EXPERIENCE WITH KICKER BEAM COUPLING REDUCTION TECHNIQUES

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Abstract

SPS beam impedance is still one of the worries for operation with nominal LHC beam over longer periods, once the final configuration will be installed in 2006. Several CERN SPS kickers suffer from significant beam induced ferrite heating. In specific cases, for instance beam scrubbing, the temperature of certain ferrite yokes went beyond the Curie point. Several retrofit impedance reduction techniques have been investigated theoretically and with practical tests. We report on experience gained during the 2004 SPS operation with resistively coated ceramic inserts in terms of kicker heating, pulse rise time, operating voltage, and vacuum behaviour. For another technique using interleaved metallic stripes we observed significant improvements in bench measurements. Advantages and drawbacks of both methods and potential combinations of them are discussed and simulation as well as measured data are shown. Prospects for further improvements beyond 2006 are briefly outlined.

INTRODUCTION

The fast extraction kickers (MKE), as used until 2000 in the CERN Super Proton Synchrotron (SPS), have been modernised to meet the Large Hadron Collider (LHC) and CERN Neutrinos to Gran Sasso (CNGS) specifications. Five kicker magnets have been installed in the Long Straight Section 4 (LSS4) and 4 more are presently under construction for LSS6 [1-5]. Their beam impedance could present limitations to the SPS operation and therefore, indirectly, to that of the LHC [6].

The SPS kickers use low impedance travelling wave magnets and generators. Their essential present limitations are the ferrite Curie temperature for beam induced losses and the beam impedance in view of the beam stability. Current efforts to improve their performance are focused on better heat conductance cooling and beam impedance reduction.

IMPLEMENTED UPGRADES

Extraction Kicker Cooling

During CNGS operation or prolonged periods with intense LHC type beam (e.g. scrubbing) the SPS extraction kickers will be exposed to a much larger beam induced thermal power resulting in significant ferrite heating. Heat evacuation through high conductivity AlN plates in the high electric field regions and subsequent water cooling have been added to the LSS4 extraction kickers while *PT100* temperature sensors provide an interlock signal to prevent equipment damage and irreversible loss of performance. Experimental data have been reported elsewhere [4, 5, 7].

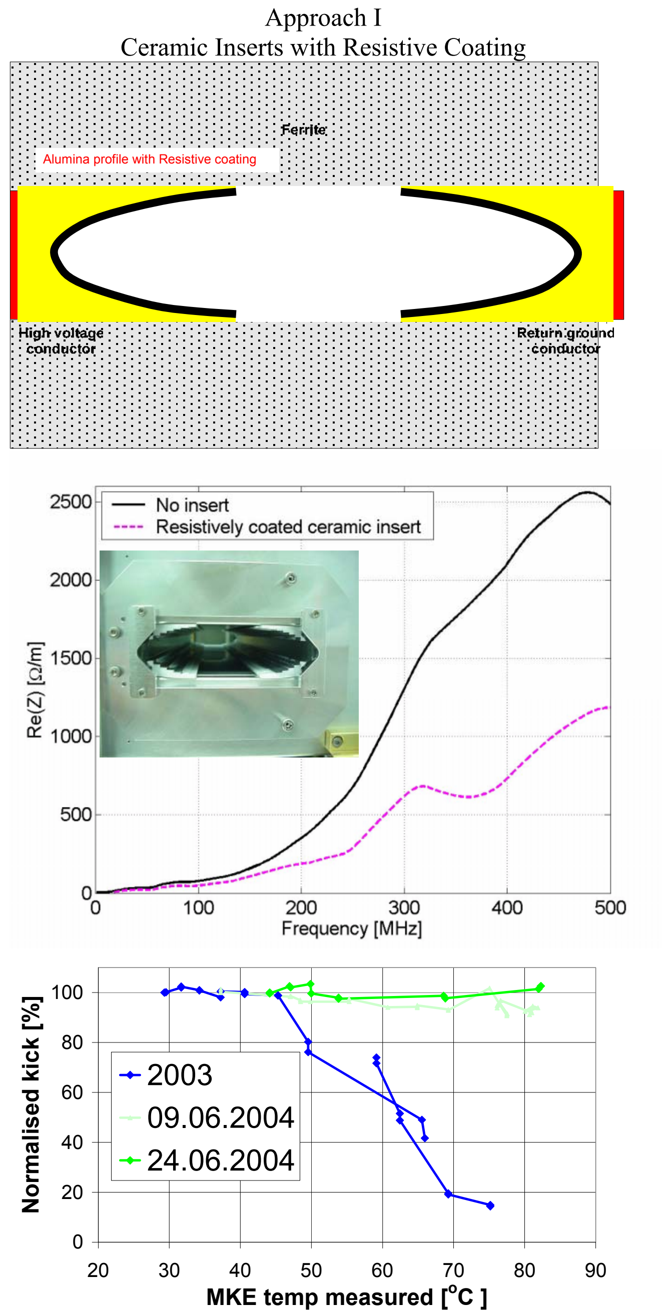

Figure 1: (Top) The modified MKQH kicker magnet: Beam gap with mounted ceramic inserts with resistive coating to reduce beam impedance and kicker ferrite heating. (Middle) MKQH longitudinal impedance (traces smoothed) measured using the wire method. (Bottom) SPS MKQH kicker heating: relative kick strength reduction as a function of the measured MKE probe temperature.

