ELECTROMAGNETIC COUPLING BETWEEN HIGH INTENSITY LHC BEAMS AND THE SYNCHROTRON RADIATION MONITOR LIGHT EXTRACTION SYSTEM

W. Andreazza, A. Bertarelli, E. Bravin, F. Caspers, M. Garlaschè, J-J. Gras, A. Goldblatt, T. Lefevre, R. Jones, E. Metral, A.A. Nosych, F. Roncarolo*, B. Salvant, G. Trad, R. Veness, C. Vollinger, M. Wendt, CERN, Geneva, Switzerland

Abstract

The CERN LHC is equipped with two Synchrotron Radiation Monitor (BSRT) systems used to characterise transverse and longitudinal beam distributions. Since the end of the 2011 LHC run the light extraction system, based on a retractable mirror, has suffered deformation and mechanical failure that is correlated to the increase in beam intensity. Temperature probes have associated these observations to a strong heating of the mirror support with a dependence on the longitudinal bunch length and shape, indicating the origin as electromagnetic coupling between the beam and the structure. This paper combines all this information with the aim of characterising and improving the system in view of its upgrade during the current LHC shutdown. Beam-based observations are presented along with electromagnetic and thermomechanical simulations and complemented by laboratory measurements, including the study of the RF properties of different mirror bulk and coating materials.

BEAM BASED OBSERVATIONS

The BSRT systems [1] provide continuous bunch per bunch beam size measurements by imaging the synchrotron radiation emitted by a superconductor undulator (for beam energies below 1.5 TeV) or the D3 dipole (above 1.5 TeV). The 2012 BSRT performances were heavily affected by heating of the light extraction system (Fig. 1) due to EM coupling with the beam, that was enhanced in 2012 by the increase of the beam total intensity and intensity per bunch. Both BSRT systems were originally equipped with silicon bulk mirrors coated with a thin dielectric (multi-layers of TiO_2 and SiO_2). The thermal cycles caused a permanent deformation of the clamps holding the mirror and a blistering of the mirror reflective coating. After their removal, other mirror types were tested in order to investigate the best option to minimize the heating effects with the present tank design, while ensuring enough reflectivity. The outcome can be summarized as follows:

1. A silicon bulk, uncoated mirror showed a similar heating (as measured with temperature probes outside the BSRT tank and observed during the MW oven tests mentioned below), and resulted to be unusable for imaging, given the distorted recorded images.

* federico.roncarolo@cern.ch

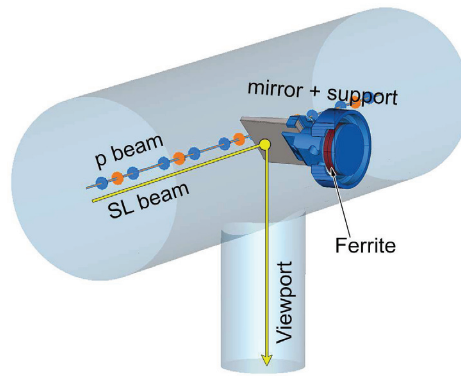

Figure 1: Mirror support system of the LHC synchrotron light monitor.

2. A glass bulk, metallic coated mirror resulted in a reduced heating effect at low beam intensities, but suffered coating deformation (evidenced by the beam spot image deformation) at high intensities.

3. A glass bulk, dielectric coated mirror resulted in a reduced heating (w.r.t. the original silicon bulk, dielectric coated mirror) and did not show any coating deformation according to the recorded images, also at high intensity.

At the moment of installing this last mirror type, the light extraction system was equipped with a set of 5 temperature probes in vacuum, that allowed characterizing the thermal behavior of the structure during a dedicated test with high beam intensity (see Fig. 2). The probes close to the ferrite (TT2-111R) located at the base of the mirror support to damp resonances, reached ∼270 ^{o}C (the ferrite Curie temperature is $\sim 375^oC$). The heat is irradiated from the ferrite to the mirror and mirror shaft. The effect is clearly enhanced by higher beam intensity and lower bunch length.

ELECTROMAGNETIC SIMULATIONS

EM simulations of the light extraction system, excited by a LHC proton bunch with nominal parameters using the *CST Studio Wakefield* [2] indicated how the heating is caused by a strong single eigenmode at ∼700 MHz of the metallic mirror holder and support shaft. This was verified by an eigenmode simulation using *ACE3P Omega3P* [3]. Such a resonance can be excited by the LHC beam, characterized by a frequency spectrum that extends well above

ISBN 978-3-95450-122-9

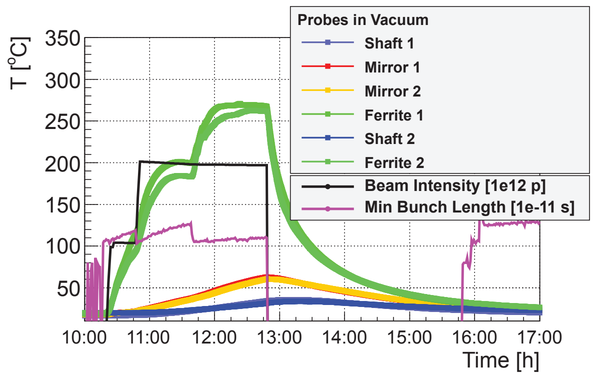

Figure 2: Thermal behavior of the BSRT structure as measured by 5 temperature probes located at strategic location in the vacuum tank, during a dedicated test with high beam intensity and variable bunch length.

