

ACOUSTIC MEASUREMENTS IN THE COLLIMATION REGION OF THE LHC*

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Abstract

The LHC accelerator at CERN has the most advanced collimation system ever being installed. The collimators intercept unavoidable particle losses and therefore are essential to avoid beam induced quenches of the superconducting magnets. In addition, they provide passive machine protection against mis-kicked beams. During material robustness tests on a LHC collimator prototype in 2004 and 2006, vibration and acoustic measurements have shown that a beam impact detection system should be feasible using accelerometers and microphones as sensors in the LHC. Recently, such sensors have been installed close to the primary collimators in the LHC tunnel. First analyses of raw data show that the system is sensitive enough to detect beam scraping on collimators. Therefore, the implementation of a sophisticated acoustic monitoring system is under investigation. It may be useful not only to detect beam impacts on primary collimators in case of failure, but also to derive further information on beam losses that occur during regular operation. This paper gives an overview on the recent installation, results of the acoustic measurements made at the LHC, and future plans.

INTRODUCTION

In 2004 and 2006, the robustness of collimator jaw materials has been tested at the SPS at CERN. The jaws were impacted by 450 GeV proton beams with intensities from 1×10^{10} to 3×10^{13} protons. The signals from accelerometers attached to the collimator support and microphones installed a few meters upstream of the collimator showed signal spikes linearly increasing with the bunch intensities. Spectral components found in the tails of the spikes matched resonance frequencies of the collimator jaw and tank [1]. The installation of acoustic sensors at the LHC was thus proposed as detection and localization tool for heavy beam impacts on collimators. In the LHC, a hierarchy of 44 collimators per beam line is currently setup for beam cleaning during operation. With the jaws as close as 6 sigmas from the beam centre, four primary collimators form the smallest aperture of the beam line [2]. In case of failure, it is most likely that the beam will first impact on the primary collimators and may possibly damage the jaw.

Microphone setup at the LHC

As a first step towards an acoustic monitoring system, a non-prepolarized, omni-directional condenser microphone (B&K type 4939) was installed upstream of each of the

four primary collimator regions (off-momentum and betatron cleaning) in the LHC during the winter shutdown 2010/2011 (c.f. Fig. 1). In addition, a second microphone was installed between the horizontal and skew primary collimators at the betatron cleaning section of beam 1 in IR7, as illustrated in Fig. 2. With the microphones being attached close to the LHC tunnel walls, they have a distance of approximately 1.5 meters to the beam pipes. Their signals are amplified with a remote controlled amplifier (B&K Nexus) which is installed upstream of the collimators and below a collimator support to reduce radiation impacts. After amplification, the signal is digitized with a data acquisition system (NI PXIe with 4496 type acquisition board) running a dedicated Server/Client application developed in Labview[®], which provides the data to any client attached to the CERN technical network. The PXIe systems are installed in shielded areas close to the collimation regions, the signals are sent over coaxial RF cables with distances of 100-300m. The acquired data can be sampled with up to 200 ksamples/s per channel and a resolution of 24 bit. The microphones cover a frequency range from 4 Hz up to 100 kHz and a dynamic range of 28-164 dB sound pressure level (SPL). The calibration of the system relies on the specifications given by the manufacturers of the components.

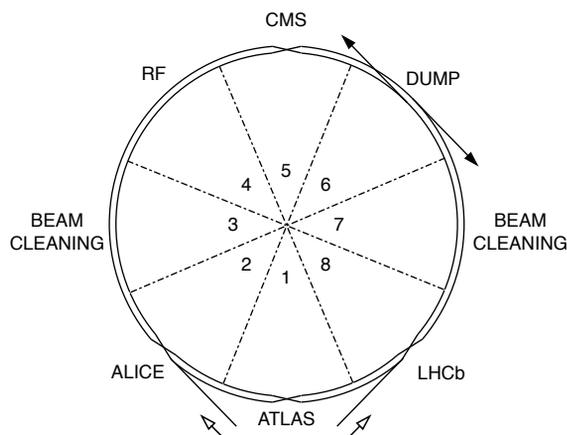


Figure 1: Scheme of the eight LHC sections. Microphones have been installed at all primary collimator regions in sector 3 and 7 for both beams.

GENERAL OBSERVATIONS

Besides the expected sounds from strong beam impacts, it is subject of current research what the microphones pick up during normal LHC operation. In the following sec-

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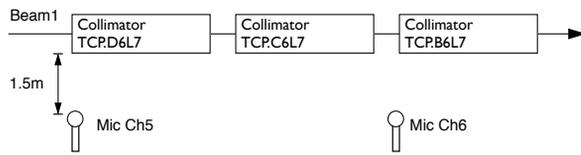


Figure 2: Positions of the microphones installed at the tunnel wall close to primary collimators in IR7 for beam 1.

tion, a qualitative description of observations is given. It is noted, that sudden beam impacts (single turn losses) on collimator jaws are limited due to safety restrictions in the LHC. With these limitations, sounds as seen in [1] have not been detected with the current installation.

