MEASUREMENT AND ANALYSIS OF SPS KICKER MAGNET HEATING AND OUTGASSING WITH DIFFERENT BUNCH SPACING

M.J. Barnes, F. Caspers, K. Cornelis, L. Ducimetière, E. Mahner, G. Papotti, G. Rumolo, V. Senaj, E. Shaposhnikova, CERN, Geneva, Switzerland

Abstract

Fast kicker magnets are used to inject beam into and eject beam out of the CERN SPS accelerator ring. These kickers are generally ferrite loaded transmission line type magnets with a rectangular shaped aperture through which the beam passes. Unless special precautions are taken the impedance of the ferrite yoke can provoke significant beam induced heating, over several hours, even above the Curie temperature of the ferrite. At present the nominal bunch spacing in the SPS is 25 ns, however for an early stage of LHC operation it is preferable to have 50 ns bunch spacing. Machine Development (MD) studies have been carried out with an inter-bunch spacing of 25 ns, 50 ns or 75 ns. For one of the SPS kicker magnets the 75 ns bunch spacing resulted in considerable beam induced heating. In addition the MDs showed that 50 ns bunch spacing could result in a very rapid pressure rise in the kicker magnets and thus cause an interlock. This paper discusses the MD observations for the SPS kickers and analyses the available data to provide explanations for the phenomena: possible remedies are also discussed.

INTRODUCTION

CERN, the European Laboratory for Particle Physics, has constructed the Large Hadron Collider (LHC) which will bring protons into head-on collisions at 2 x 7 TeV [1]. Two counter-rotating beams circulate in two horizontally separated beam pipes. Each of the two LHC beam pipes is filled by 12 batches of protons injected, at 450 GeV, successively on the machine circumference from the Super Proton Synchrotron (SPS).

The SPS has several sets of kicker magnets: MKP kicker magnets for injection into the SPS; an MKQ system for tune (Q) measurement; an MKD system for dumping the beam; and two MKE systems for extracting the beam towards the LHC. The MKD system is the most problematic in terms of outgassing and the MKE systems, the SPS kickers with the highest longitudinal impedance, are of particular interest as one of these kickers has beam impedance reduction techniques implemented.

The function of the MKD system is to extract and sweep the beam to distribute the beam energy over a large volume of an absorber block. There are two vertical kickers, known as MKDV1 & MKDV2, and three horizontal kickers known as MKDH1, MKDH2 & MKDH3. The MKE4 fast extraction system serves both the anti-clockwise ring of the LHC and the long baseline neutrino (CNGS) facility. The MKE4 system has five horizontal kickers: 3 of these are “large aperture” (L type) and 2 are “small aperture” (S type). The MKE6 fast extraction system serves the clockwise ring of the LHC. The MKE6 system has three horizontal kickers: 2 of these are L type and 1 is S type.

The SPS kickers are generally ferrite loaded transmission line type magnets with a rectangular shaped aperture through which the beam passes (Fig. 1).

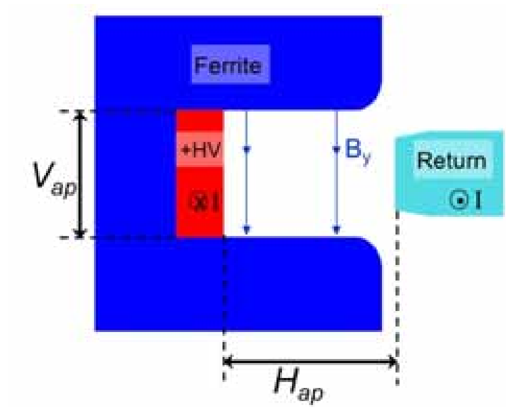

Figure 1: Simplified cross-section of a kicker magnet.

Table 1 summarizes the aperture dimensions, cell length, and number of cells for each of the 30 kicker magnets installed in the SPS. All of these kickers, except for the MKDH, use ferrite for the magnet material; in general 8C-11 ferrite is used. However the MKDH magnets use 0.35 mm thick steel laminations.

