

BEAM INDUCED RF HEATING IN LHC IN 2015

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Abstract

Following the recurrent beam induced RF issues that perturbed the CERN Large Hadron Collider (LHC) operation during Run 1, a series of actions were put in place to minimize the risk that similar issues would occur in Run 2: longitudinal impedance reduction campaigns and/or improvement of cooling for equipment that were problematic or at the limit during Run 1, stringent constraints enforced on new equipment that would be installed in the machine, tests to control the bunch length and longitudinal distribution, additional monitoring of temperature, new monitoring tools and warning chains. This contribution reports the outcome of these actions, both successes as well as shortcomings, and details the lessons learnt for the future runs.

INTRODUCTION

Beam induced RF heating was one of the major limitations to increasing the LHC luminosity in Run 1 [1]. Temperature increase in near-beam devices, due to electromagnetic fields generated by the proton beam interacting with the longitudinal beam coupling impedance of these devices, was indeed observed to cause severe damage, delays or dumps [2].

During the first long LHC shutdown in 2013-14 (LS1), many actions were taken by CERN equipment groups as well as experiments to solve existing problems and prevent new ones for modified or newly installed hardware [3].

These actions are summarized in the next section, followed by the resulting performance in 2015 with respect to beam induced RF heating and the expectations for 2016.

ACTIONS TAKEN DURING LS1

The main actions focused on the equipment already damaged (BSRT synchrotron light monitor, TDI injection protection collimator), that have limited the machine performance (MKI injection kicker, Roman pots) or new hardware (Roman pots, tertiary and secondary collimators with ferrite). High Curie temperature ferrites are now systematically used.

BSRT Synchrotron Light Monitor

Following the severe heating damage that affected the BSRT mirror, ferrites and support before LS1, a new design that would minimize the shunt impedance of low frequency resonances below 1 GHz and avoid the use of ferrite was studied and installed during LS1 [4].

TDI Injection Protection Collimator

Following abnormal deformation of the two TDI beam screens observed in 2011, as well as vacuum, and jaw deformation measurements during the 2011 and 2012 run that suggested significant heating, and mechanical issues at the end of the 2012 run [5], the two TDIs were refurbished in order to improve the stiffness of the beam screen (copper was replaced by stainless steel) and reduce beam induced heating (copper coating was planned to be applied on top of the titanium coated ceramic absorber). However, technical issues with the copper coating of those absorber blocks led to abandon the coating for the 2015 run. The jaws were therefore put back as they were before LS1 from that point of view.

MKI Injection Kickers

Following the observed increase of temperature that could threaten to go beyond the Curie temperature of the ferrite yoke of one MKI, a new design aimed at reducing the longitudinal impedance of the MKIs by better screening the ferrite from the beam, was implemented for the installed MKIs during LS1 [6, 7].

TCP.B6L7.B1 Skew Primary Collimator

A skew primary collimator caused beam dumps in 2011 and 2012 due the steady increase of its jaws' temperature during physics fills. Electromagnetic and thermal simulations were consistent with a non-conformity of the cooling and it was replaced during LS1. A non-conformity of the cooling circuit routing was confirmed after inspection during LS1 [8].

TOTEM Roman Pots / Beam Screen Regulation

During most of Run 1, the beam screen of the standalone quadrupole magnet Q6R5 had no margin for increased cryogenic cooling. Correlation with vacuum and loss activity observed at a nearby TOTEM Roman

Pot indicated that this pot could be responsible for the beam screen regulation issues. It was indeed found out that the ferrites of this TOTEM pot had not been baked out and that some ferrites were damaged. During LS1 the valves for standalones were replaced to allow a higher cooling flux. Roman Pots to be used at high luminosities were equipped with RF shields to reduce the impedance, and new high Curie temperature ferrites were installed after proper bake-out.

ATLAS-ALFA Roman Pot

During Run 1, the ATLAS-ALFA detectors' temperature entered the range that is expected to lead to detector damage. Ferrites were relocated far from the beam and closer to an active cooling circuit, while an additional electromagnetic shielding was installed to reduce the longitudinal impedance of the pots (see Fig. 1).

