UPGRADE OF THE SUPER PROTON SYNCHROTRON VERTICAL BEAM DUMP SYSTEM

V. Senaj, L. Ducimetière, E. Vossenberg, CERN, Geneva, Switzerland

Abstract

The vertical beam dump system of the CERN Super Proton Synchrotron (SPS) uses two matched magnets with an impedance of 2 Ω and a combined kick strength of 1.152 Tm at 60 kV supply voltage. For historical reasons the two magnets are powered from three 3 Ω pulse forming networks (PFN) through three thyratron-ignitron switches. Recently flashovers were observed at the entry of one of the magnets, which lead, because of the electrical coupling between the kickers, to a simultaneous breakdown of the pulse in both magnets. To improve the reliability an upgrade of the system was started. In a first step the radii of surfaces at the entry of the weak magnet were increased, and the PFN voltage was reduced by 4%; the kick strength could be preserved by reducing the magnet termination resistance by 10 %. The PFNs were protected against negative voltage reflections and their last cell was optimised. In a second step the two magnets will be electrically separated and powered individually by new 2 Ω PFNs with semiconductor switches.

INTRODUCTION

The vertical beam dump system of the CERN SPS consists of two kicker magnets MKDV1 and MKDV2 with a vertical aperture of 56 mm, and a horizontal aperture of 75 and 83 mm, respectively [1]. The magnets are of delay line type with 5 cells and characteristic impedance of 2.135 Ω and 2.080 Ω, respectively, and are terminated by matched resistors (TMR). The combined kick strength is 1.152 Tm at 60 kV supply voltage, which correspond to a pulse of 15 kA in each magnet for a duration of 25 µs. The field kick rise time is less than 1.1 µs, and the flattop has 5 undulations of roughly ±15 %. These undulations, combined with a horizontal dump system producing a sweep, ensure a dilution of the energy deposition over the dump block.

The two magnets are powered from three generators consisting each of a 3 Ω pulse forming network (PFN) and a power switch. The power switch is a parallel arrangement of a three-gap thyratron with three series-connected ignitrons. The thyratron ensures a precise switching and fast rise time of the pulse, while the ignitrons conduct the bulk of the current. A total of 48 coaxial cables type RG220U connect the three power switches to the two magnets, i.e. 16 per switch and 24 per magnet - see Fig 1.

Following recent problems an upgrade program has been started. In a first phase the present system has been made safer by improvements of the magnets and generators, which are described in this paper. In a second phase two new PFN's and switches will be built, and connected independently to each magnet.

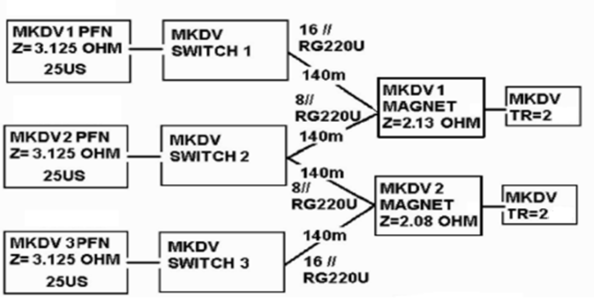

Figure 1: Principal schematic of the MKDV system connections.

PRESENT LIMITATIONS OF THE SYSTEM

Voltage Holding and Consequences

In 2006 flashovers occurred in the MKDV1 magnet leading to fast degradation of its voltage holding capability [2]. Such flashovers in one of the magnets short-circuit all three PFNs pulses because of the common cabling, which could have bad consequences for the accelerator. Full pulse reflection from the short-circuit is also potentially harmful for the generators. At the end of 2006 up to one flashover occurred per week at the nominal PFN voltage of 52 kV. The resulting damage to the magnet is shown in Fig 2.

Figure 2: Traces of the arcs on the HV plate at the entry of the MKDV1 magnet.

In order to reduce the sparking frequency the maximum PFN operating voltage was limited to 49 kV – a value still sufficient to deflect the kicked beam onto the surface of the dump block; this measure allowed to temporary continue the operation.

Beam Related Limitation

In the past significant magnet heating and outgassing, for particular beam filling patterns, were observed [3]. The fast outgassing effects are attributed to an electron cloud while the slower temperature rise is a result of heating due to the beam coupling impedance of the magnet. Since the vertical distance between the magnet current conductors is relatively small (56 mm), the main impedance contribution comes from the entry and exit gaps between the beam pipe and the magnet itself. Measurements of the beam coupling impedance showed several local maxima in the frequency spectrum of the real longitudinal impedance which can lead to significant heating. These local maxima are suppressed when transition pieces are installed.

