GENERATION OF CONTROLLED LOSSES IN MILLISECOND TIMESCALE WITH TRANSVERSE DAMPER IN LHC

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Abstract

A controlled way of beam losses generation is required in order to investigate the quench limits of the superconducting magnets in the LHC. This is especially difficult to achieve for losses with millisecond duration. A series of experiments using the transverse damper system has proven that such a fast loss can be obtained even in the case of rigid 4 TeV beams. This paper describes the optimization of beam parameters and transverse damper waveform required to mimic fast loss scenarios and reports on the tracking simulations undertaken to fully understand the temporal and spatial structure of these losses. The application of this method to the final quench tests is also presented.

INTRODUCTION

Unidentified Falling Objects (UFO) [1, 2] are presumably micrometer sized macro particles that lead to beam losses with sub-millisecond duration when they interact with the beam. Between 2010 and 2013 58 LHC fills were terminated due to UFO events and the mitigation was to raise Beam Loss Monitor (BLM) beam abort thresholds. No quench was provoked by UFOs, but at higher top energy after the Long Shutdown 1, UFO related quenches are expected due to the higher beam losses and lower quench margin of the superconducting magnets. Therefore the knowledge of the quench limit for UFO losses is crucial and it was proposed to investigate it during the quench test campaign [3].

In order to investigate UFO-timescale beam losses and evaluate the quench limit of the magnets for this timescale, a mechanism to generate such losses had to be developed. A good candidate is the wire scanner and it was used during the quench test in 2010 [4]. The disadvantages of this approach are:

- fixed location: wire scanner can generate losses only on the MBRB magnet in IR4 of LHC,
- magnet type: the MBRB magnet is operated at 4 K and is not representative for LHC arc dipole and quadrupole magnets which have a different type of superconducting cable and are operated at 1.9 K,
- potentially risky quench: the situation of spare magnets of type MBRB raise concerns about a reparation time in case of failure of this magnet.

Therefore it was decided to use the transverse damper (ADT) [5] to generate beam losses. As this was never tried before a set of tests were performed to prepare the final quench test. This paper describes these tests in chronological order, presents the final procedure and simulations which were performed in order to explain the observed beam behaviour.

TESTS

The following tests took place before the actual quench test:

- on March 26, 2012: test of excitation methods at injection (450 GeV),
- on June 22, 2012: test of procedure at 4 TeV,
- on October 13, 2012: test the combined excitation of tune kicker and transverse damper,
- on January 30, 2013: test with ultra-low intensity beams.

In all these tests the aperture limitation was chosen to be on the collimators and leakage to cold magnets was monitored in order to make sure that the test leads to localized losses. Unexpected loss locations were never observed.

The final test took place on 15 February 2013. The concept of the test, combining the orbital bump with ADT excitation, is shown in Fig. 1. The goal: quenching the magnet at a millisecond timescale, was achieved.

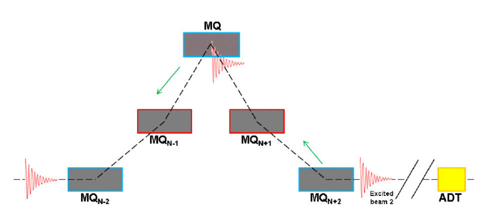

Figure 1: The concept of the quench test: a three-corrector orbit bump and beam excitation with ADT.

Excitation Method

The first test took place on 26 March 2012. It was done at injection energy (450 GeV) with a pilot bunch ($5 \cdot 10^9$ protons) and no other special settings. The goal was to test the principle and see which of the excitation methods gives the best results.

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There are three beam excitation methods possible with the current ADT setup:

- coherent excitation where beam is excited with frequencies swept around the beam tune; it is used to clean the abort gap,
- white noise excitation, also used to blow up the beam emittance in the loss map procedure which is used to verify the hierarchy of collimator setup,
- feedback sign flip, which locks on the beam tune with positive feedback.

