

## EMBEDDED COLLIMATOR BEAM POSITION MONITORS

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### Abstract

The LHC collimation system is crucial for safe and reliable operation of proton beams with 350 MJ stored energy. Currently the collimator set-up is performed by observing beam losses when approaching the collimator jaws to the beam. For about 100 LHC movable collimators the procedure may take several hours and since it has to be repeated whenever the beam configuration changes significantly, the collimator setup has an important impact on the overall machine operation efficiency. To reduce the collimator setup time by two orders of magnitude the next generation of the LHC collimators will be equipped with button beam position monitors (BPMs) embedded into the collimator jaws. This paper describes the BPM design and presents prototype results obtained with beam in the CERN-SPS.

### INTRODUCTION

At present, in so called Phase I, 43 collimators per beam are installed in the LHC ring [1]. In the future 8 tertiary, 4 dispersion suppressor (DS) and 16 Phase II collimators will be added.

Currently the standard collimator set-up method relies on positioning the collimator jaws with respect to the circulating beam by moving the jaws towards the beam until they touch the primary beam halo, creating beam loss, which is then detected by downstream beam loss monitors (BLMs). The procedure is long: even the 2011 optimised semi-automated version still requires some 36 hours for all LHC collimators. For safety reasons this procedure cannot be performed with physics beam

configuration and special low intensity machine fills are used. This imposes tight specifications of beam orbit stability for much different beam intensities.

Integration of BPMs into collimator jaws will allow much faster jaw positioning with the beam configuration used for physics. In addition the actual beam orbit between the jaws will be measured, allowing continuous beam centring either by adjusting jaw positions or by using the collimator BPM readings in the orbit feedback system and steering appropriate orbit correctors to keep the beam exactly between the collimator jaws. This will relax requirements for beam orbit stability and reproducibility and allow potential improvements of the collimation efficiency.

The idea of BPMs embedded into the collimator jaws was tested on a prototype collimator, so called "BPM demonstrator", based on a modified version of the phase I LHC collimator with graphite plates on the jaw surface [2]. Its sketch and photographs of the BPM regions are shown in Fig. 1. The prototype was installed in the CERN SPS for beam tests. This paper provides details about this prototype and obtained results.

### BPM REQUIREMENTS

The collimator jaws can be placed as close as 0.25 mm to the circulating LHC beam, with a distance in the order of 1 mm for nominal operation at 7 TeV. The jaws themselves are water cooled to withstand the thermal load due to beam losses, which can be as high as 10 kW for a jaw of the future phase II collimator. However, it is not the case for the BPM buttons, due to their relatively weak

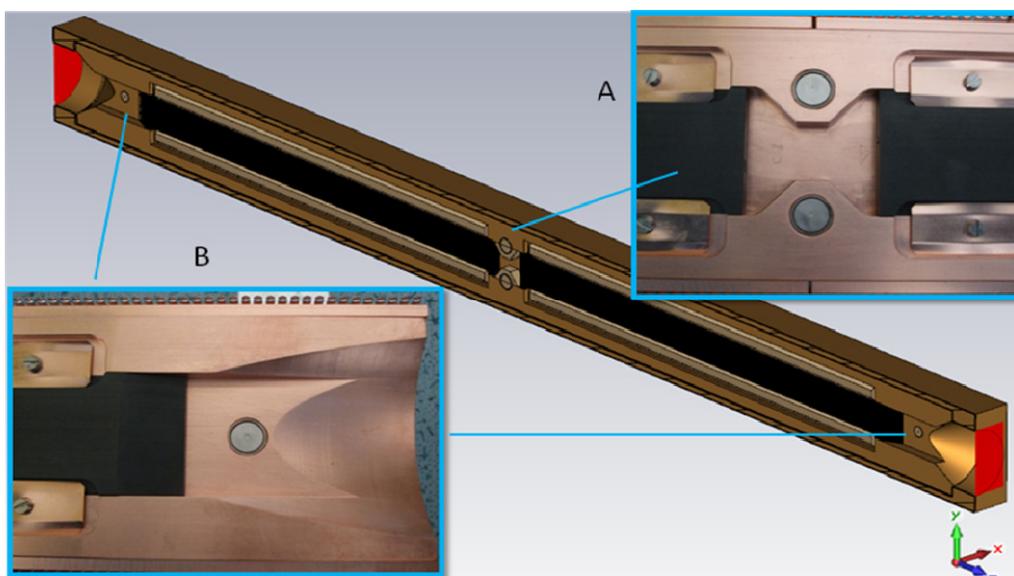


Figure 1: A model of one jaw of the collimator demonstrator. Detail A: the button pair in the middle, detail B: buttons in the tapered regions at the jaw ends.

thermal coupling to the jaws. In addition the beam loss current on BPM electrodes would perturb their signals and in turn the position readings. Therefore, the BPM electrodes should be placed on the jaws in such a way to protect them from the beam losses related to nominal collimator operation. These beam losses generate strong radiation, which must be withstood without electrical changes by all collimator components, including the BPMs.