Table 1: SPS Kicker System Parameters

Kicker Magnet	Nb of magnets	H_{ap} (mm)	V_{ap} (mm)	Length x number of cells
MKP-S	12	100	61	26mm x 17
MKP-L	2	140	54	26mm x 22
MKQH	1	135	33.9	242mm x 2
MKQV	1	56	102	788mm x 2
MKDH1/2	2	97.1	56	1256mm x 1
MKDH3	1	106.1	60	1256mm x 1
MKDV1	1	56	75	512mm x 5
MKDV2	1	56	83	512mm x 5
MKE4-L	3	147.7	35	240mm x 7
MKE4-S	2	135	32	240mm x 7
MKE6-L	2	147.7	35	240mm x 7
MKE6-S	1	135	32	240mm x 7

All of the MKE kickers, but none of the MKDV kickers, presently in the SPS have transition pieces installed between the magnet and vacuum tank [2]. One of the MKE kickers, MKE6-L10, is serigraphed [3], to reduce the beam coupling impedance, while the other MKE kickers are not serigraphed.

KICKER MAGNET OBSERVATIONS DURING MDs

Temperature Issues

Various MDs have been carried out to study the effect of bunch spacings of 25 ns, 50 ns and 75 ns. One such MD was performed from August 12 through to 14, 2008, inclusive. Fig. 2 shows a plot of temperature rise of the MKDV and MKE magnets during this MD. During operation, with 25 ns bunch spacing, the MKDV1 magnet has a higher temperature than MKDV2. Fig. 3 shows the Real Longitudinal Coupling Impedance (RLCI) for MKDV1 & MKDV2, obtained analytically [2]: the analytical RLCI is higher for MKDV1 than MKDV2 and thus it is expected that MKDV1 is more susceptible to beam induced heating. However once operation with 75 ns bunch spacing commenced the temperature of MKDV2 considerably exceeded that of MKDV1: the reason for this is not evident from the analytical RLCI. Fig. 2 also shows the temperature for two of the three MKE6 kickers: the MKE6-L10 kicker is serigraphed and MKE6-L9 is not. The MKE6-L10 shows a maximum temperature rise of only 10°C, compared to 35°C rise for MKE6-L9: this is consistent with the serigraphed kicker generally having a significantly lower RLCI (Fig. 3).

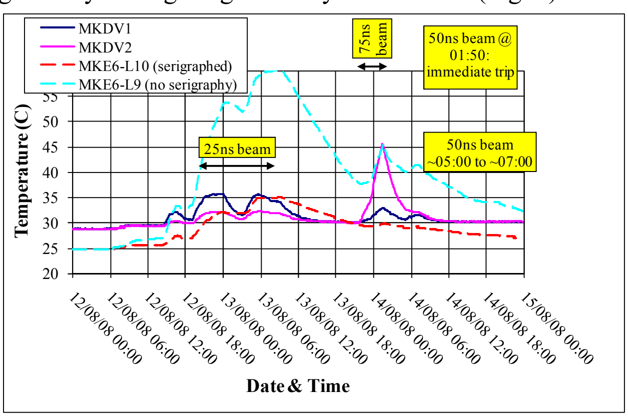

Figure 2: Temperature of MKDV1, MKDV2 and two MKE6 magnets during MD of 12 to 14 August, 2008.

Figure 3 also shows measurements of the RLCI for MKDV1, made with and without transition pieces between the magnet and vacuum tank [2]: the MKDV magnets installed in the ring (during the 2008 operation) do not have transition pieces. Without transition pieces resonances occur at just over 200 MHz (Fig. 3), which corresponds to λ/2 based on the length of the magnet: the minima of the RLCI resonances are, up to 1.6 GHz, in good agreement with the analytical calculation of RLCI.

Figure 4 shows the beam spectrum for 25 ns, 50 ns and 75 ns bunch spacing: there is little spectral power beyond 500 MHz. The 25 ns (75 ns) bunch spacing results in spectral lines which are 40.05 MHz (13.5 MHz) spaced. Thus, the 75 ns bunch spacing is considerably more likely to result in a spectral line, which contains significant current, coinciding with an RLCI resonance than is the case for 25 ns bunch spacing. No numerical RLCI measurement data is presently available for MKDV2, however a screen dump of measurement data shows similar resonances to those of MKDV1. These resonances may occur at slightly different frequencies to those of MKDV1 (possibly due to a different V_{ap} (Fig. 1)), and hence one or more of these resonances may coincide with a spectral line containing significant current, causing a higher temperature rise with 75 ns bunch spacing (Fig. 2).