The main outcome of this test was that the last method gives the fastest beam loss.

Test at 4 TeV

The beam at 4 TeV energy is much more rigid than at injection, therefore the ADT excitation is less efficient. In the test performed on 22 June 2012, the 4 TeV beams were used and the losses were generated in both horizontal and vertical planes and for both beams. As expected, the measured temporal loss profiles do not depend on the betatron phase advance between transverse damper and loss location.

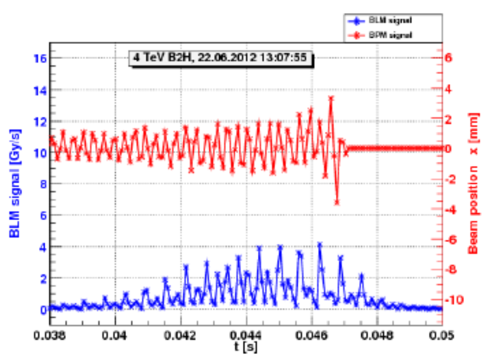

Figure 2: Comparison of BLM (blue line) and BPM (red line) signals (4 TeV).

In order to simulate losses on one side of the aperture an asymmetric setting of the collimators was used. In addition the excitation was made bunch-by-bunch, in order to have multiple measurements for various excitation parameters. The BLM study buffer with 80 μs temporal resolution and a duration of 350 ms was used for data acquisition. The time structure of the losses was observed. Figure 2 shows a comparison of Beam Position Monitor (BPM) and BLM signals for excitation with 200% of the maximum strength of ADT normally used in operation. For the details of this test see [6].

Using Tune Kicker for Initial Kick and Full ADT Strength

On 13 October 2012 an initial excitation with the tune kicker (MKQ) was applied to increase the oscillations growth rate. Furthermore, the ADT excitation window was increased to more than 1 μs to achieve a three times higher normalized kick strength and oscillation rise time. Relation between oscillation window and maximum amplitude is explained in Fig. 3.

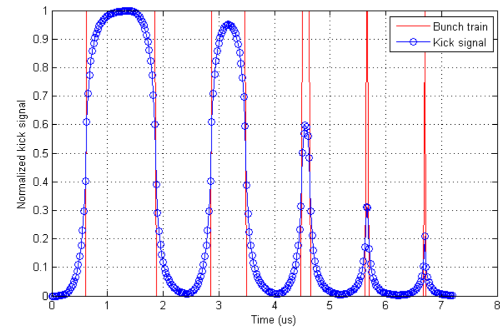

Figure 3: Shape of the ADT excitation for various gating scenarios.

In order to reduce the natural damping and increase the linearity of the optics, the octupoles were set to zero current and the chromaticity was reduced to less than 5 units. The root-mean-square of the arc BPMs is shown in Fig. 4 illustrating the increase in amplitude of the oscillation. The first kick, just before turn 90, is due to MKQ. The rate of increase of the orbit oscillations is $8.3\ \mu\mathrm{m/turn}$. For comparison, at injection energy this rate is $76.4\ \mu\mathrm{m/turn}$.

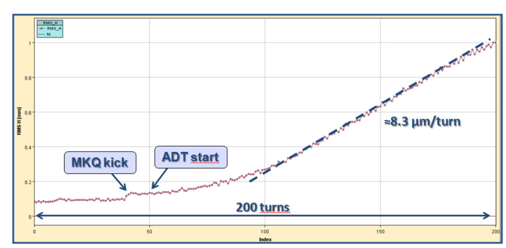

Figure 4: The root-mean-square of the orbit oscillations growing in time.

Tuning ADT and Instrumentation for Ultra-low Intensity

The quench limit corresponds to losses of the order of 10^8 protons, which is much below the typical intensity of a pilot bunch and out of the dynamic range of most beam instrumentation. Therefore, a dedicated test was performed on 30 January 2013. Ultra-low sensitivity settings were applied for the ADT and the pickups were calibrated with orbit bumps to provide bunch-by-bunch beam position information.

