

THE FAST EXTRACTION KICKER SYSTEM IN SPS LSS6

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Abstract

A new fast extraction has been set up in SPS LSS6 to transfer 450 GeV/c protons as well as ions to Ring 1 of the LHC, via the transfer line TI 2. The system includes four travelling wave kicker magnets, all powered in series, energised by a single PFN generator and terminated by a short circuit. The layout and the modifications to the magnets and the high voltage circuit are described along with the impact of design choices on the performance of the system. Results from laboratory tests are reported on approaches to overcome the effects of the beam induced kicker heating observed earlier, including a beam screen in form of metallic stripes printed directly onto the ferrites and the use of high Curie temperature ferrites. Prospects for further improvements are briefly discussed.

INTRODUCTION

To transfer protons as well as ions to the clockwise ring of the Large Hadron Collider (LHC) at CERN the existing extraction in long straight section 6 (LSS6) of the Super Proton Synchrotron (SPS) has been converted into a fast extraction, similar in concept to the already operational extraction in LSS4 to the counter-clockwise LHC ring and CNGS [1-3], thus resulting in significant operational and cost advantages.

The requirements and design parameters of the new fast extraction kicker system are summarized in table 1.

Excessive beam induced kicker heating would be a cause for performance limitation in the SPS [4] and the additional transverse beam coupling impedance of the kicker magnets contributes to lower the threshold for beam instabilities with LHC-type beam in the SPS [5]. Therefore, these aspects have been addressed.

Table 1: SPS LSS6 extraction kicker system parameters.

	LHC*
Energy [GeV/c]	450
Total system deflection angle θ [mrad]	0.429
# MKE-L (large aperture) magnets	2
# MKE-S (small aperture) magnets	2
Magnetic field length [m]	1.674
2-98% Rise and fall time [μ s]	8.8
Operating voltage [kV]	26.0
Induction field MKE-L [mT]	82.6
Induction field MKE-S [mT]	90.4
Usable flat top length [μ s]	7.9
Flat top ripple (overshoot)	< 1%

*: for protons

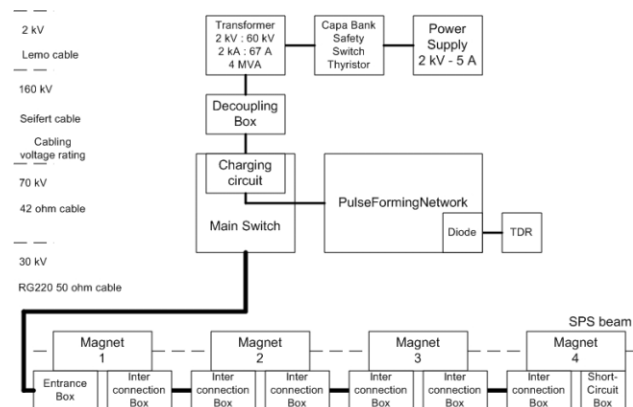


Fig. 1. Schematic of the SPS LSS6 fast extraction kicker system.

EXPERIMENTS AND RESULTS

Existing kicker magnets were re-used, equipped with ferrite heat conductance cooling similar to the fast extraction kickers in LSS4. However, the fast extraction kicker system in LSS6 has additional improvements with respect to both generator and magnets.

Kicker System layout

A single PFN generator powers all four kickers in series with a short-circuit at the end (Fig.1), as engineered with PSpice simulations to take full advantage of the time available for kick rise- and fall-time.

Compared with a characteristically terminated system rise- and fall-time are doubled but only half the voltage is needed for the same “kick” strength. In addition voltage stress only occurs during rise- and fall-time. Advantages are operational cost savings by being less demanding on extraction kicker magnets and thyatron switch. The negative reflection generated by the short circuit travels through the PFN and an inverse solid state diode stack, and is absorbed by a matched dump resistor. The PFN capacitors have been designed to withstand repetitive negative voltages.

OPERA™ 2D FEM field calculations showed the feasibility of operating with only three instead of four kicker magnets, thereby operating closer to the ferrite core current saturation limits of the existing magnets ($B_{sat}=157\text{mT}$). This will be further checked experimentally during 2006 commissioning with beam.

Conventional moulded cable connectors have been operational for over thirty years in CERN SPS kicker systems and showed good performance. However, for cost and maintenance reasons an alternative design, derived from LHC kicker development [6], is used for the magnet inter-connections (Fig.2). These new connector



Fig. 2. Left: Connector sockets with multi-contact system; Right: RG220 high voltage cable with connectors.

assemblies were extensively and successfully tested before implementation in the SPS.

