DESIGN OF COLD BEAM POSITION MONITOR FOR CADS INJECTOR II PROTON LINAC

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Abstract

Cold beam position monitor based on capacitive buttons are designed for Chinese Accelerator Driven System (CADS) Injector II proton LINAC. This LINAC is aiming to produce a maximum design current of 15 mA at the 10 MeV energy with an operating frequency of 162.5 MHz. Cold button BPM will be installed in the Cryomodule, which will be in the middle of the superconductor cavity and the superconductor magnet. Some special issues must be considered when designing a cold BPM: low-beta beam in the cryogenic environment, strong rf-field from the superconductor cavity and high magnetic field from the superconductor magnet. In this contribution, the status of cold BPM will be presented, focusing on the electromagnetic response for low-beta beams and mechanical design in the cryogenic environment.

INTRUDUCTION

Cold BPMs are the essential and the only diagnostics components in the Cryomodule of CADS Injector II proton LINAC. Due to the work temperature of 4K, the clean-room environment and the influence of high magnetic field from superconductor (SC) solenoid, we choose the cold button BPM as the first choice for this project. On the one hand, the simple and robust mechanical structure makes button BPM more reliable when used in the cryomodule. On the other hand, for a low beta velocity beam, the capacitive BPM pick-up is more efficient in terms of output signal power, than an inductive one of the same physical size like strip-line BPM [1].

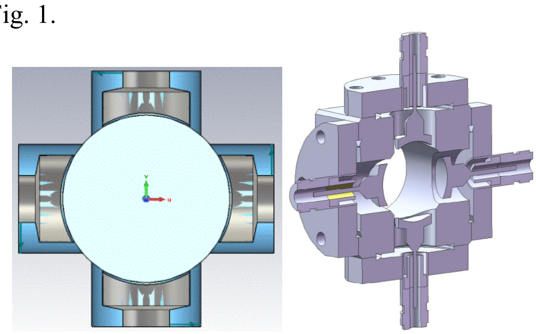
Table 1: CADS injector II proton LINAC cold BPM parameters

Parameters	Value
Beam pipe diameter	40 mm
Beam energy	2.1 MeV – 10 MeV
Bunch frequency	162.5 MHz
Beam pulse length	0.1 ms-CW
Bunch length(rms, sigma)	0.1 ns-0.5 ns
Average current	0.01 mA-15 mA
Peak current	20 mA
Position accuracy	1% of half-aperture
Position resolution	0.1% of half-aperture
Phase accuracy	1-3 deg
Phase resolution	0.1-0.3 deg

BPM's main measurement is to determine the beam position and beam phase, with a spatial resolution of 10μm and 0.1 degree on a continue-wave (CW) beam, by calculating the ration of the difference over sum voltage between two opposite pick-ups. The sum signal from a BPM can be also used as a relative measurement for the beam current. The main parameters are summarized in Table 1.

ELECTROMAGNETIC AND MECHANICAL DESIGN

To improve and extend calculations of the signal response of the monitors, numerical simulations were done by using the code CST PARTICLE STUDIO (CST PS) with the wake-field solver [2]. The excitation source was defined by a Gaussian-shaped longitudinal charge distribution. The cold button BPM consists of four 20.8mm diameter button electrode feedthroughs mounted orthogonally in a 40mm diameter beam pipe. The electrodes are curved to follow the beam pipe aperture and are retracted by about 0.5 mm to avoid charge accumulation on the BPM electrodes due to scattered ions. The cross section drawing of cold button BPM is shown in Fig. 1.



(a) (b)

Figure 1: (a) Cold Button BPM model of CST PS, (b)3D mechanical drawing of cold button BPM chamber

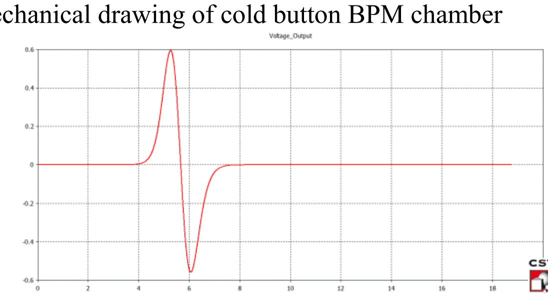


Figure 2: Simulated output signal of one button BPM when a single bunch passing vacuum chamber.

Figure 2 shows the simulated signal read by one button BPM. The beam parameters are the bunch length of 10mm for one sigma, the beam velocity of 0.145 and the beam charge of 90nC.