Tune Kicker Impedance Reduction

The SPS horizontal tune kicker MKQH was used as test bench for a beam impedance reduction technique. In 2003, before the modifications, it was heating beyond its operational Curie temperature during beam scrubbing and machine development studies [4, 5].

A simulation model of the MKQH kicker was used to calculate wakes and estimate kicker impedances; we compared two setups, (1) uncoated ceramics and (2) a perfect conductor in place of the ceramics. The model showed that bypasses on ceramics could reduce the longitudinal (inductive) impedance by a factor of 4 [8].

Table 1: Results of MKQH kicker magnet modifications.

	2003	2004
Kick rise time 10-90% [μs]	0.5	2.9
T^*_{Curie} reached at $T_{MKE, reference}$ [°C]	45	>90

The magnet was equipped with two resistively coated ceramic inserts ($R_{d.c.}$=10 Ω) (see Figure 1 top). Kick and beam impedance measurements were made on the non-modified and modified kicker [8]. In 2004, measurements in the SPS revealed a strong reduction in kicker heating as compared to the situation in 2003. No significant kick strength reduction – indicating a heating beyond the Curie temperature – was any more observed (Fig.1 bottom, Table 1), for MKE sensor temperatures up to 90 °C (the MKE temperature served as reference since the MKQH is itself not equipped with a sensor). However, along with this improvement, the kick rise time increased and the maximum hold-off voltage decreased significantly [8]. While this is not of great concern for the operation of the MKQH it means that this approach is not directly applicable to other SPS kickers where the requirement on field rise or fall time or the kick strength, but also on available beam aperture, can not be relaxed.

FURTHER DEVELOPMENTS

Extraction Kicker Impedance Reduction

Two different approaches (II, III in Fig. 2) were studied in laboratory setups to reduce the beam impedance of the MKE kickers.

For approach II 2 mm wide fingers were placed on each side of 1.3 mm thick alumina plates with 1 mm spacing and connected at each side to the subsequent high voltage plates of the kicker magnet cells. A clearing distance of 5 mm on the sides, respectively 20 mm at the far ends, is respected to prevent electrical field breakdowns.

For approach III 2 mm wide by 30 μm thick fingers have been directly "printed" on the ferrites (or alternatively 200 μm painted) which are connected at each side to the subsequent high voltage plate of the kicker magnet cells, with a 20 mm clearing distance in between and at the far ends. The resulting measured capacitance between each cell side was 30 pF, the stored electrical energy thereby being 2.7 mJ per stripe. The resulting estimated stripe temperature rise induced by the "kick field" would be 9

Figure 2: (Top) Approach II: Alumina plates with metallic finger strips. (Middle) Approach III.: Stripes printed directly on ferrites. (Bottom) Longitudinal

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impedance of a one-cell kicker unit measured using the wire method.

K, respectively 190 K due to beam image currents, under the assumption of a 6.5 A CNGS beam current (well below the melting point of the strip material Ag), in which we assumed all heat is evacuated to the extremities by heat conduction through the metal.

The longitudinal impedance for a one-cell kicker setup, with the same shape as one of the seven cells of an MKE kicker, was evaluated by wire measurements which earlier showed reliable results with respect to heating issues and with the advantage that the electromagnetic wave is confined to the kicker gap [8]. Thus, parasitic effects such as cavity modes between the ferrite module and the tank are not present. The beam spectrum frequency range to be considered here is 200 - 600 MHz. Below 200 MHz the longitudinal impedance reduction by inserts is not very significant, since most of the image current runs on the outside kicker tank. For higher frequencies a considerable impedance reduction is observed with inserts in place (6 dB attenuation for approach I and even up to 20 dB for II and III). The ferrites on top and bottom form a magnetic wall and literally push the beam induced electric (and magnetic) field sideways to the "hot" and "cold" conductor. Thus we get a transverse field distribution far away from the usually expected TEM-like case, thereby enhancing the desired bypass effect.

After these first tests and measurements one of the 4 MKE kickers for LSS6 has been equipped on 2 of its 7 cells with printed stripes, to assess the high voltage behaviour under vacuum and the pulse shape in a full scale travelling wave kicker setup. So far d.c. conditioning of this magnet has been successful up to 25kV operational voltage. If the tests continue to be conclusive it is planned to equip like this all 7 cells of this magnet and to install it in the machine. If the beam tests in LSS6 foreseen for 2006 will give overall positive results, other MKE magnets could be equipped like this from 2007 onwards. However, a severe test programme concerning kick field rise time as well as high voltage and vacuum behaviour must be successfully passed in the laboratory before a large scale SPS installation can be envisaged.

SUMMARY

Useful experience has been and is being gained in terms of impedance reduction of existing SPS kickers. The diagnostics added recently has been very helpful in this process, confirming the positive impact of various equipment upgrade actions in the framework of the improvement of the SPS as LHC injector.

The beam coupling reduction technique applied to the horizontal tune kicker magnet has proven successful and served as test-bed, providing experimental confirmation for results obtained in simulations. In addition it has lifted the limitations related to this particular device Further studies are ongoing, using metallic interleaved comb structures on ceramic plates or stripes directly printed on ferrites, to assess the applicability of such methods to other SPS kicker systems with more stringent requirements. Simulations and beam impedance measurements using the wire method let expect a significant reduction in impedance over the relevant frequency range. More development work and a thorough test programme are needed to evaluate and optimise issues like hold-off voltage, out-gassing and kick field rise time.

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