A RETROFIT TECHNIQUE FOR KICKER BEAM-COUPLING IMPEDANCE REDUCTION

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Abstract

The reduction of the impedance of operational ferrite kicker structures may be desirable in order to avoid rebuilding such a device. Often resistively coated ceramic plates or tubes are installed for this purpose but at the expense of available aperture. Ceramic U-shaped profiles with a resistive coating fitting between the ellipse of the beam and the rectangular kicker aperture have been used to significantly reduce the impedance of the magnet, while having a limited effect on the available physical aperture. Details of this method, constraints, measurements and simulation results as well as practical aspects are presented and discussed.

INTRODUCTION

The SPS (Super Proton Synchrotron) MKQH (horizontal tune measurement) kicker [1] served as a test bed for an unconventional impedance reduction technique. Indications that the SPS MKQH tune kicker was heating significantly had been found during the SPS 2003 beam scrubbing run and other machine development studies [2, 3]. This kicker is running in a travelling wave mode with up to 25 kV rectangular pulses. Details of the kicker generator and magnet as well as operating parameters can be found in [1]. This kicker is particularly well suited for such an experiment, since certain alterations of performance specifications, such as an increase in rise-time or reduction in kick strength are not too critical for SPS operation.

IMPLEMENTATION OF MKQH MODIFICATIONS

Engineering Design Work

The design work on the modifications of the MKQH kicker started in November 2003 mainly based on wire method simulations [4] and led to a final design in February 2004 as illustrated in Figure 1. The MKQH magnet has been equipped with two ceramic inserts (type AL300 from Wesgo, Erlangen, Germany) approaching closely the ellipse of the beam boundary. A resistive layer using the Heraeus thick-film paste R490H which has a nominal surface resistance of $R = 1\ \Omega\cdot m^{-2}$ is applied to the “inner” surface of these ceramic inserts. The thick film paste is designed to stand high peak voltages (normally used for surge suppression circuits) and is also fairly insensitive to extended firing times (100 °/hour heating and cooling, with a peak at 850 °C). The measured DC resistance of each insert was about 10 Ω.

Production

Subsequent production and installation into the existing MKQH tune kicker enabled measurements to be taken during the early SPS 2004 run.

Figure 1: The modified MKQH kicker magnet: Beam gap with mounted ceramic inserts with resistive layer coating to reduce beam impedance and kicker ferrite heating.

MKQH MEASUREMENTS

Reference measurements

An inductive probe was used to enable a detailed measurement of the magnetic field pulse in the laboratory [5].

Beam impedance wire method reference measurements and inductive probe magnetic field kick reference measurements were done on the existing non-modified MKQH tune kicker magnet (see Fig. 2). The availability of SPS machine measurement data from the SPS 2003 run [2] was very beneficial.

The 6.25 Ω MKQH kicker was tested in the available 10 Ω MKE (extraction kicker magnet) generator system laboratory installation. The results obtained were evaluated using PSpice simulations.

High voltage laboratory measurements and tests

The 10 to 90 % kick field rise time was found to increase from 0.5 μs before to 1.4 μs after insertion of the coated ceramics (see Fig. 2 for a comparison of the measured MKQH kicker pulse characteristics before and after the modifications).

Useful D.C. conditioning of the modified MKQH magnet turned out to be impossible due to conductivity loss currents related to the resistive layers and ceramic inserts.

High voltage pulse tests were performed up to 25 kV. After some days the hold-off voltage characteristics slowly improved. No significant breakdowns were observed up to 20 kV. At 25 kV some breakdowns occurred for longer kick pulse lengths. The modified MKQH magnet successfully passed the laboratory tests.

SPS machine reinstallation and tests

The modified MKQH magnet was reinstalled in the SPS tunnel, aligned and vacuum pumped. Subsequent SPS machine high voltage commissioning without beam of the modified SPS LSS1 (Long Straight Section) MKQH kicker magnet with various kick pulse lengths and kick strengths was done during the SPS cold check-out.

A reduction in the maximum hold-off voltage (14 kV) was observed for long kick pulse lengths (> 10 μs).