High Curie temperature ferrites

As an alternative strategy to cope with beam induced kicker heating, high Curie temperature ferrites were used in one of the extraction kicker magnets to enable operation at higher local ferrite temperatures. With respect to usual ferrite grades, high Curie temperature ferrites have a lower permeability. OPERA 2D FEM transient field simulations did not show significant degradation of the field uniformity in the magnet aperture. The analyses included hysteresis and remnant field effects. No adverse effects were found.

The out-gassing properties of several “specialty accelerator” ferrites have been measured (Fig.3).

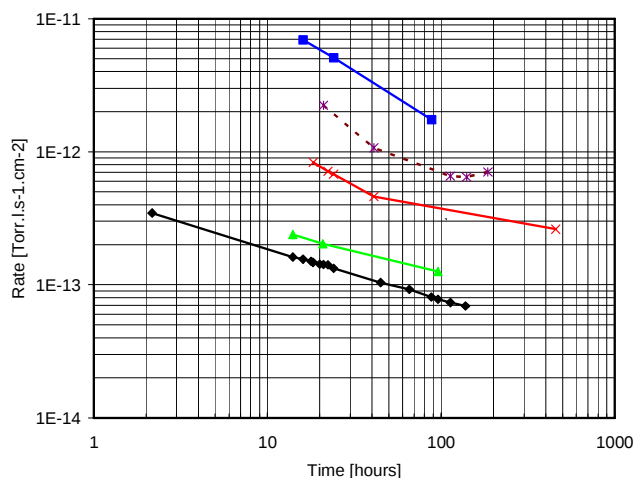


Fig. 3. Ferrite-out gassing rates after bake-out under vacuum at 1000°C. Black: reference dome; red: CMD10 $T_c=230^\circ\text{C}$; dashed purple: Ferroxcube 8C11 $T_c=125^\circ\text{C}$; green: Ferroxcube 4E2 $T_c=400^\circ\text{C}$; blue: Ferroxcube 4E2 baked out under atmospheric pressure.

After 8 days of pumping at 600 l/s total speed and a Ferroxcube 4E2 ferrite surface of $3 \cdot 10^6 \text{ cm}^2$ the resulting pressure is expected to be $6 \cdot 10^{-12} \text{ mbar}$ for bake-out under vacuum and respectively $6 \cdot 10^{-11} \text{ mbar}$ for bake-out under atmospheric pressure.

Reduced beam impedance

In order to reduce the significant beam induced ferrite heating for nominal LHC beam [1] a reduction of the SPS kicker beam impedance is highly desirable [4, 5].

Earlier bench measurements were carried out for several kicker beam coupling impedance reduction techniques and already showed significant improvements [7]. One SPS extraction kicker magnet (MKE-L10) has been built with serigraphically printed (30 μm thick film) stripes on ferrite blocks (Fig. 4). The metallic stripes are capacitive coupled, which provide:

- reduction of the beam impedance $\text{Im}\{Z\}$ and $\text{Re}\{Z\}$
- reduction of heating via $\text{Re}\{Z\}$

The longitudinal beam coupling impedance was measured using the one wire-method for an MKE kicker magnet without, partial (on two out of seven cells) and stripes on all ferrites. The results are shown in Fig. 5. The induced heating should thereby drop considerably to a kicker ferrite temperature of 47°C at 39 W/m (from 120°C at 165W/m previously) as calculated using the measured beam power spectra [4]. With stripes there are two additional low frequency resonances at 5 MHz and 46 MHz related to the physical stripe geometry. Measured reduced imaginary transverse beam coupling impedance will diminish the beam instability likelihood [5]. Installed temperature probes record kicker heating data with SPS beam. The MKE-L10 kicker magnet passed all lab tests and is expected to be installed next year in order to perform full scale tests with beam. If proving successful, this solution could be retrofitted for all nine SPS extraction kicker magnets.