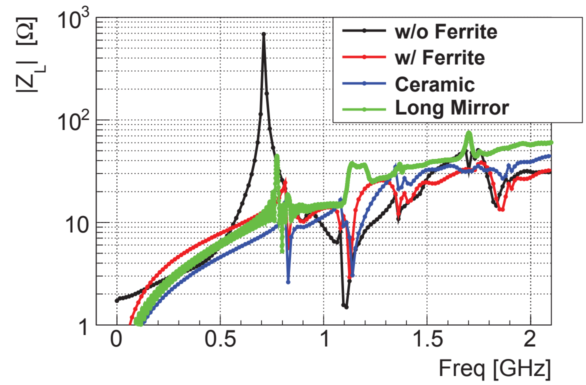

Figure 3: Comparison of different mirror support configurations (with logarithmic scale of the wake impedance).

1 GHz. Different mirror support geometries and various material choices have been studied, using as input i) the nominal LHC bunch parameters (50 mm RMS bunch length, 17 nC bunch charge), ii) a +10 mm horizontal beam offset with respect to the pipe axis and iii) the mirror system at the nominal position (outer mirror edge at -10 mm from the pipe axis). The wake was simulated along 20 m. Fig. 3 compares the magnitude of the longitudinal wake-impedance for different configurations:

w/o ferrite The present geometry without ferrite absorbers, causing a a resonance with very high longitudinal wake impedance at ∼700 MHz.

w/ ferrite The resonance effects of the present geometry are absorbed by two ferrite cylinders. This results in an over-heating of the ferrite, which becomes ineffective above its Curie temperature.

ceramic shaft and holder A possible modification of the current configuration replaces the metal mirror holder and shaft by a ceramic material (e.g. *Macor* or *Shapal*), thus making the the structure more transparent to EM-fields.

long mirror This geometric modification hides mirror holder and shaft completely, a longer mirror is inserted through a slit in the beam-pipe.

The last two options show no dominant resonance effects in the wake impedance, thus avoiding the need for resonance damping materials, e.g. ferrites. For the case of the present design (with ferrite), thermo-mechanical simulations starting from the power estimated by the EM simulations (∼ 50 W on the ferrite, for a typical LHC beam) qualitatively explained very well the heat flux from the ferrite to the other components. More simulations are undergoing to quantitatively characterize the present design and the possible alternatives.

STRETCHED WIRE MEASUREMENTS AND SIMULATIONS

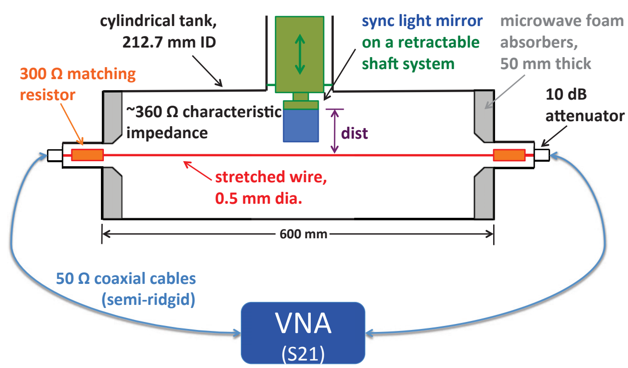

Figure 4: Stretched wire measurement setup.

In order to crosscheck the EM simulations, we performed a series of laboratory measurements based on the *stretched wire* method [4], using a spare BSRT tank. As Fig. 4 indicates, an abrupt transition with an integrated matching resistor adapts the high characteristic impedance of the coaxial wire setup (∼360 Ω) to the 50 Ω vector network analyzer (VNA) impedance. This matching is (partially) effective only for frequencies <1 GHz and the high frequency matching was realized by a disk made out of 50 mm thick microwave absorbing foam. Fig. 5 compares the matching for a reference beam tube with and without absorbing foam when measuring a bare BSRT-like beam pipe (600 mm long, 213 mm diameter, no mirror extraction system). The foam effect at high frequencies is impressive, whereas, as expected, at low frequencies the matching with lumped resistors is not perfect. After qualifying the stretched wire setup, a series of transmission measurements (in terms of the S21 scattering parameter) have been performed, and compared to a electromagnetic simulation of the stretched wire configuration. Center frequencies and Q-values of the ∼700 MHz resonance for different horizontal positions ("dist" in Fig. 4) of the metallic mirror support

