by a period of about 20 min, one for beam acceleration, the other for deexcitation of the superconducting magnets. The beams will be dumped at the end of the physics period and the deexcitation period will then be used to automatically check the correct functioning of the dumping systems and to perform the electrode conditioning. The program starts by connecting the PSS anode to ground and the centre electrode to a high voltage source, by means of 2 computer controlled high voltage relays. For conditioning purposes each gap is equipped with 4 symmetrically distributed ceramic capacitors of 0.5 nF each, in series with a 5 Ω resistor. These components have only a negligible influence on the normal operation. Both switch gaps will then be pulsed in parallel for several minutes at high repetition rate with a progressively increased voltage up to +35 kV. The procedure is then repeated with negative polarity to condition both gaps with correct polarity. This conditioning scheme permits to test each gap at double nominal voltage without requiring an upgraded high voltage design of the pulse generator. It monitors furthermore over the years on a daily basis the reliability state of each switch gap. The results are given in Fig. 2. The switch has previously been subjected to $5*10^4$ damped oscillatory discharges of about 12 μs duration with 30 kA peak and 50 % negative overswing. The results show that for a maximum test voltage of 35/2 kV the estimated spontaneous breakdown rate is < 10^{-5} / h which is acceptable for this application.

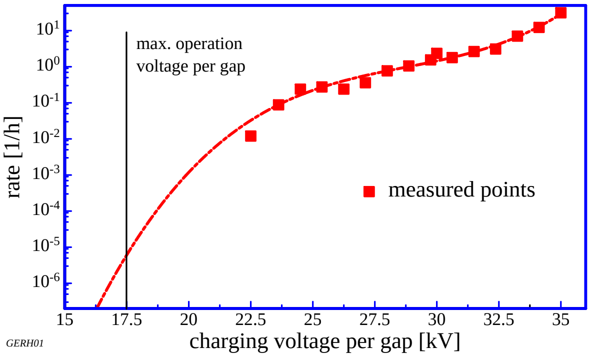

Fig. 2 Spontaneous conduction rate as function of charging voltage
(2 gap switch, dc=12 mm, W-electrodes, 25 Pa)

Suppression of Current Quenching

Current quenching is a phenomenon appearing in low pressure gas switches including thyratrons and pseudospark switches. It is characterised by a sudden downward step or even interruption of the discharge current accompanied by a large inductive spike of the gap voltage (Fig.3).

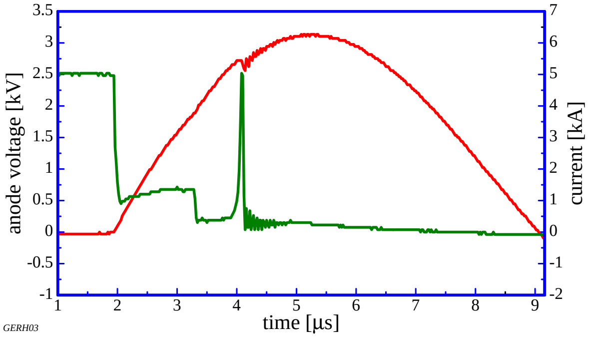

Fig. 3 Current and voltage wave forms with quenching (at t = 4 µs) and forward voltage step (at t = 3.2 µs) (dc=19 mm, SSt-electrodes, 25 Pa)

Due to the highly emissive heated cathode quenching appears in thyratrons at comparatively high values of transferred charge allowing to operate them below the quench region. To the contrary in pseudospark switches quenching occurs already at rather low transferred charge values so that one generally works above the quench region.

In the course of the development program many systematic measurements have been made to discover the parameters that determine quenching. A strong influence of gas pressure, gas species and electrode geometry could be determined whereas no dependence on electrode materials could be detected. The following Fig. 4-6 summarise the main results.

Fig. 4 shows the influence of gas pressure: The charging voltage range during which quenching appears decreases with increasing pressure. Furthermore, the voltage spikes and current steps became less pronounced at higher pressure.

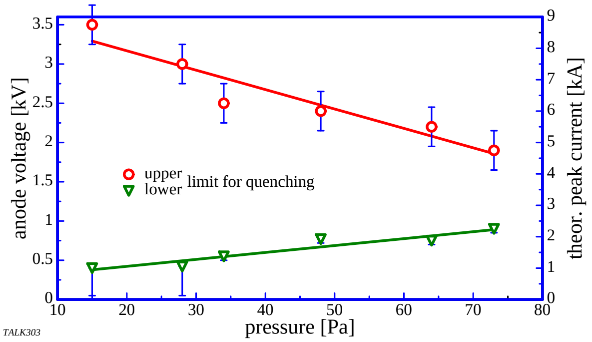

Fig. 4 Influence of gas pressure on the range of quenching (dc=6 mm, SSt-electrodes)

Fig. 5 shows the charge transferred through the switch before the system quenches as a function of charging voltage and gas pressure. The transferred charge is constant for a given pressure and electrode configuration over a wide range of peak currents and corresponding rates of current rise.