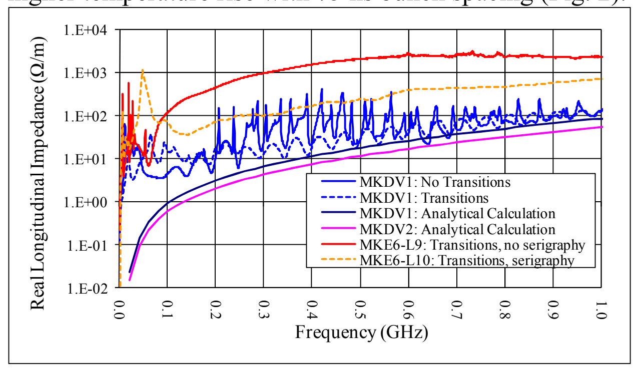

Figure 3: Analytical RLCI for MKDV1 & MKDV2 & measured RLCI for MKDV1 & 2 MKE6 kicker magnets.

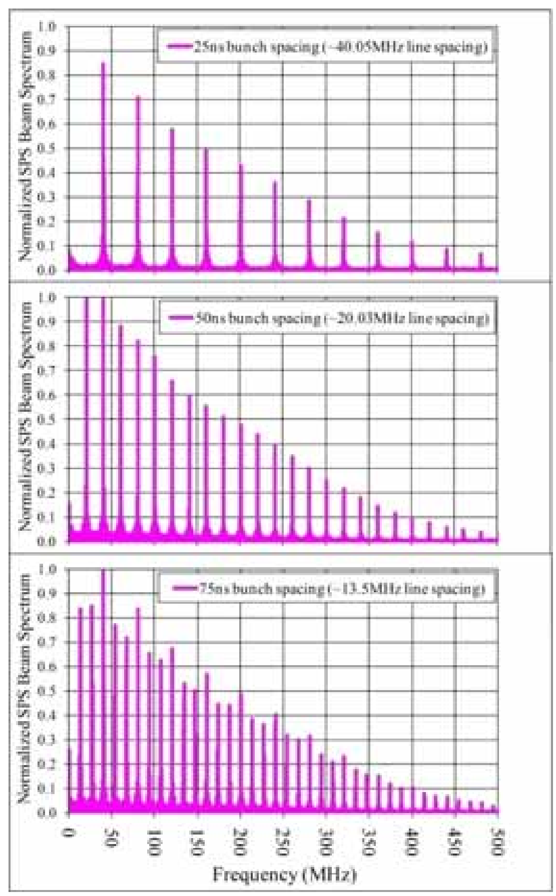

Figure 4: Normalized, measured, SPS beam spectrum for 25 ns, 50 ns and 75 ns bunch spacing.

The RLCI resonances are considerably suppressed when transition pieces are added (Fig. 3). Thus adding transition pieces to MKDV2 in the future may significantly reduce its temperature rise with 75 ns bunch spacing.

Pressure Issues

Figure 5 shows the pressure rise measured for MKDV1 and MKDV2 on 14th August 2008: the data is logged with 1 s resolution. During operation with 75 ns bunch spacing there is no significant pressure rise. However, as soon as 50 ns bunch spacing commences there is an "instantaneous" rise in pressure in both MKDV1 and MKDV2. The same observation is true for all the other SPS kickers with the exception of MKQH for which pressure shows most activity with 75 ns bunch spacing. The MKE6 kicker magnets show a similar pressure rise with 50 ns beam whether or not they have serigraphy.

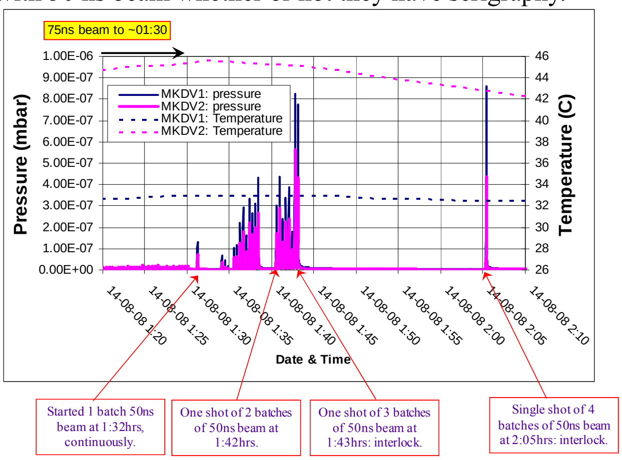

Figure 5: Pressure rise in MKDV1 & MKDV2 during MD of August 14, 2008.

