BPM DESIGN AND IMPEDANCE CONSIDERATIONS FOR A ROTATABLE COLLIMATOR FOR THE LHC COLLIMATION UPGRADE*

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Abstract

The Phase II upgrade to the LHC collimation system calls for complementing the 30 high robust Phase I graphite secondary collimators with 30 high Z Phase II collimators. This paper reports on BPM and impedance considerations and measurements of the integrated BPMs in the prototype rotatable collimator to be installed in the Super Proton Synchrotron (SPS) at CERN. The BPMs are necessary to align the jaws with the beam. Without careful design the beam impedance can result in unacceptable heating of the chamber wall or beam instabilities. The impedance measurements involve utilizing both a single displaced wire and two wires excited in opposite phase to disentangle the driving and detuning transverse impedances. Trapped mode resonances and longitudinal impedance are to also be measured and compared with simulations. These measurements, when completed, will demonstrate the device is fully operational and has the impedance characteristics and BPM performance acceptable for installation in the SPS.

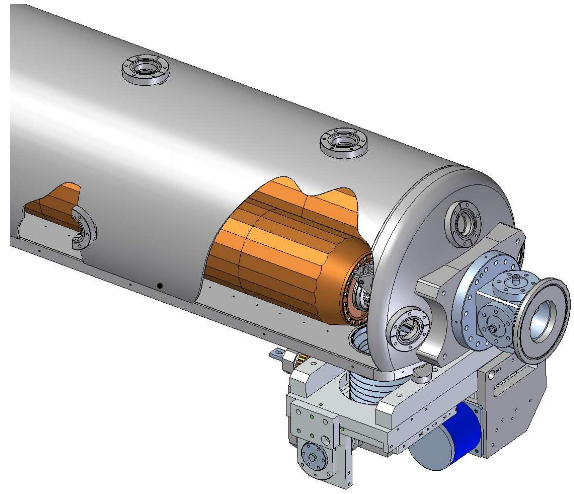

Figure 1: LARP rotatable collimator with BPM assembly.

THE BPM DESIGN

Each end of the device incorporates a BPM assembly housing as shown in figure 1 to be used to align the jaws relative to the beam with a resolution of 25 microns or better. Positioning the BPMS at the end of the device has several advantages over locations nearer to the jaws:

1. The chamber is rigid and therefore the buttons will not move.
2. The use of the standard 34mm LHC IR7 BPMW buttons ensuring good signal compatibility with the LHC BPM processing electronics.
3. The buttons are located in a round beam pipe as far away as possible from the complex geometry of the collimator jaws. This decreases any stray RF fields from interfering with the button signals improving BPM performance and precision.

Positioning the jaws relative to the beam requires good fiducialization between the jaws and BPMs. The jaw drive system has been demonstrated to position the jaws reliably to within several microns and the LVDTs have been found to have a long term stability of ± 10 microns [1], so fiducialization to within the jaw flatness of 25 microns is not expected to be a problem. A precisely determined fiducial point, or home position, for the jaws can also be established to periodically reset the jaw position relative to the BPMs and avoid long term drift.

The use of the standard IR7 BPM ensures that the button design has been demonstrated to work with LHC beams. The most significant concern is the leaking of RF fields from the collimator chamber into the beam pipe housing the buttons. Ideally, any signals near 40 MHz emanating from the chamber would be damped by at least 60 decibels at the buttons. Based on the formulation by Abe [2], calculations have shown that for a 30.5 mm radius beam pipe, the dominant TE11 mode at 40 MHz damps at the rate of 524 dB/m. Damping 60 dB would require 11.5 cm of pipe length. The current design has 6 cm, or a damping of 31 dB. Although not ideal, this is deemed acceptable for a decent BPM signal. It should also be noted that the lowest trapped mode found in the collimator is 53 MHz – far away from the 40 MHz BPM signal and so little RF at 40 MHz should be generated in the collimator chamber [12].

The BPM resolution should be at least 25 microns as this is the flatness specification for the jaw surfaces. The button has a maximized surface area to maximize signal strength. Also, there is no need for bunch by bunch diagnostics so the signal can be integrated over several thousand bunches improving resolution tremendously. A 25 micron resolution is not considered problematic and similar BPMs can achieve resolutions much better.

