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HIGH POWER SEMICONDUCTOR SWITCHES IN THE 12 kV, 50 kA PULSE GENERATOR OF THE SPS BEAM DUMP KICKER SYSTEM

J. Bonthond, L. Ducimetière, P. Faure and E.B. Vossenberg

Abstract

Horizontal deflection of the beam in the dump kicker system of the CERN SPS accelerator is obtained with a series of fast pulsed magnets. The high current pulses of 50 kA per magnet are generated with capacitor discharge type generators which, combined with a resistive free-wheel diode circuit, deliver a critically damped half-sine current with a rise-time of 25 μs. Each generator consists of two 25 kA units, connected in parallel to a magnet via a low inductance transmission line.

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Horizontal deflection of the beam in the dump kicker system of the CERN SPS accelerator is obtained with a series of fast pulsed magnets. The high current pulses of 50 kA per magnet are generated with capacitor discharge type generators which, combined with a resistive free-wheel diode circuit, deliver a critically damped half-sine current with a rise-time of 25 µs. Each generator consists of two 25 kA units, connected in parallel to a magnet via a low inductance transmission line.

Originally the pulse generators were equipped with ignitron switches. Unfortunately ignitron switches suffer sporadically from self-firing. In addition these mercury filled devices present a serious danger of environmental pollution in case of an accident.

Since the development of new power semiconductor devices now offers an alternative, replacement of the ignitron switches was decided. A suitable semiconductor switch was developed with the same dimensions as the ignitron and compatible with its trigger unit. It consists of a stack of four Fast High Current Thyristor (FHCT) devices with snubber capacitors, a voltage divider and a specially designed trigger transformer.

This paper gives a description of the circuit and the construction of the switches, together with measurement results, which were found to be in good agreement with simulation results.

I. INTRODUCTION

The SPS Beam Dump kicker system is composed of a series of vertical deflection magnets (MKDV), a series of horizontal deflection magnets (MKDH) and a set of absorber blocks (TIDV, TIDH) (ref. 1).

The high current pulses for the MKDH magnets are generated with capacitor discharge type generators which, combined with a resistive free-wheel diode circuit, deliver a critically damped half-sine current pulse with a rise-time of 25 µs.

Each generator is composed of two 25 kA units, connected in parallel to a magnet via low inductance transmission lines. The maximum operating voltage is 12 kV, the pulse repetition rate is ≥ 5 s and the dissipated energy per switch is approx. 150 J per discharge at 12 kV.

II. BASIC CIRCUIT DESCRIPTION

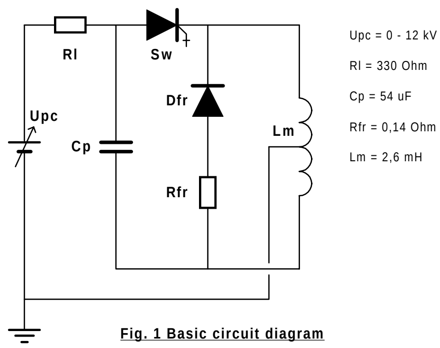

Fig. 1 Basic circuit diagram

As is shown in fig. 1, Capacitor C_p is charged to a positive voltage with a regulated DC power converter U_{pc}, via resistor R_l.

The first phase of the magnet pulse starts at the moment switch Sw is closed and a current I_m starts to flow from capacitor C_p into the magnet L_m. Due to the polarity of the free-wheel diode D_{fr}, during this phase no current can flow into the freewheel circuit D_{fr}, R_{fr}.

The magnet current is a damped sine wave: $I_m(t) = \frac{e^{-\delta t}}{\sqrt{1-\xi^2}} \cdot \frac{U_0}{Z_0} \cdot \sin \omega t$

with $\delta = \frac{R_m}{2L_m}$, $\xi = \frac{R_m}{2Z_0}$, $Z_0 = \sqrt{\frac{L_m}{C_p}}$ and

$\omega \cong \omega_0 = \sqrt{\frac{1}{L_m C_p}}$ $\rightarrow \tau_0 \approx 105$ µs (ref. 5).