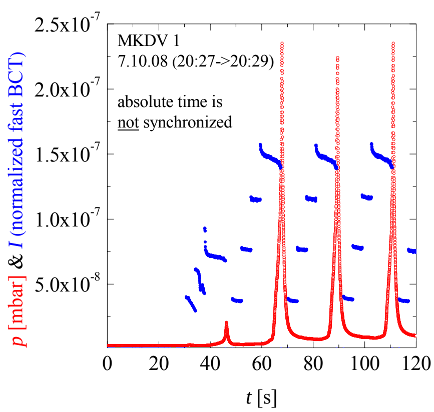

Figure 6: Fast BCT (blue) and pressure (red) data.

Measurements of MKDV1 pressure were repeated during an MD from October 6th to 8th, 2008: the logging resolution was increased from 1 s to 16 ms. With 50 ns bunch spacing there is peak of pressure every 24.6 s, which corresponds to the SPS super-cycle. Fig. 6 shows pressure data together with the sum over the fast Beam Current Transformer (BCT) channels. The pressure and BCT data were logged using two totally independent systems whose clocks were not synchronized; thus the displayed time synchronization of the two data sets is assumed. Following the 4th injection, acceleration starts. During acceleration the pressure increases rapidly, as bunch length decreases, and reduces rapidly after the beam is dumped. The very rapid rise in pressure, as soon as acceleration of beam with 50 ns bunch spacing commences, indicates that the phenomenon is a surface effect. The rate of pressure fall is reasonably consistent with the installed pumping rate [4].

Figure 7 shows pressure rise in the MKDV kickers versus bunch intensity, for 50 ns bunch spacing and 4 batches: the instantaneous pressure rise in the MKDV kickers show a clear threshold effect with intensity ($>6\text{x}10^{10}$ protons/bunch). The pressure rise also shows thresholds with number of batches and bunch length: this is consistent with an electron-cloud effect. However, monitors and simulations both show maximum electron-cloud density with 25 ns bunch spacing. MKDV1 does show a pressure rise with 25 ns bunch spacing, during the MDs, but at a much reduced level.

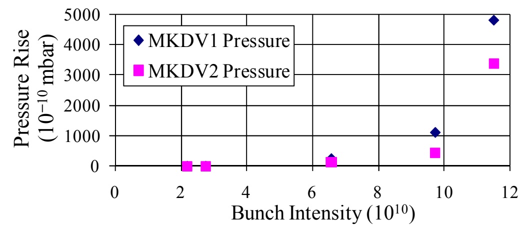

Figure 7: Pressure rise in MKDV kickers versus bunch intensity (50 ns bunch spacing and 4 batches).

CONCLUSIONS

The temperature rise of MKDV2, with 75 ns bunch spacing, is believed to be attributable to impedance resonances coinciding with one or more beam spectral lines of significant current. Measurements on MKDV1 show that the resonances are significantly attenuated by the use of transition pieces. It is planned to install transition pieces in MKDV2: this is expected to reduce the temperature rise with 75 ns bunch spacing. MDs with 50 ns bunch spacing caused immediate pressure rise (surface effect) for both MKDV1 & MKDV2. The pressure rise shows thresholds with intensity ($>6\text{x}10^{10}$ protons/bunch), number of batches and bunch length: this is consistent with an electron-cloud effect. However, monitors and simulations both show maximum electron-cloud density with 25 ns bunch spacing. The measured pressure rise appears to be real as subsequent pressure fall is consistent with the installed pumping rate. Pressure rise is not affected by serigraphy of the ferrites. Further work is required to fully understand the phenomenon.

REFERENCES

[1] LHC Design Report, http://ab-div.web.cern.ch/ab-div/Publications/LHC-DesignReport.html.

[2] M.J. Barnes et al, "Measurement of Longitudinal and Transverse Impedance of Kicker Magnets Using the Coaxial Wire Method", Proc. of this conference.

[3] E. Gaxiola et al., "The Fast Extraction Kicker System in SPS LSS6", LHC Project Report 913, Geneva (2006).

[4] M.J. Barnes, E. Mahner, V. Senaj, "SPS Kicker-Magnet Outgassing with Different Bunch Spacings", ECLOUD Workshop, Nov. 20-21, 2008, CERN.