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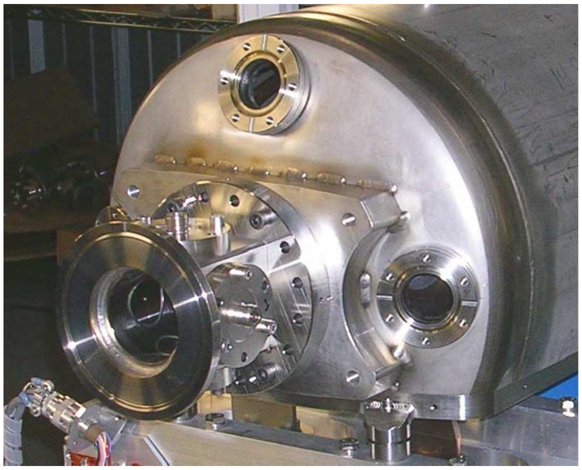

Figure 2: LARP rotatable collimator.

BPM Measurements

The BPMs are standard 34mm LHC IR7 BPMW buttons used in the IR7 warm section of the LHC. The principle tests performed involve using a Time-Domain Reflectometer to get high frequency response of the buttons such as connectivity and capacitance. Coupling with any trapped modes in the collimator can be performed by extending an antenna through the device excited at 40 MHz and measuring any pickup on the buttons. In addition to a wire stretched down the center of the device (or displaced from center), antennas can also be positioned using the numerous feedthrough ports positioned along the device. It is anticipated that no 40 Mhz trapped mode signals will couple to the BPMs because the lowest trapped mode is estimated to be about 53 Mhz and also the attenuation of 40 Mhz signals along the 60 mm BPM assembly pipe is estimated to be 30 db.

Figure 2 shows one of the BPM assemblies attached to the tank. The first measurements were performed with just the BPM end assembly with individual buttons attached to both a TDA and VNA. This allows for measurements of the coupling and capacitance between the buttons. Capacitance of each button was measured by fitting a decay curve to the response of the TDA when connected to each button. The measured capacitance is 16 pF and consistent with the capacitance measured on the buttons at CERN [6]. Coupling between the horizontal and vertical buttons is 62 dB at 40 Mhz which is small.

IMPEDANCE CONSIDERATIONS

There are four principle impedance considerations for the collimator 1. resistive wall impedance, 2. geometric impedance, 3. sliding contacts and 4. trapped mode resonances. The resistive wall impedance is driven by the copper jaws. Due to the close proximity of the jaws to the beam (1 mm) and the low frequencies of concern a new inductive impedance regime has been discovered and verified [3]. This contribution is unavoidable because the copper must be long and close to the beam in order to perform as a collimator. With this in mind, the target impedance design goal is to ensure the resistive wall impedance dominates over the other contributions which can be minimized with proper design. The geometric impedance is driven by the taper at each end of the collimator. Using the standard Yukoya collimator impedance formulas [4] the kick factor contribution from both the resistive wall and geometric were calculated. The taper length was optimized to maximize the jaw length and still let the resistive wall dominate the impedance. The resistive wall kick factor was calculated to be $1.418789479 \times 10^{14} \frac{V}{C \cdot m}$ and the geometric $2.805352013 \times 10^{13} \frac{V}{C \cdot m}$ – approximately 5 times less.The sliding contact between the rotating jaw and the stationary RF foil must also have a low contact resistance in order to not dominate the impedance. Aspects of the sliding contact are discussed in another paper [5]. Trapped modes may still be a concern and are discussed below.

Impedance Measurements

Before installation in the SPS, bench-top impedance measurements must be performed. These will then be compared with beam dynamics studies (i.e. tune-shift, beam breakup, etc...) in the SPS after the collimator is installed. CERN must also have reliable estimates of impedance characteristics before the device will be permitted to be installed in the SPS. The bench-top impedance measurements must measure longitudinal, transverse dipole (or driving) and transverse quadrupole (or detuning) impedances. The longitudinal measurement is performed with a single stretched wire along the longitudinal axis of the device. The transverse with a single wire displaced from the longitudinal axis and two wires excited asymmetrically. The method is described in several sources [7, 8, 9, 10, 11].