MECHANICAL UPGRADE OF THE MAGNET

Mechanical upgrades consisted of two families of modifications, which have been implemented during the overhaul of the MKDV1 magnet.

Voltage Holding Improvement

The first urgent modifications consisted of restoring / improving the voltage holding. The electrostatic field intensity in the vicinity of the magnet HV region where arcing appeared (Fig. 2) has been reduced by increasing the radii of all metallic parts.

Beam Related Upgrades

The second type of modifications was aimed at reducing the beam coupling impedance. Transition pieces have been added between the flange of the vacuum tank and the magnet frame on both extremities of the magnet in order to provide a path for the beam image current, and to avoid resonances in the free gap. That reduces magnet heating and therefore outgassing.

In order to improve the analysis and diagnostic of beam induced heating, temperature sensors were placed close to a ceramic spacer which supports the magnet ferrite blocks. They allow a reliable and accurate monitoring of the magnet ferrite temperature.

GENERATOR UPGRADE

The electrical upgrade of the generators comprised two families of modifications as well.

Protection Against Negative Reflections

The first one was aimed at protecting the PFN capacitors against polarity reversal in case of magnet flashover and associated reflections. A negative polarity protection circuit, consisting of a stack of diodes and a power resistor, has been added on the PFN end opposite to the switch. The diode stack is made of 7 multi-chip diodes (5SDA27Z1350 made by ABB), each containing 6 wafers and rated for 12 kV. The power resistance is a stack of 5 disks of type HVR AB43093M006, 0R10. The value of 0.5 Ω has been chosen as a compromise between minimizing the value of reverse voltage and good absorption of the waveform reflected from the short-circuit.

Reduction of the Voltage Applied to the Magnet

The second set of modifications included modifications of the TMR value and PFN with the goal to reduce the magnet entry cell voltage while maintaining the kick strength and rise time.

Measurements of the magnet input voltage and TMR current, for the original 2 Ω TMR value and the PFN charged to 30 kV (voltage given by a HV probe limitation) are shown in Fig 3. The measurement shows that a peak magnet input voltage of 17.53 kV appears during the second undulation, while the first one, which influences the magnet current rise time, is visibly lower and can hence be optimised.

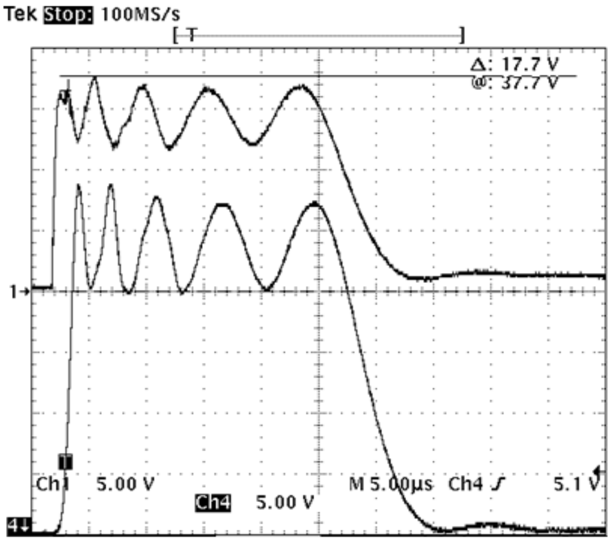

Figure 3: Magnet entry voltage (Ch1, 5 kV/div) and TMR current (Ch4, ~1.5 kA/div) with PFN charged to 30 kV.

The PFN voltage has been reduced, to obtain a safety margin, by slightly reducing (mismatching) the TMR value while maintaining the same nominal current. The extreme solution would be operation of the magnets in short-circuit mode, but in this case the two-way propagation delay through the magnet is too long to achieve the required kick rise time – in our case below 1.1 µs. PSpice simulations showed that an acceptable compromise can be obtained by reducing the TMR value by approximately 10 %, to 1.8 Ω. A minor re-adjustment of the PFN's was found necessary to keep the rise time within specification. The result of a simulation of the magnet input voltage, TMR current and kick strength before modifications, for a PFN voltage of 30 kV, is shown in Fig 4.