Operation of MKDH requires deflection of the beam only during the first quarter of the sine wave. At $\tau_0/4$ the factor $e^{-\delta t} \approx$ 0,995 can therefore be neglected. The output current is damped after the first maximum when the magnet voltage U_m changes polarity and becomes negative.

The second phase starts at the moment the current from the capacitor into the magnet is interrupted. The magnet voltage U_m changes polarity and the free-wheel diode D_{fr} starts to conduct. From that moment on $I_m(t)$ decays with a time constant: $t_d \approx \frac{L_m}{R_{fr}}$.

III. GENERATOR DEVELOPMENT

In order to limit the voltage the insulation of the magnet winding has to withstand, a design with two symmetrical half-windings and a grounded centre connection has been chosen (ref. 2). In order to limit transient over-voltages, mainly due to cable reflections, each half-winding is protected with a RC filter (R_m, C_m in fig. 2).

Originally the units were equipped with water-cooled, high-density graphite anode ignitrons, type National™ NL488A, capable of operation with a peak anode voltage of 25 kV. As mentioned above, at the start of the second phase the voltage changes polarity and becomes negative. Because at that moment the ignitron has not yet completely recovered, the reverse magnet decay current partially flows through the switch. Due to their limited reverse current capability the ignitrons had a rather poor lifetime

As a first improvement around 1986 the generator was split into two separate identical units, allowing the switch in each unit to conduct only half of the reverse current. In addition, such a design presents an important improvement in the operational safety of the MKDH system. In case of failure of a unit, the magnet current is reduced by 50% only. In 1991 further improvement was possible when power diodes with the required high ratings became available. Each switch was equipped with a series diode, thus blocking the reverse current entirely. The result of this modification was a doubling in lifetime of the ignitrons. The latest upgrading in the design was the replacement of the ignitrons by semiconductor switches, described in the next chapter. Of course, the absence of self-firing in semiconductor switches is another important improvement in operational safety.

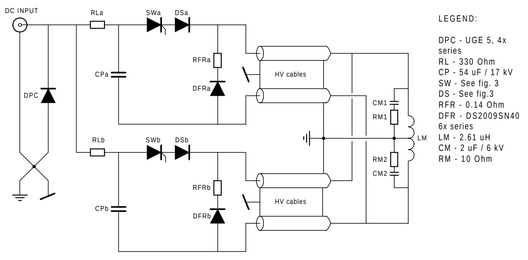

Fig. 2 : Circuit Diagram - MKDH Pulse Generator Power Part

Fig. 2 shows the simplified circuit diagram of a double unit generator. Safety devices and measurement facilities are not shown.

IV. THE SEMICONDUCTOR SWITCH

Asymmetrical FHCT's have been chosen as switching devices. Because the required DC voltage holding level cannot be obtained with a single device, a stack of four FHCT's was mounted in series, thereby keeping the voltage per device well within the rated values. In order to reduce both stray inductances and radiation of electrical noise, the stack is constructed as much as possible as a coaxial assembly.

The circuit diagram of the semiconductor switch in fig. 3 shows the FHCT stack with its snubber capacitors, voltage sharing divider and trigger transformer. Of coarse, such a stack requires a trigger transformer with four separate outputs.

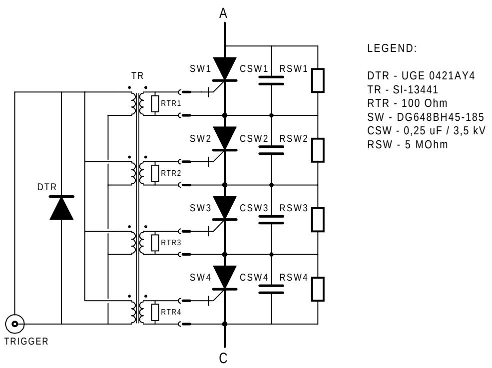

Fig. 3 : Circuit Diagram - MKDH Semiconductor Switch

The original capacitor discharge trigger unit, designed for the ignitrons, delivers a pulse of 2400 V peak, with a rise time of < 1.5 μs and a pulse width of ≈ 50 μs.