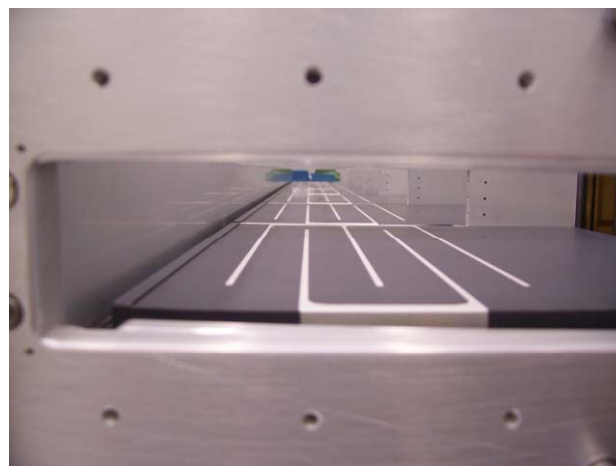


Fig. 4. MKE-L10 extraction kicker magnet with stripes printed directly on ferrites (inter-digital comb structure with 20 mm spacing).

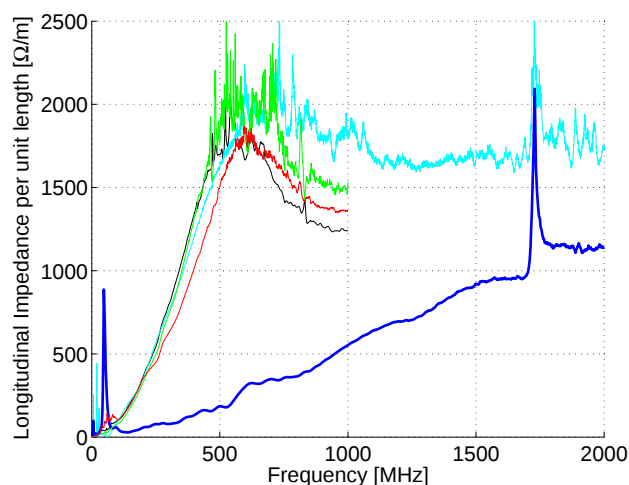


Fig. 5 Real part of the longitudinal beam impedance for extraction kicker magnets: no measures (MKE-S3: green, MKE-L8: black, MKE-L9: magenta); stripes on two out of seven ferrite cells (MKE-S6: red) stripes on all ferrites (MKE-L10: blue).

Commissioning and “kick” measurements

The LSS6 extraction kicker system was tested and installed. It will be commissioned with beam in August 2006.

After the modifications described above pulsed field quality measurements have been carried out on each individual magnet by two different methods:

- with an inductive probe in the magnet aperture as an absolute field calibration reference; not useable after installation in the SPS machine;
- with the magnet’s capacitive pick-ups permitting further kick measurement in the SPS.

The results of both measurements are shown in Fig. 6. The kick strength, rise-, fall- and flat-top pulse length times and flat-top (overshoot) as well as post-pulse ripple were quantified and found in agreement with the simulations.

No high voltage transient sparking, vacuum activity, nor degradation of rise- and fall-times was observed for the high Curie temperature ferrite kicker MKE-L9 nor for the reduced beam coupling impedance kicker MKE-L10. Tests with beam in the CERN SPS complex are to confirm the above.

If successful an upgrade of all 9 MKE fast extraction kickers in LSS4 and LSS6 is foreseen, starting in 2007.

SUMMARY

The SPS MKE fast extraction kicker system in LSS6 has been built, tested and installed. It fulfils the specification for LHC extraction, and will be fully commissioned with beam in summer 2006.

- Kick field and ferrite kicker temperature diagnostics added to the original equipment have proven invaluable.

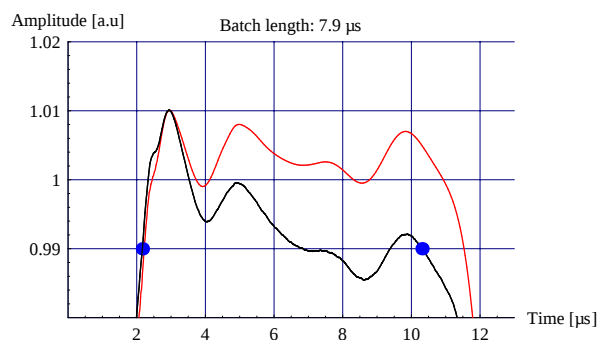


Fig. 6. Measured field: with capacitive pick-ups (red); with inductive probe (black).

- High voltage vacuum breakdown discharge characteristics were studied and tested for reduced beam coupling impedance travelling wave kickers.
- The new layout with magnets connected in series and short-circuited at the end will provide a good reliability.

The heat conductance cooling of the magnet has been implemented, and decisive progress have been made in reducing the beam coupling impedance, with in addition providing some margin for a potential future intensity increase. Results have to be confirmed with beam.

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