The principle measurement method involves stretching a wire down the center of the Device Under Test (DUT) connected to a network analyzer. This method relies on the fact that the electromagnetic field distribution of an ultra-relativistic charged beam is very similar to a TEM transmission line such as exhibited by an excited stretched wire. For longitudinal measurements a single wire is suspended down the center of the DUT. Measurements are made over a frequency range from as low as 1 kHz up to 2 Ghz. To minimize reflections during the measurements the circuit must be matched over this entire range. This can be performed with two-way or one-way matching. A $Z_0 = 50\Omega$ through calibration can then be performed to account for the frequency dependence of the resistors.

The impedance is measured using the transmission coefficient, $S_{21,DUT}$, but must also be compared to a reference line, $S_{21,REF}$, which should be a homogenous matched line of the same length as the DUT. A simple direct measurement can be performed using a copper pipe. A single wire suspended through the center of the DUT will not excite transverse modes. The simplest method to excite trans-

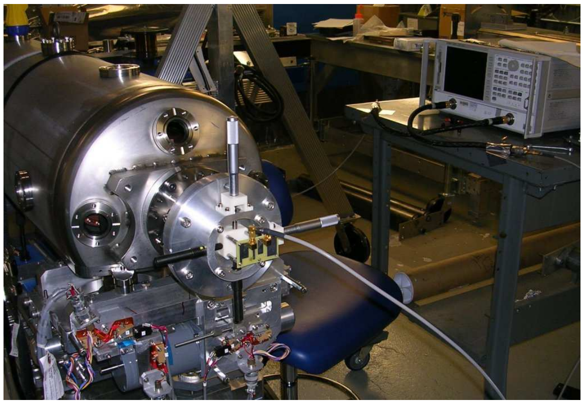

Figure 3: LARP rotatable collimator with wire measurement setup.

verse modes is to transversely offset the wire, but this excites all higher order transverse modes. To just observe the dipole mode two wires should be driven antisymmetrically. Using both a single displaced wire and a pair of wires, both the dipolar (or driving) and quadrupolar (or detuning) impedances can be measured [10]. Higher order excitations (third order and higher) are assumed to be small if the wire offset is small [7].

This wire measurement is beginning to be set up for use with the prototype collimator. Figure 3 shows the collimator with the wire circuit assembled. A PCB with parallel and series resistors is used as the matching circuit. The network analyzer is an Agilent 8720ES. Four linear micrometers are used to position a plastic block supporting either a single wire or a pair of wires. Measurements so far have shown a poor signal to noise ratio. It is anticipated that placing the matching circuit inside a grounded box and shortening the length of the wire outside the device will improve the measurements. Work is ongoing.

Trapped Modes

There is concern that trapped modes may pose a problem in the device for both chamber heating and multi-bunch instabilities. Simulations are ongoing to study the effects of these trapped modes as discussed in a different paper [12]. There are two parameters to consider with trapped modes, namely the Quality Factor, Q, and R/Q. The latter can only be changed with changing the geometry of the device and modelling is currently lending insight into any subtle changes to be made. We have discovered that the transition foils play a large part in the longitudinal modes. Modifications to these foils have damped the longitudinal modes by almost two orders of magnitude. Simulations have also suggested that the Q and R/Q may be too high for some of the lowest transverse modes. The R/Q for the transverse modes is more difficult to lower but Q can be damped using an absorbing material such as ferrite. Trans-Tech TT2-111R ferrite has been demonstrated to absorb electromagnetic fields well at low frequencies [13]. Ferrite tiles will be clamped along the base plate below each of the two jaws out of line of sight of the beam.

The same impedance measurement setup as described above can also detect trapped modes as distinct resonances on the impedance curves. From these resonances it is simple to measure the quality factor for each mode. These measured frequencies and Q values can then be compared with simulations. Current simulations give a damping of the trapped mode Q values by two orders of magnitude when the ferrite is installed.

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