The required mechanical stability of the collimator jaws is some 40  $\mu\text{m}$  on the full length of 1200 mm for the expected temperature increase of 50° C, and similar requirements apply for the BPMs. However, the complete collimators will be baked out in situ up to 250° C and the BPMs must be compatible with this procedure. This is necessary because collimator components are located inside the collimator tank, which is directly connected to the machine vacuum chamber and therefore must be compatible with ultra high vacuum (UHV) requirements.

The LHC collimators contribute significantly to the machine impedance budget and their design must be optimised also for this parameter.

### BPM INTEGRATION

The BPM demonstrator has copper jaws with graphite inserts, whose electrical conductivity is some orders of magnitude smaller than copper. This is why the button pick-up electrodes should be placed at the copper surface level, to intercept the beam image current flowing there. The demonstrator prototype was built with four buttons per jaw, as shown in Fig. 1. The two buttons at the jaw ends are placed in the tapering region on the longitudinal symmetry axis and the button surface is precisely adjusted to the copper surface of the jaws, resulting in 10 mm retraction from the graphite surface (thickness 10 mm, length 1 m). This position guarantees that the beam will not touch the BPM buttons during collimator operation.

As it was not sure that stray particle showers coming from jaw beam scraping would not perturb signals of these buttons, a pair of buttons were put in the jaw

middle, displaced from the jaw longitudinal symmetry axis by 20 mm.

The presented positions of the buttons are a compromise between mechanical constraints, button response and protection from the direct beam impact. For the demonstrator prototype commercial buttons integrated with coaxial feedthroughs with SMA connectors are used ( $\varnothing$  10.3 mm, 3.8 pF). Their response was simulated with CST Particle Studio [3].

Due to the expected radiation dose and temperature increase only coaxial cables with SiO<sub>2</sub> insulator could be used to connect the buttons to the tank vacuum feedthroughs. Such cables also provide exceptionally low hysteresis for electrical length and attenuation during temperature stresses. For UHV compatibility the outer conductor of the hermetic cable is made of 304L stainless steel ( $\varnothing$  2.3 mm), copper plated from the inside to lower the cable attenuation.

The cables connecting the buttons to the feedthroughs of vacuum tank are shaped to accommodate the jaw maximal displacement of 62 mm, see Fig. 3. As shown in Fig. 2, the cables are fixed to the tank before the vacuum feedthroughs to remove mechanical stress on the connector and to improve contact reliability, needed during many jaw displacement cycles. The cables of each button pair are matched for electrical delay within 20 ps.

The UHV vacuum feedthroughs passing the BPM signals from the inside of the collimator to the outside are mounted on a UHV flange and are equipped with coaxial SMA connectors on each side (Fig. 2).

### MEASUREMENTS

To keep signals from the opposing buttons equal for the centred beam, the buttons are sorted on a test bench by their response amplitude. Pairs with the closest response are then mounted onto the collimator jaws.

Once the collimator demonstrator was assembled, a wire was stretched between the collimator jaws for lab measurements in both, frequency and time domain. A result example from such measurements is plotted in

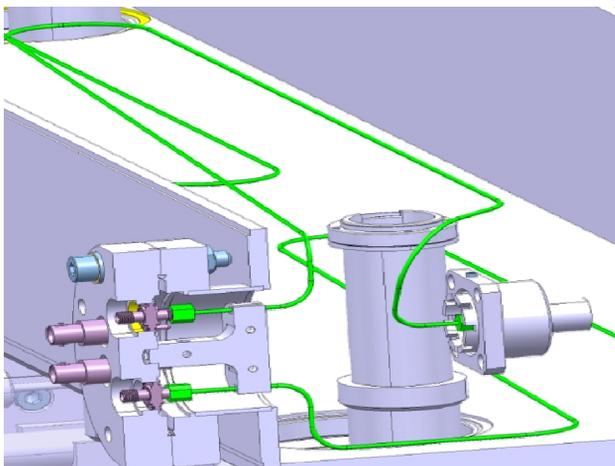


Figure 2: A cross-section view of one tank feedthrough assembly and a cable shape up to the button fixture.



Figure 3: The two copper jaws and the special cables inside the collimator demonstrator (no upper tank cover).