Background noise

Sounds emanating from fluid dynamics and mechanical parts in the surrounding area and electrically induced noise form a noise footprint, which is different at each section and may even change over time due to changes of the parts' operational state. High amplification and a large voltage range of the DAQ board is beneficial to reduce electrically induced noise after the amplifier. With this setting, an average background noise level of 70db SPL was found to be present. Figure 3 shows an exemplary footprint for IP7 left.

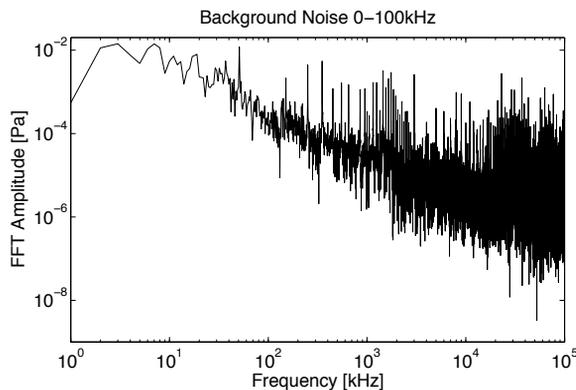


Figure 3: FFT of background noise in IP7 left. Tonal components are mainly EM induced noise.

Signal spikes during losses

Particle losses create spikes in the microphone signal, c.f. Fig.4. They easily exceed background noise level and reached 143 db SPL for the highest observed loss rate (3 Gy/s). The signal envelope resembles spikes observed during earlier material tests, but does have longer rising times. It was already stated in [1], that these spikes may be induced by radiation effects. Radiation may impact directly into the condenser capsule of the microphone, to the electronics of the built in microphone preamplifier, to all cables and even to the amplifier which is installed a few meters upstream of the collimation section.

Beam revolution frequency

The FFT spectra during particle losses show a rising component at the beam revolution frequency $f_{rev} = 11.245$ kHz of the LHC beam and its harmonics. Apparently, this is a consequence of the multi turn characteristics of particle losses which have been observed. For such losses, a bunch loses particles each time it passes the collimator for multiple turns. The amplitude of the FFT component increases with the loss rate.

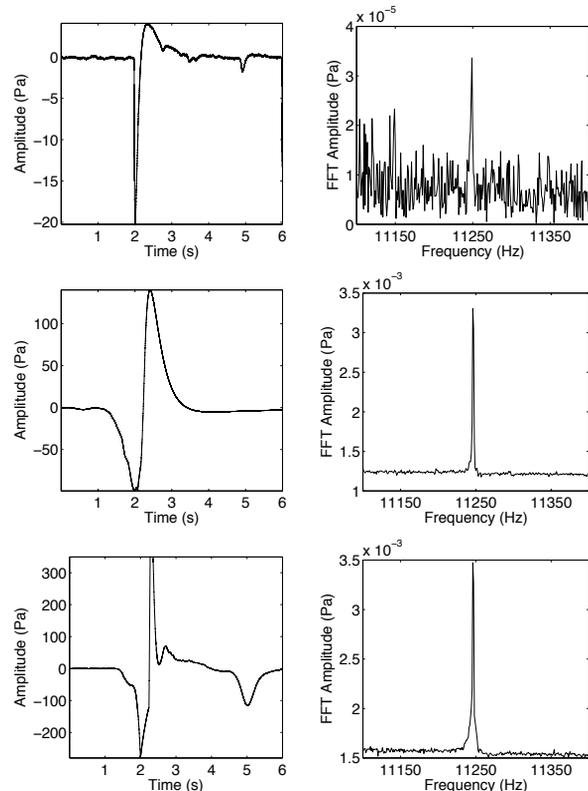


Figure 4: Spikes in microphone signals during beam losses with low, medium and high loss rates (top, middle, bottom). Amplitude vs. time (left) and FFT Amplitude vs. frequency (right). FFT size of 200 ksamples, 1s window triggered at the beginning of the spike, Hanning window.

RESULTS FROM BEAM SCRAPING WITH COLLIMATORS

During a halo scraping experiment, the signals of CH5 and CH6 (Fig.2) were recorded. Several stepped beam scrapings with the primary collimators in vertical (TCP.D6L7), horizontal (TCP.C6L7) and skew (TCP.B6L7) position were performed with a step size of $40 \mu\text{m}$ and an interval of 4 s [3]. For comparison with the measured loss rate from a reference beam loss monitor (BLM) with a running sum of 1.3 s, the integrated microphone signal was calculated with an integration time of 1.3 s for each timestamp of the BLM values (read out frequency is 1Hz).