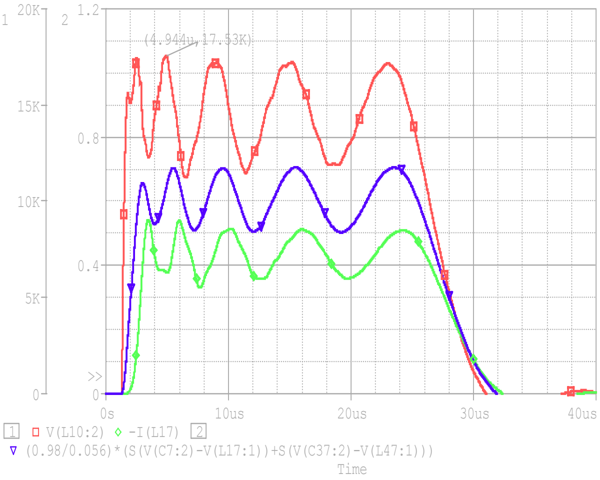

Figure 4: Simulation of the magnet voltage (red), TMR current (green) and kick strength (blue) with PFN charged to 30 kV.

Figure 5 shows the results of PSpice simulations for the TMR value of 1.8 Ω, with the PFN voltage reduced from 30 kV to 28.5 kV. To obtain the same kick rise time the first cell of the PFN has been optimized.

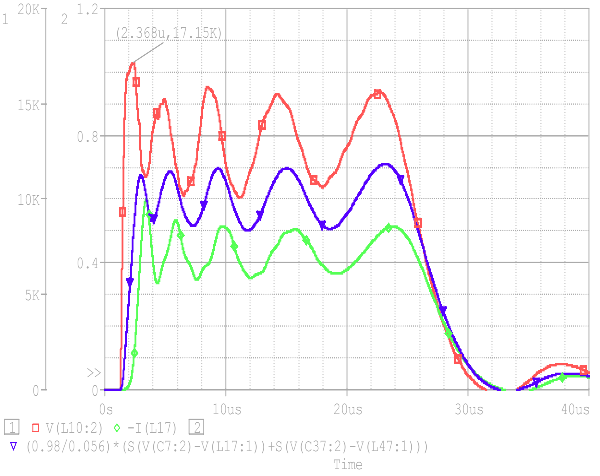

Figure 5: Simulation of the magnet voltage (red), TMR current (green) and kick strength (blue) with above mentioned modifications and PFN charged to 28.5 kV.

At the same time the magnet peak input voltage was slightly reduced for the first undulation (-0.3 kV), in comparison with the situation before modifications, prior to beam (i.e. during the kick rise time). In addition the magnet peak input voltage is reduced significantly (-1.7 kV), in comparison with the situation before modifications, for later undulations, during which beam is present.

The simulated modifications have been implemented. The original TMR consisted of 10 disc resistors of 0.2 Ω each; the modification consisted of replacing one of the disc resistors by a brass disc with the same dimensions. The PFN first cell optimisation consisted of reducing its inductance by approximately 40%.

The beam dump tracking function, controlling the PFN voltage as a function of the beam energy, was modified in such a way that the PFN voltage was reduced by 4 % (instead of the theoreticaly possible 5 %) in order to gain back same safety margin in the beam position on the beam block.

The result of a measurement on the MKDV1 magnet, after all described modifications is shown in Fig 6.

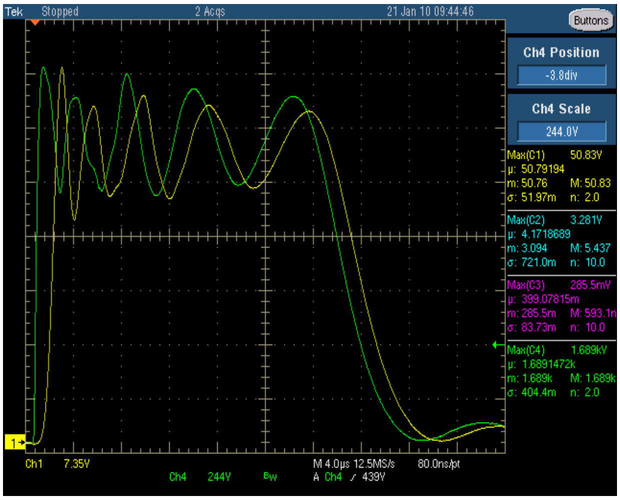

Figure 6: MKDV1 magnet entry voltage (Ch4, ~2.5 kV/div) and TMR current (Ch1, ~1.5 kA/div) following the modifications.

CONCLUSION AND OUTLOOKS

The first phase of the planned modifications has been successfully implemented. The measured waveforms of the magnet input voltage and terminating resistor current agree quite well to the simulated ones. During over one year of operation no further magnet flashovers were observed. The next phase will consist of a complete separation of the two magnets and replacement of the composite thyratron-ignitron switches by solid-state switches.

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