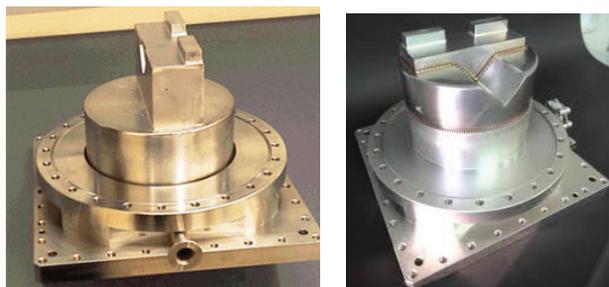


Figure 1: ATLAS-ALFA Roman Pot before LS1 (left) and optimized from longitudinal impedance point of view after LS1 (right). Old and new ferrites are not shown. Courtesy Sune Jakobsen.

It is important to note that other hardware that were affected by heating issues before LS1 were also removed (vacuum modules VMTSA and two beam tertiary collimators TCTVB).

Heating Monitoring Tools

Additional monitoring tools were implemented for the LHC Run 2 to detect abnormal beam induced heating [8]. These include additional temperature probes for target hardware (e.g. TDI, goniometer, BGI, BGV, ALICE beam pipe), systematic logging of temperature data into the logging databases, fixed displays on the operation consoles for efficient monitoring, vocal and text message warnings if the temperature reaches predefined levels. This strategy paid off as it allowed for instance to detect, analyse, diagnose and solve a non-conformity with the cooling circuit of a collimator at a very early stage, before it could become a limitation [9].

Issues with temperature probes were also diagnosed by careful monitoring of their evolution during beam intensity ramp-up: several probes measured unphysical values during beam presence (very abrupt temperature variations for large massive devices), and studies will be launched to assess the causes for the perturbations [8, 9].

EXPECTATIONS FOR 2015

The beam conditions after LS1 (up to 2748 bunches spaced by 25 ns with close to nominal bunch population of $1.15 \cdot 10^{11}$ protons per bunch (p/b) at 6.5 TeV and similar bunch length as 2012) were not expected to yield a significant increase of beam induced RF power loss for equipment with a broadband longitudinal impedance spectrum, but the impact on narrow band impedances excited by the 50 ns beam before LS1 was expected to be “double or quits” with the switch to 25 ns beam in 2015 [3].

RESULTS IN 2015

A summary of beam induced RF heating issues for 2015 is provided in Table 1. It can be seen that the effort provided by all teams involved paid off: all blocking issues, with the notable exception of the TDI, disappeared.

The reduction in temperature increase was decisive for the new designs of the BSRT (for which almost no temperature increase could be observed in 2015), ATLAS-ALFA (for which the maximum temperature remained far from the danger zone, see Fig. 2). The new collimator design with embedded ferrites (TCTP, TCSP) have also shown no significant difference in 2015 with respect to the design without ferrite. No vacuum issue was observed near TOTEM Roman pots despite regular insertions to 3-4 mm from the beam during high luminosity physics fills [10].

Table 1: Summary of LHC Equipment Heating in Run 1, Prospects for 2015 before the run and what really happened*

LHC device	Problem	Run 1	Expected 2015	What happened in 2015
VMTSA	Damage	Black	Green	Green
TDI	Damage	Black	Yellow	Black
BSRT	Damage	Black	Green	Green
MKI	Delay	Red	Green	Green
collimators	Few dumps	Red	Green	Green
TOTEM	Impact on Q6R5	Red	Green	Green
ALFA	Risk of damage	Red	Green	Green
BGI	Vacuum	Yellow	Yellow	Yellow

Thanks to these improvements, it was even possible to let the full bunch length decay freely well below 1 ns due

* The colour code indicates the need for follow up of the considered heating problem on LHC operation. Black means damaged equipment; red means detrimental impact on operation (dump or delay or reduction of luminosity); yellow indicates need for follow up; green means solved.

to synchrotron radiation, which could enable gaining more luminosity, but which also increased the maximum frequency excited by the beam and therefore the beam induced heating (see Fig. 3). In case issues would have come up, studies to flatten the bunch distribution by applying an RF phase modulation [11] were performed and succeeded in reducing the heating on certain components.

The Case of the TDI

The TDI in point 8 for beam 2 (TDI8) unfortunately remained a severe limitation in 2015 for injection and scrubbing periods due to abnormal temperature, vacuum and loss behaviour. Beam impedance observables indicated that the impedance of TDI8 was significantly higher than that of TDI2 (TDI in point 2 for beam 1). Comparison with impedance predictions in different failure cases indicated that the coating could have been compromised, and indeed it turned out that the Titanium coating was severely degraded on TDI8 [12].