Fig. 4, showing the response of the buttons with respect to the wire signals excitation as a function of the button distance. It can be seen that the signal for the button at the jaw end increases with its distance to the wire decreasing, while for the button in the middle the signal is decreasing to a very small value for very small jaw distances. Such behaviour was anticipated, but the middle buttons were put on the jaws in case the buttons at the jaw ends suffer too much from beam loss.

The transfer impedance (i.e. the ratio of the button voltage to the simulated beam current) was found to be  $0.17 \Omega$  at .6 GHz for fully opened jaws (distance 62 mm).

After the successful laboratory measurements the collimator demonstrator was installed in the SPS for beam tests. The most important question to answer was whether the end buttons can operate in the presence of jaw-induced beam loss.

To answer the question a digital oscilloscope with an Ethernet connection was installed close to the SPS tunnel, where the collimator cables were coming to. Ports of each pair of the end buttons were connected to the oscilloscope. An example of the obtained signals can be seen in Fig. 5.

The signals did not change with the jaws motion towards the SPS beam, even with losses corresponding to some  $10^{10}$  charges per step. Signals were also not perturbed by beam losses generated with a second upstream SPS collimator.

Since the end buttons worked well in the presence of strong beam loss, the buttons in the middle became less important and they were removed from the final jaw design. This simplifies mechanical design of the jaws, especially the water cooling channels.

The collimator BPM signals will be processed with dedicated high-resolution electronics based on compensated diode detectors, whose prototype was also tested with the SPS beam. However, the SPS beam stability was not adequate for evaluating its performance. Alternatively the electronics was tested on the LHC, showing sub- $\mu\text{m}$  resolution [4]. It will be preceded by a passive signal multiplexer, switching the signals from the opposing BPM electrodes to the same electronics channel. In this way slow drifts of the electronics parameters are not important, as centring of the beam will be achieved by equalizing the signals from the opposing button electrodes, measured alternately by the same electronics channel. In this way the absolute centring accuracy is defined by the electronics resolution, its short-term stability and symmetry of the signal multiplexer.

## CONCLUSIONS

The button BPMs embedded into the collimator jaws will be an important improvement of the performance and reliability of the LHC collimator system. The first implementation of this idea on an SPS prototype was successfully tested in the laboratory and with the SPS beam. All future collimators will be equipped with integrated BPMs. It is foreseen that the collimator BPMs

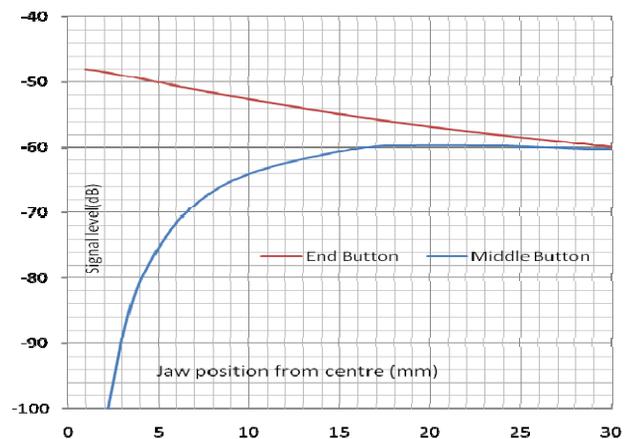


Figure 4: Button sensitivity vs. jaw position for fully opened jaws, measurement at 600 MHz.

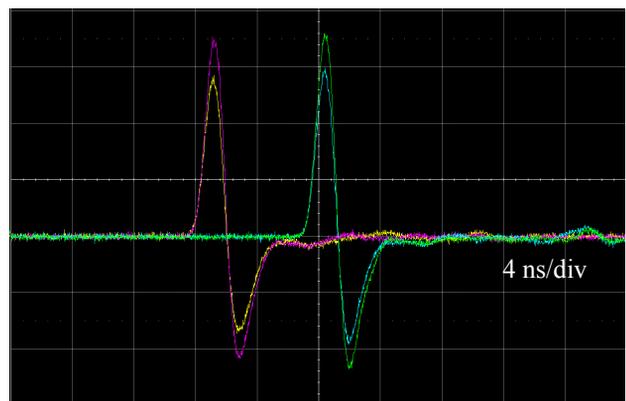


Figure 5: End button signals corresponding to a single bunch of  $1.7 \times 10^{10}$  protons, 1 GHz scope bandwidth.

connected to the dedicated high resolution electronics will provide beam position measurement with the resolution better than  $1 \mu\text{m}$  even for fully opened jaws.

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