Microphone vs BLM signal

Fig. 5 shows a comparison of integrated microphone signal, FFT components at f_{rev} and the reference BLM signal for the TCP.D6L7 scraping. It can be seen that, once the spike level exceeds the background noise, the shape of the scraping is similar.

When plotting the derived values from the microphone signal at each scraping step against the BLM values, a linear dependency becomes obvious for both, the integrated signal amplitude and the FFT components at f_{rev} , c.f. Fig. 6. It is noted that CH6 downstream of the collimator is by a factor of 3.5 (Amplitude) and 5 (FFT) more sensitive than CH5.

CH6 is installed approximately 1.5 m downstream of the impacted collimator, while CH5 is installed at the level of the upstream end of the collimator, c.f. Fig. 2. Sounds emanating from vibrations of the collimator are assumed to propagate omni-directional from the source, while radiation appears much stronger downstream due to the particles relativistic velocity. Therefore, it is concluded that both effects, the spike as well as the f_{rev} component, are induced by radiation.

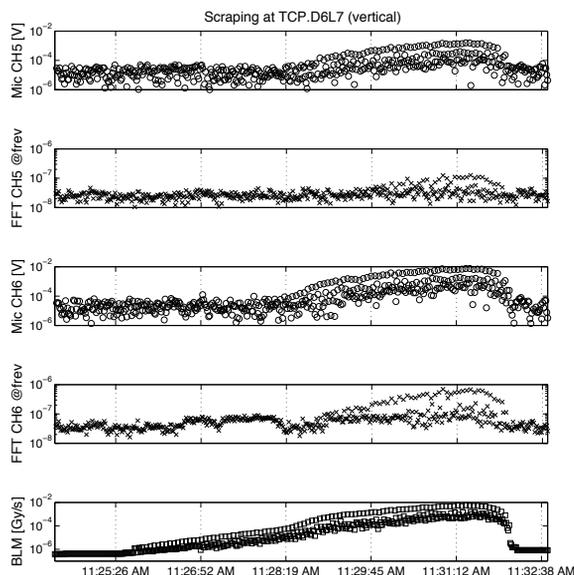


Figure 5: Comparison of microphone signals CH5 and CH6 with a running sum of 1.3 s and a sample rate of 1 Hz, the corresponding FFT bins at f_{rev} , and the reference BLM signal at collimator TCP.C6L7 during a scraping at TCP.D6L7 vertical collimator. A similar response to losses can be seen in all signals. Loss spikes exceed background noise level at approximately 10^{-4} Gy/s for both microphones.

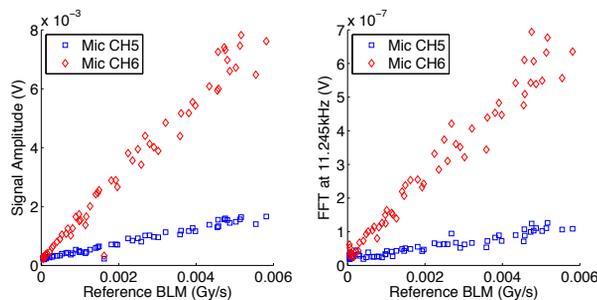


Figure 6: Scraping at TCP.D6L7 vertical collimator. BLM vs. microphone signal (left) and vs. FFT component at f_{rev} (right). A linear dependency can be seen for both effects. Microphone CH6 is more sensitive to losses than CH5.

SUMMARY

In this paper, an overview on the current microphone installations at the LHC was given. Results from a beam scraping test with collimators show that spikes in the microphone signals increase linearly with the loss rate and are radiation induced effects. Background noise sets a lower detection limit to approximately 10^{-4} Gy/s measured at a reference BLM close to the microphone. The constant ratio between BLM and microphone responses can be used as scaling coefficient to determine instantaneous loss rates at the collimators directly from the microphone signals.

The sampling rate of up to 200 kHz would in principle be sufficient to bunch wise resolve higher particle losses. Determining parameters of the signal shape of radiation effects as seen in this paper, e.g. the rising time of the spikes, may yield a good quantification of signal losses.

However, measurements of beam induced sounds from shockwaves require stronger impacts. The intensity for sudden beam impacts on collimator jaws is limited in the LHC for safety reasons, thus, further measurements at the HiRadMat facility during jaw material tests are planned for 2011/2012. It is also proposed to move one of the DAQ systems to the beam dump section in IR6 to pick up the sound of full nominal intensity beam dumps.

The microphone data will also be used for sonification applications and made available to the public. Samples can be found at [4].

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