UPGRADE OF THE SPS EXTRACTION KICKERS
FOR LHC AND CNGS OPERATION

E.H.R. Gaxiola, J.A. Uythoven, M.A. Timmins

Abstract

The extraction kickers of the Super Proton Synchrotron (SPS) need to be upgraded to meet the Large Hadron Collider (LHC) and CERN Neutrino to Grand Sasso (CNGS) requirements. Commissioning of the extraction towards one of the LHC rings and the CNGS facility under construction is foreseen for 2003. The ferrites of the kicker magnets will be heated significantly by the circulating beam and need to be cooled to stay below the Curie temperature. A cost-effective solution to this problem is presented consisting of AlN water cooled plates on the top and bottom of the ferrites. Model predictions are compared with preliminary laboratory measurements and machine data from the SPS. Commissioning of the extraction towards the other LHC ring is planned for 2006. Beyond the heat load issues, this latter extraction needs a larger horizontal “kick” and thus a higher magnetic field and larger horizontal beam aperture. The rise and fall time requirements of these kickers are less strict, therefore a new system with lower impedance permitting a larger magnetic field can be used.

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1 INTRODUCTION
The extraction from the SPS (as used since late 70’s until 2000) is being upgraded to comply with the LHC and CNGS requirements [1]. The extraction in LSS4 is common between the LHC and CNGS. For LHC and particularly CNGS the existing MKE kickers are upgraded and/or renewed to meet these specifications, see Table 1. For extraction towards CNGS two extractions per SPS-cycle are foreseen, requiring the field to increase from 0 to $B_{max}$ or vice versa in a rise time / fall time < 1.1 µs. This is the space between two (10.5 µs long) bunch trains. For LHC there is only have one extraction per SPS-cycle, requiring a field rise time / fall time < 10 µs and a flat top length of 7.9 µs. For the planned 2003 SPS LSS4 kicker extraction the implemented cooling solutions for the expected significant magnet’s ferrite heating are being reported.

2 SYSTEM OVERVIEW

2.1 General Layout
The kicker system is a characteristically terminated travelling wave system, powered by a resonant charging circuit consisting of two parallel 2 kV 50Hz a.c. power supplies that charge two capacitor banks, which feed via (safety) thyristors a 60 kV step-up transformer. The resonant charging circuit is connected to five Pulse Forming Networks (PFN’s) via a capacitor, diode and resistor auxiliary circuit permitting switch-off and over-voltage limitation. Extraction is triggered by a pre-pulse to the resonant charging supply, charging the PFN’s to the required voltage, after which the five “main” thyatron switches are triggered discharging the PFN’s into the magnets and Terminating Magnet Resistors (TMR). Subsequently triggering of the five “clipper” switches quenches the magnetic field and dumps the remaining PFN energy into the diode-stack and Terminating Dump Resistor (TDR). The second extraction starts with recharging the PFN with the second capacitor bank. Figure 1 shows the LSS4/ECA-4 kicker installation’s schematic.

Beyond the kickers, septa deflect the extracted beam into the transfer line. If a switch “missing” (switch doesn’t close when triggered) or “erratic” (switch closes without being triggered) occurs, all clipper switches are triggered to protect the septa [2].

2.2 Semiconductor power diodes
A system (configuration) has been developed in which the thyatron (gas discharge) “dump” switches are replaced by semiconductor power diodes to reduce long term costs and improve lifetime and reliability. The 72 kV diode-stack, with 36 / 1 MΩ series’ resistors in parallel for a uniform voltage distribution, consists of 6x6 2 kV series diode-units. If one diode-stack unit short-circuits the dump still functions properly.

2.3 Kicker diagnostics
The magnetic field is measured within the required tolerance in the laboratory with an inductive probe. A measured pulse is shown in Fig.2. Here the 2-98% rise

<table>
<thead>
<tr>
<th>Table 1 SPS LSS4 MKE kicker parameters</th>
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<tr>
<td>E.H.R. Gaxiola, J.A. Uythoven, M.A. Timmins, CERN, Geneva, Switzerland</td>
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### Table 1 SPS LSS4 MKE kicker parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>LHC</th>
<th>CNGS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy [GeV]</td>
<td>450</td>
<td>400</td>
</tr>
<tr>
<td>Total system deflection angle $\theta$ [mrad]</td>
<td>0.4788</td>
<td>0.4788</td>
</tr>
<tr>
<td># MKE-L magnets</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td># MKE-S magnets</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Magnet length [m]</td>
<td>2.174</td>
<td>2.174</td>
</tr>
<tr>
<td>2-98% Rise time [μs]</td>
<td>&lt; 10</td>
<td>&lt; 1.1</td>
</tr>
<tr>
<td>Operating voltage [kV]</td>
<td>47.0</td>
<td>47.0</td>
</tr>
<tr>
<td>Induction field MKE-L [T]</td>
<td>0.0828</td>
<td>0.0828</td>
</tr>
<tr>
<td>Induction field MKE-S [T]</td>
<td>0.0905</td>
<td>0.0905</td>
</tr>
<tr>
<td>Flat top length duration [μs]</td>
<td>7.9</td>
<td>10.5</td>
</tr>
<tr>
<td>Overshoot (flat top ripple)</td>
<td>&lt; 1%</td>
<td>&lt; 2%</td>
</tr>
<tr>
<td>98-2% Fall time [μs]</td>
<td>&lt; 10</td>
<td>&lt; 1.1</td>
</tr>
</tbody>
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*: Tor protons
Fig. 1 MKE LSS4 installations schematic layout.