Wire scans were done in order to check if emittance can be measured. For the intensity measurement, the abort gap monitor (based on synchrotron light monitor) and the wall current monitor were used in addition to the DC and fast beam current transformers (DCBCT, FBCT)

Additional BLMs have been installed on the targeted magnet; their functionality has been verified by beam losses due to a large orbit bump.

The Quench Test

The quench test took place on 15 February 2013 with the following initial settings:

- ADT gain: 400%,
- octupoles to zero current,
- chromaticity below 5 units,
- MKQ gain: 100%,
- normalized horizontal beam emittance: $0.5\ \mu$m,
- normalized vertical beam emittance: $80\ \mu$m.

After ramping the beam to 4 TeV, and applying the settings, an orbit bump was established in MQ.12R6.B2 until beam losses appeared when the retraction was smaller than the opening of the collimators. First all bunches were scraped horizontally by reducing the opening of the collimators to bunch intensities of about 10^9 protons. After this, the horizontal collimators were completely retracted.

The intensities of individual bunches were then reduced further down: to $1 \cdot 10^8$ protons for the first attempt. This was done by vertical blow-up (white noise) with the ADT. The individual bunches were then excited with the described combination of MKQ and ADT. The excitations were repeated with the next bunch with increasing initial intensity. With an initial intensity of $8.2 \cdot 10^8$ protons ($< 1\%$ of a nominal bunch intensity) the losses led to a quench of MQ12L6. With $4 \cdot 10^8$ protons no quench has been observed. As the loss patterns are very spiky, with peak losses which may have reached the upper limit by the BLM electronics for the BLM dump thresholds, the ADT gain was reduced during the test to 200%.

SIMULATIONS

Dedicated tracking studies with MadX [7] have been performed to model the spatial distribution of the lost beam particles and its dependence on time. In order to fully describe the experimental conditions, the simulations are done in several steps. Firstly, the 3-corrector orbit bump is applied as it is done in the final quench test, then after several turns the MKQ kicks the bunch, and at a delay time of 1 ms (11 turns) the ADT starts the excitation. The ADT pickup data (BPMCA.7R4.B2, BPMC.9R4.B2) is used for controlling the strengths of the MKQ and ADT-kicks. In the simulations the ADT kick is treated as a sine function with growing amplitude for the first 100 turns. After that the saturation is reached and the excitation continues with the full kick either in one or the other direction, depending on the phase advance of the particles in the ADT. The parameters are tuned to give the best agreement with the experiment. In Fig. 5 the simulated beam position at BPMCA.7R4.B2 is compared to the measured beam position.

The time and loss position of every particle touching the aperture is stored. The results from the tracking simulations will be used as input for dedicated particle shower simulations to estimate the peak energy density in the magnet, which can be compared to the predicted quench limits.

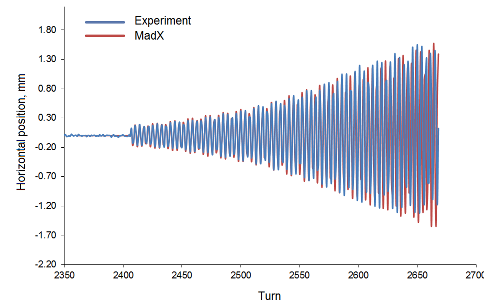

Figure 5: Comparison of MADX simulation and data collected during quench test.

CONCLUSIONS

The transverse damper was successfully used to generate controlled beam losses above the magnet quench level on the millisecond timescale at a beam energy of 4 TeV. Due to a limitation of the BLM electronics the loss duration for the final quench test had to be increased to about 10 ms, though.

With about $8.2 \cdot 10^8$ lost protons (less than 1 percent of a nominal bunch) the LHC arc quadrupole magnet Q12L6.B2 quenched. A preliminary estimate shows that the observed quench limit is about a factor 6-13 higher above the expected quench limit. A detailed analysis is ongoing.

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