SPS machine measurements with beam

Measurements with beam in the SPS have revealed a strong reduction of heating as compared to last year's situation. The diagnostics is not straightforward, since no (direct) temperature probes are available on the MKQH magnet. Thus, only the Curie point related kick strength reduction as a function of the MKE reference temperature is measurable. No significant kick strength reduction could be demonstrated for sensor temperatures up to 90 °C. This limit was reached at 45 °C before implementation of the MKQH modifications [2]. In short, so far the Curie point temperature has not been reached in the MKQH magnet this year in the SPS, while other kickers already exceeded this value.

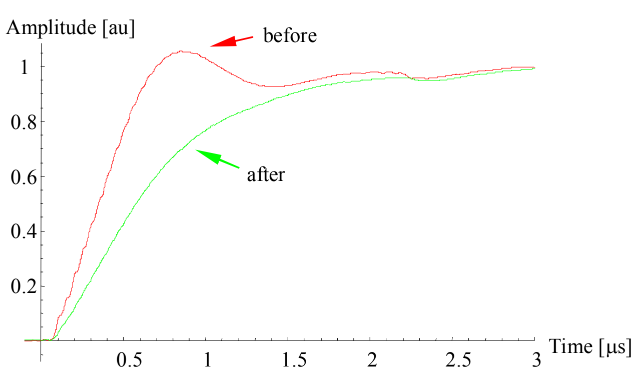

Figure 2: Measured MKQH kicker pulse characteristics

before modification: $t_{r,10-90\%} = 0.5$ μs

and after the modification: $t_{r,10-90\%} = 1.4$ μs.

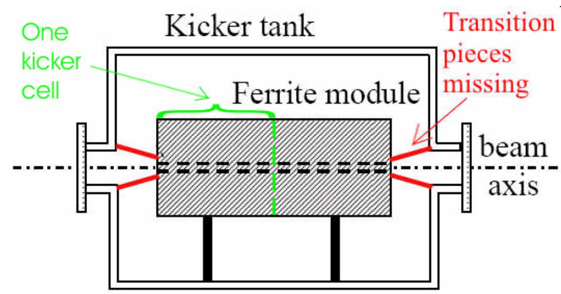

Figure 3: Longitudinal cut of the MKQH kicker. The ferrite module comprises two cells. Note that the cone-shaped transition pieces are not installed in the kicker.

IMPEDANCE MEASUREMENTS

The longitudinal impedance of the MKQH kicker was evaluated in various stages of the project by wire measurements. The most reliable results with respect to the heating issues were found in measurements on a one cell mock-up, representing one of the two cells of the MKQH kicker as sketched in Figure 3. The advantage of this kind of measurements stems from the fact that the electromagnetic wave is confined to the kicker gap. Thus, parasitic effects such as cavity modes between the ferrite module and the tank can be ruled out.

The results are discussed in [4]. It was demonstrated that a considerable reduction of the real part of the impedance is possible by installation of an additional RF by-pass.

Measurements on the entire kicker

Figure 4 shows the longitudinal impedance as calculated from the measurement results. The curves were smoothed in order to get rid of the superimposed ripple and resonance peaks. Below 200 MHz the improvement by the insert is not very significant, since most of the image current runs on the outside kicker tank. For higher frequencies a considerable drop in impedance is observed with the inserts in place. The absence of the transition cones has several simultaneous effects. For lower frequencies (< 200 MHz) a certain amount of image current passes over the inner surface of the kicker tank; however for higher frequencies (> 500 MHz) cavity resonances appear and limit the range of validity of the wire method. This is due to electromagnetic waves running between the ferrite module and the kicker tank. It is shown elsewhere [6] that transition pieces as sketched in Figure 3 would not only make wire measurements easier but also decrease the impedance of the entire device.