Table 2 MKE kicker beam induced ferrite dissipation for typical operating conditions (bunch length: $l_0$) [5].

<table>
<thead>
<tr>
<th>Bunch length</th>
<th>LHC Ferrite 8C11</th>
<th>CNGS Ferrite 8C11</th>
<th>CNGS Ferrite 4E2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.35 ns</td>
<td>1.02 kW·m$^{-1}$</td>
<td>0.79 kW·m$^{-1}$</td>
<td>0.72 kW·m$^{-1}$</td>
</tr>
<tr>
<td>0.49 ns</td>
<td>0.43 kW·m$^{-1}$</td>
<td>0.33 kW·m$^{-1}$</td>
<td>0.30 kW·m$^{-1}$</td>
</tr>
</tbody>
</table>

loss of ferrite permeability above the Curie temperature, i.e. loss of (magnetic field) extraction kick–ability.

2.4 Second phase: LSS6

For the 2006 LSS6 extraction it is planned to make a new kicker design. The PFN(’s) and magnets will need to meet the earlier described required specs for “kick” and “timing”. There is only space for two ($l=2.2m$) MKE kickers requiring a larger (horizontal) “kick/larger $B$ field together with a larger horizontal beam aperture. The voltage rating of the system is limited by the maximum operating voltage for the thyatron switches, so as to obtain a larger current $I$ (at the same voltage $U$), a reduced impedance ($Z=vL/C=6.25Q$) for the PFN’s and the magnets is needed. A similar cooling solution as for the LSS4 MKE-L and MKE-S magnets is foreseen for the LSS6 MKE magnets to assure proper extraction for future LHC and CNGS experiments [4].

3 COOLING

In the SPS a beam induced temperature rise of 24 K was measured in the MKE kickers for $2.9*10^7$ protons in a so-called “fixed target proton machine cycle” at a calculated ferrite power dissipation of 43 W/m$^2$. For the proposed LHC and CNGS beam-operating conditions the SPS extraction kickers will be exposed to a much larger beam induced thermal power. Table 2 shows the operating conditions for the upgraded MKE kicker magnets. The ferrites will be heated due to the high frequency polarization (power losses) of the magnetic (ion) dipole moments. For kicker applications in particle accelerators the used magnetic materials are ferrites (ferromagnetic, typically: NiZn), which have spontaneous magnetisation at room temperature, and show hysteresis and saturation effects. Above the Curie-temperature (see Fig.3) the spontaneous magnetisation disappears and the material becomes paramagnetic [7, 8, 9].

To cope with the ferrite heat dissipation ratings quoted in Table 2 cooling measures are implemented in the MKE kicker magnet. Temperature probe measurements were taken under lab conditions and compared to those measured in the SPS machine.

The results from the various cooling tests combined with the modelling results are shown in Fig.3 together with 0-dimensional equivalent electrical-circuit model and 3-dimensional STAR-CD® steady-state calculations. It also shows the results of cooling options under study: a copper block connecting frame and base plate, and a
water-cooled base plate. The 0-D modelling corresponds well with the measured values describing the various temperatures before implementation of additional cooling measures, since radiative cooling previously was the then dominant mechanism (not included in our 3-D model). The tests after the cooling (heat conduction) modification are more accurately described with the 3-D model. From Fig. 3 it can be seen that the effect of the magnet’s frame-base plate connection and water-cooled baseplate is marginal. For the series it has been decided to equip the frame-base plate connection and water-cooled baseplate is.

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From Fig. 3 it can be seen that the effect of the magnet’s frame-base plate connection and water-cooled baseplate is marginal. For the series it has been decided to equip the magnets with AlN (aluminium nitride, thermal conductivity $\sigma = 180 \text{ Wm}^{-1}\text{K}^{-1}$) cooling plates on the top and bottom of the ferrites combined with water-cooling at the AlN plates’ extremities. For this solution we found 343 $K$ as the maximum temperature for 0.33 $kW$-m$^{-1}$ (according to the 3-D model) corresponding to $8 \times 10^{13}$ protons (CNGS type beam) with a 0.49 ns bunch length, which is well below the ferrite 8C11’s Curie temperature $T_c = 398 K$ (at which also out-gassing will become relevant). The observed kicker heating has a typical time constant of several days.

To reduce the ferrite heat dissipation it is also foreseen to increase the bunch length as indicated in Table 2.

A further option is the use of an alternative ferrite (e.g. make: Ferroxcube, grading 4E2 instead of grading 8C11 [10]) with a higher Curie temperature (see Fig. 3). Out-gassing tests will be performed on this ferrite type.

4 CONCLUSIONS

A new PFN energy dump clipper switch / diode-stack system has successfully been tested at full voltage.

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