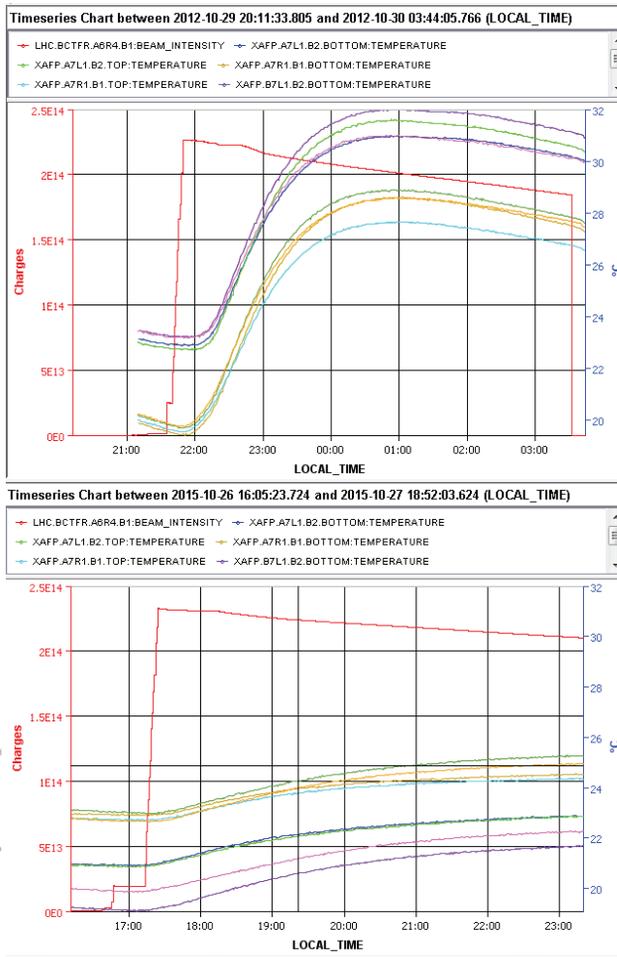


Figure 2: ATLAS-ALFA Roman pots temperatures during fills of similar beam intensities (in red) for a physics fill with 50 ns spacing in October 2012 (top) and for a physics fill with 25 ns spacing in October 2015 (bottom).

Both TDIs were planned to be replaced during the year end technical stop 2015-2016 with new graphite absorber blocks coated with copper in order to avoid these issues as well as non-conformities of the bulk ceramic absorber block also discovered in 2015. These issues are therefore not expected to come back in the next years.

OUTLOOK

Following the severe issues with beam induced RF heating that have affected LHC operation in 2011 and 2012, many actions were taken in LS1 to prepare safe and smooth running in 2015, and it paid off. The heat load gains with the optimized designs were significant and allowed the MKIs, BSRT, new or shielded Roman pots and collimators with ferrites to be operated without limitations. A non-conformity on one TDI has however affected operation in 2015, but it is expected to be solved for 2016. Dedicated temperature monitoring tools have proven their importance and will continue to be improved during the next years of LHC operation.

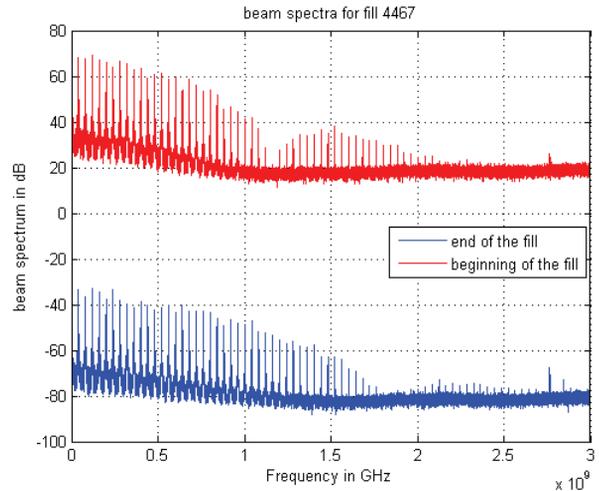


Figure 3: Effect of reducing bunch length on measured beam spectrum (in dB) for LHC fill 4467 from 1.35 ns (total, 4 σ) at the start of stable beams (in red) to 0.82 ns measured 22 h later (in blue). The first notch of the distribution is observed to shift from 1.2 GHz to 1.8 GHz.

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