IMPEDANCE CALCULATIONS

A simplified MAFIA model of the kicker was used to calculate wakes and estimate kicker impedances. The approach is similar to [7]. While the model geometry was close to that shown in Figure 1, with only one cell, significant approximations have been made in the material properties to make simulations possible. Most importantly, the ferrite magnetic permeability was taken

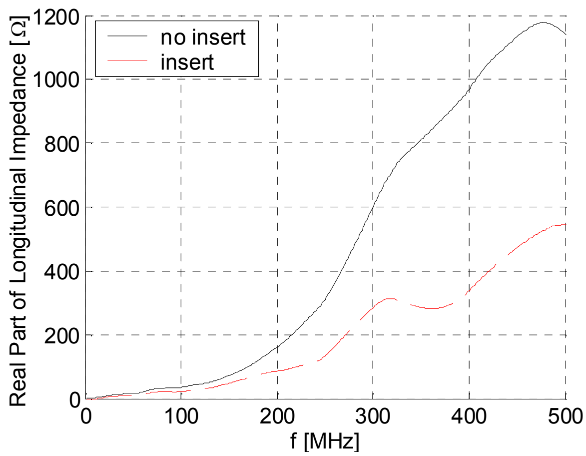

Figure 4: Measured longitudinal impedance of the complete 2 cell MKQH kicker, using the wire method. The traces were smoothed.

to be frequency-independent and real, μ = 200 or 50. In addition, it is difficult to model a thin resistive layer in MAFIA. Instead, to see the effect of the ceramic coating (bypass) on kicker impedances, we compare two setups: (1) uncoated ceramics, and (2) a perfect conductor replacing ceramics. The modulus of the longitudinal impedance (only weakly depending on μ for this type of numerical simulation) of the MKQH kicker model for frequencies up to 500 MHz is plotted in Figure 5.

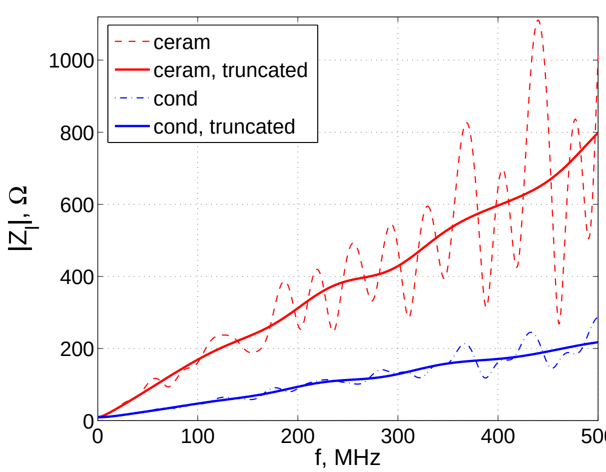

Figure 5: Calculated longitudinal impedance of the MKQH kicker model versus frequency (single cell).

The real part of the impedance in our simplified model is small at low frequencies, and is only due to resonances in the ferrite. They are also responsible for wiggles of $|Z|$ seen in Figure 5. Introducing the imaginary part of μ would create losses that damp such resonances. We can mimic this damping by truncating the wakes (calculated up to 12 m after the bunch) before the first reflection peak. The truncation effect is clearly seen in Figure 5 (solid lines).

Our simulations indicate that bypasses on ceramics reduce the kicker longitudinal (inductive) impedance at low frequencies by a factor of up to 3 to 4. One should note that there could be no direct comparison of the results in Figure 4 and Figure 5 because our MAFIA model does not account for losses both in ferrite and in metals, which would certainly contribute to Re Z.

CONCLUSIONS AND RECOMMENDATIONS

The implemented modifications have proven successful in the sense that the MKQH magnet is no longer a limiting heating object for present SPS operation. No significant kick strength reduction could be demonstrated for MKE sensor reference temperatures up to 90 °C (before implementation of the MKQH modifications, in the long SPS stop, this limit used to be reached at 45 °C). However, the kicker rise time increased from 0.5 μs to 1.4 μs, and also the maximum hold-off voltage decreased significantly. No out-gassing problems have been observed. Wire method beam impedance measurements and simulations have shown a significant reduction in impedance over the relevant frequency range. This is an important experimental confirmation of the precedent studies and has solved the problem for this particular application. Further studies with interleaved comb structures on ceramic plates as well as coatings directly printed or painted on ferrites are underway, to explore the applicability of this method to other SPS kickers with more stringent aperture requirements. Much development work is still needed to evaluate and optimise issues like hold-off voltage, out-gassing and field rise time.

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