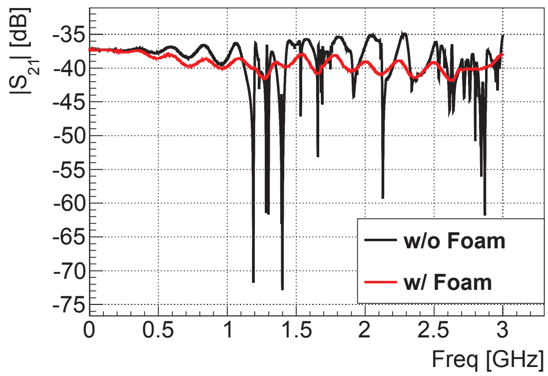

Figure 5: Damping of the parasitic modes in the stretched wire setup by microwave absorbing foam.

have been studied (Fig. 6). The agreement (in frequency) between wire measurement and EM-simulation (*CST Microwave Studio*) is within $\pm 10\%$. Any resonance-free modification of the mirror support, e.g. with ceramic mirror holder and shaft or a long mirror with hidden support structure, will be qualified with this stretched wire setup.

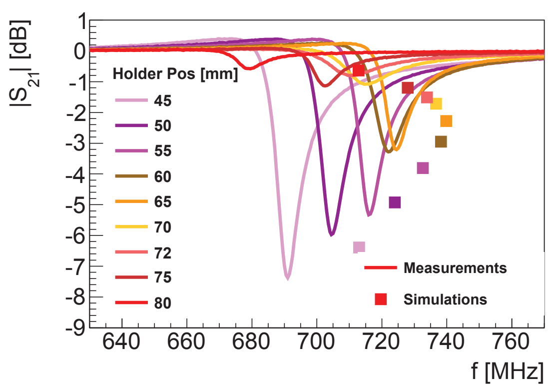

Figure 6: Resonance vs. horizontal mirror holder position, as measured and simulated with the stretched wire method.

S-BAND AND MW LABORATORY MEASUREMENTS

One of the original silicon bulk mirrors with dielectric coating, after its removal in 2012, was used for an S-Band transmission measurement. The resulting $|S21|$ parameter has been compared to the same measurement with an identical spare (e.g. new) mirror and with the empty cavity (Fig. 7). The used and new mirrors gave similar results and the fact that, above the cavity cut-off frequency ($\sim$2 GHz), the transmission is below 0 dB (solid red and green lines) and that $\sqrt{|S_{21}|^2 + |S_{11}|^2} < 1$ (square dots) assesses that the mirror acts as an RF absorber in the microwave regime. This was confirmed by a qualitative test with a commercial microwave oven (2.45 GHz) that consisted in inserting different mirror types and powering the oven to 700 W. Silicon bulk mirrors (dielectric coated or uncoated) became very hot after 1 minutes, whereas glass bulk mirrors (even with a metallic coating), remained cold after 2 minutes.

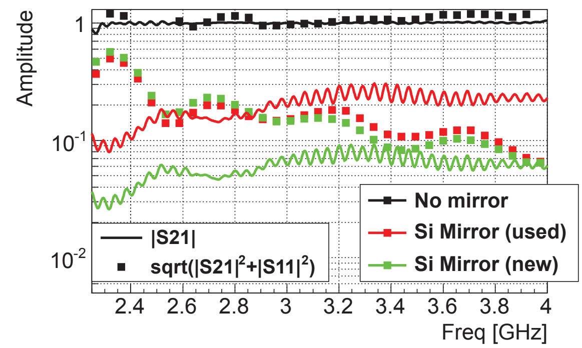

Figure 7: S-Band transmission measurement of a used and a new silicon bulk-dielectric coated mirrors, compared to the same measurement on an empty cavity.

CONCLUSIONS

The studies following the observation of strong heating on the BSRT light extraction system allowed characterizing the effect as RF coupling between the beam and the structure. This phenomenon is particularly enhanced by the LHC beam spectrum and intensity. It was demonstrated that the original mirror (silicon bulk) acts as an RF absorber and it will be changed for a glass (fused silica) mirror. In addition, the stainless steel support induces strong coupling even without mirror. EM simulations showed that two modified designs (one consisting in a ceramic support and another in a longer mirror) would minimize the resonance effect and possibly the heating. Further simulations (e.g. to verify the impact on beam stability) and stretched wire measurements on simplified prototypes, complemented by thermomechanical simulations, will allow deciding the final design, needed for the LHC re-start.

ACKNOWLEDGMENT

The authors would like to sincerely thank the LHC operation and impedance teams for their help and support.

REFERENCES

[1] T. Lefevre et al., "First Beam Measurements with the LHC Synchrotron Light Monitors, Proc. IPAC, Kyoto, Japan, (2010).

[2] *Computer Simulation Technology (CST)*, `http://www.cst.com/`

[3] *Advanced Computational Electromagnetics 3P (ACE3P)*, `https://portal.slac.stanford.edu/sites/ard_public/acd/`

[4] F. Caspers, "Impedance determination - Bench measurements," in Handbook of accelerator physics and engineering, World Scientific Publishing, edited by Alex Chao, M. Tigner, p. 574

ISBN 978-3-95450-122-9