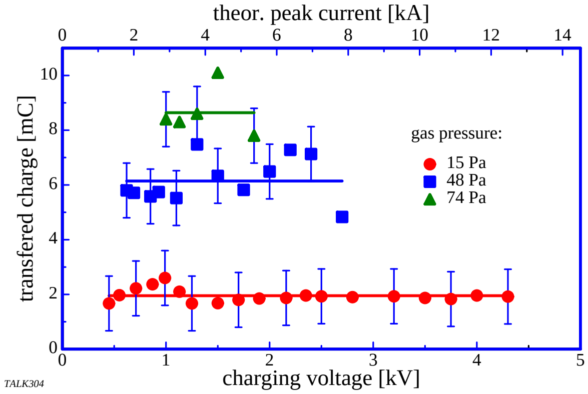

Fig. 5 Dependence of charge, transferred through the switch up to the quench instant, on charging voltage and gas pressure (dc=6 mm, SSt-electrodes)

Fig. 6 shows the influence of the electrode geometry on the quenching instant for a rather low pressure where the dependance is best visible. The smaller the ring gap diameter, the earlier is the time and the lower the charging voltage at which quenching appears. For large ring gap diameters and high pressures quenching is less pronounced and appears preferentially after the current peak during the fall of the pulse, when it can be neglected.

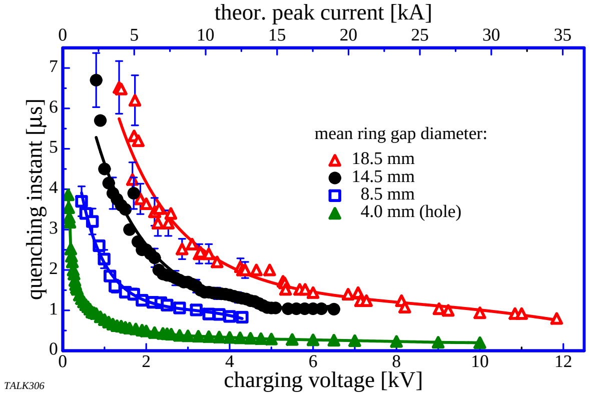

Fig. 6 Dependence of the quench instant on charging voltage and electrode geometry (SSt-electrodes, 15 Pa)

An alternative solution to this problem was triggered by the repeated observation that new tubes never quench during the first 500 to 1000 pulses. It was then concluded that heavier gases adsorbed onto the electrode surface and released by the initial discharges may suppress quenching before being absorbed by the gas reservoir. The latter is a Zr based non-evaporable getter that pumps all gases except the noble ones and hydrogen that can be released by heating. A rather heavy noble gas (Kr) was then added to the D_2 atmosphere, at a pressure ratio of about 1 to 3, with the effect that quenching disappeared completely.

The final solution to the quench problem will be a combination of both methods.

Steps in Forward Voltage

A second problem, related to the large voltage operation range, are sudden steps in forward voltage, appearing at irregular time instants at low operation voltage (see Fig. 3, at 3.2 µs). At the step instant the gap impedance drops from about 150 mΩ to about 25 mΩ and causes a jitter of the peak discharge current. Our investigations have shown that the appearance of steps cannot be influenced by the gas species or pressure. However a strong dependence on electrode material and geometry has been found. The results are given in Figs. 7 and 8.

Fig. 7 shows the electrode material dependence. We have tested W, SSt, W with 1% La_2O_3, W with 20% 4of Ca,Ba,Al_2O_3 (dispenser cathode material), and Al. It was found that the discharge current at which steps appear is smaller with lower melting temperature and work function of the material.

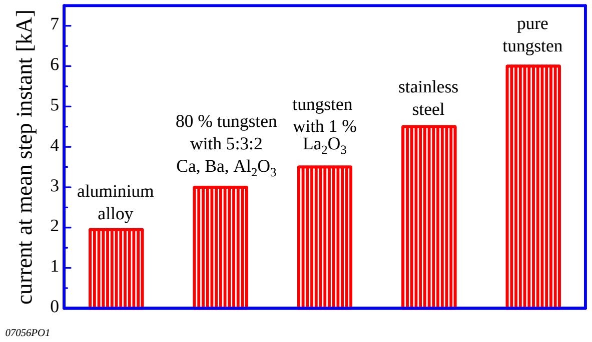

Fig. 7 Mean current at step instant for different electrode materials (dc=12 mm, 50 Pa)

The influence of the electrode geometry is given in Fig. 8. The smaller the ring gap diameter the lower is the mean current at which the steps appear. Best results are obtained with the hole geometry. Above a ring gap diameter of about 15 mm the effect becomes marginal.

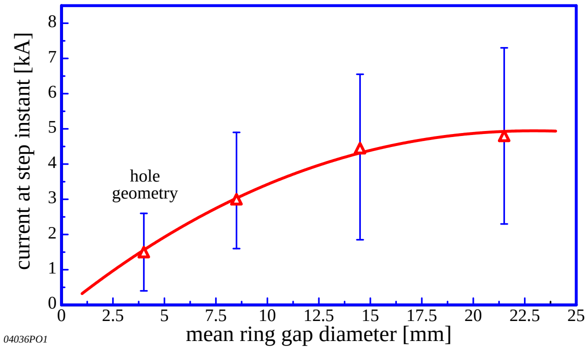

Fig. 8 Mean current at step instant for different electrode geometries (SSt-electrodes, 50 Pa)

Conclusion

Recent design modifications and a novel test procedure have improved the performances of the LHC pseudo spark switch such that nearly all performance requirements are met. In particular, the spontaneous conduction rate has been reduced to a sufficiently low level and current quenching has been suppressed. Important progress has also been made to shift the step in forward voltage below the voltage operation range. This development work is continuing. Whether a pseudospark or a solid-state switch will be chosen for the final application will be decided at the start of the design of the series equipment in 1997.

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