In order to obtain a slightly higher dI/dt on the secondary side (factor 1.25), the trigger transformer was designed with a ratio of 5:1. The secondary windings (≈ 400 V peak) of the transformer are floating and the insulation voltage between primary and secondary windings is 20 kV. Identical coupling between the primary side of the transformer and each floating secondary winding being required, the primary is divided into four separate windings, connected in parallel, with each primary winding coupled to one of the secondary windings.

The conduction of a FHCT is determined mainly by three parameters:

- The first and most important parameter is the dI/dt of the gate current. During tests, described in refs. 3 and 4, it was found that in this kind of application the dI/dt of the gate current has to be ≥ 160 A/μs. The corresponding dI/dt at the primary of the trigger transformer is ≥ 130 A/μs. As mentioned above, the output voltage of the original trigger unit is 2400 V. Thus, for a gate current dI/dt of ≥ 130 A/μs, the total inductance has to be ≤ 18.5 μH ($U = L\frac{dI}{dt}$). The inductance of the 18 m trigger cable being ≈ 5 μH, the stray inductance of the trigger transformer for this parameter had to be ≤ 13.5 μH.
- The second parameter is the amplitude of the gate current. For this parameter the tests described in refs. 3 and 4 have shown that the optimum amplitude is ≈ 180 A. This corresponds to a primary current amplitude of 150 A. Therefore, the impedance of the trigger circuit ($Z = \sqrt{R^2 + \frac{L}{C}}$), seen from the primary side of the transformer, has to be ≤ 16 Ω.

The trigger unit has a current limiting resistor of 6.75 Ω and the total gate-cathode resistance of the four FHCT's, referred to the primary side, is ≈ 0.35 Ω.

Thus the total resistance in the trigger discharge circuit is 7.1 Ω.

Operation with the optimised transformer at minimum trigger energy allowed the reduction of the capacitor in the trigger unit from 470 nF to 100 nF while still generating a sufficiently high gate current. Thus, for this parameter the maximum allowable total stray inductance is 20 μH. As mentioned above, the cable inductance being ≈ 5 μH, the maximum allowable stray inductance of the transformer for this parameter is 15 μH.

- The third parameter is the gate pulse duration. The conduction time of the switch is about 50 μs, during which the gate current has to remain ≥ 50A. Therefore a free-wheel diode is introduced on the primary side of the transformer. A time constant ($\tau = \frac{L}{R}$) of 25 μs for the free-wheel current proved to be sufficient. The total resistance in the free-wheel circuit being 0.4 Ω, for the third parameter the minimum allowable stray inductance is 10 μH.

As a result of the above-explained considerations, the final value specified for the stray inductance of the transformer is 10 μH.

V. MEASUREMENT RESULTS

Good agreement is obtained between measurement and simulation results. In addition, both agree well with the circuit calculations.

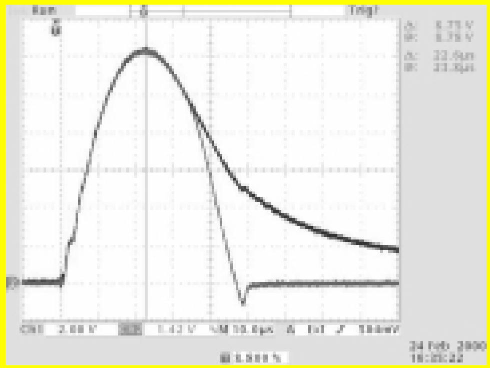

Fig. 4. Magnet and Switch current @ 11 kV, 4 kA/μs, 25 kA peak.

VI. OPERATIONAL EXPERIENCE

Two switches operated in the SPS for more than a year without any failure. Thereafter the four remaining ignitrons were replaced recently.

References:

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