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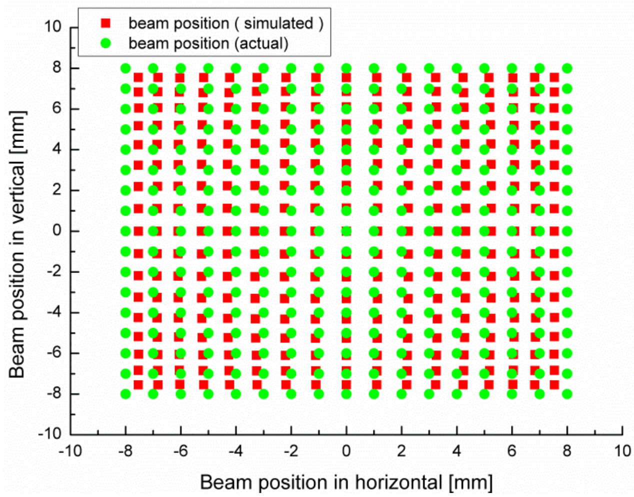

Figure 3: Sensitivity map of the cold button BPM at 162.5 MHz and β = 0.067. Vacuum aperture: 40mm, button diameter: 20.8mm.

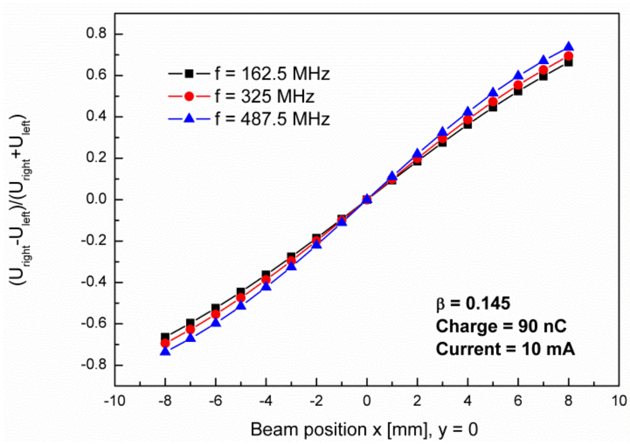

Figure 4: Position calculation of the Difference over Sum method for cold button BPM at the fundamental, first and second harmonic frequency.

Figure 3 shows the sensitivity map obtained by plotting the delta-over-sum values from the signals of two opposite pick-ups for the first harmonics of the accelerating frequency i.e 162.5MHz at β = 0.067. Figure 4 shows the simulated position factor of button BPM for the different harmonic frequency. The linear area is a box of 2.0 mm.

In Cryomodule, the vacuum aperture is 40 mm and the longitudinal length of cold button BPM diameter is 180 mm. The whole layout of one cryomodule is shown in Fig. 5. Due to the influence of high magnetic field from SC solenoid, the cold button BPM and its mounted body are all made by stainless steel AISI 316LN with a maximum magnetic permeability from 1.01 to 1.05 after manufacturing process.

We use removable feedthroughs help the maintenance and replacement of leaking elements. And the bellows and rotatable flanges are used to facilitate beam line installation and alignment. The foresee alignment plane references and alignment holes for targets are also designed and as shown in Fig.6.

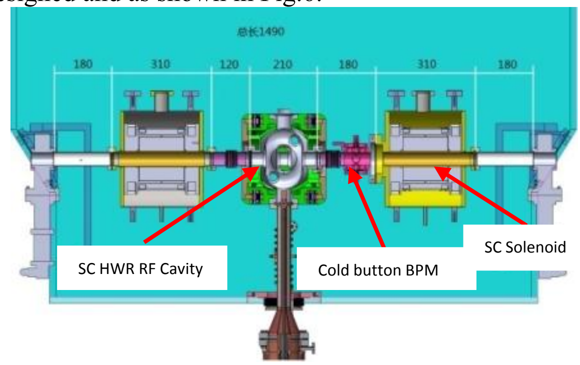

Figure 5: Cross section of one cryomodule including one SC half wave resonator cavity (HWR), one cold button BPM and two SC solenoids.

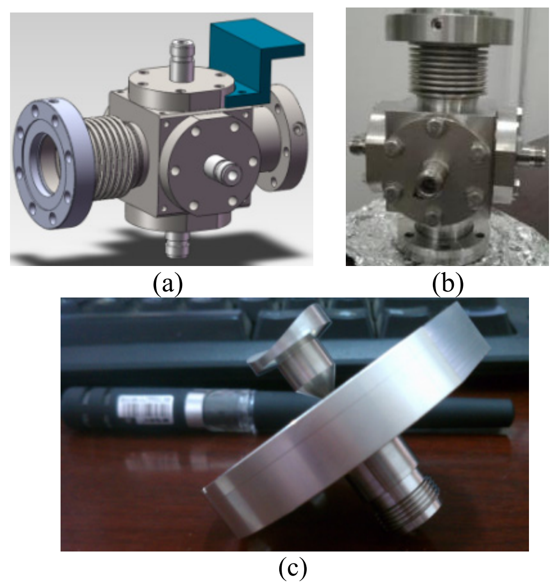

Figure 6: (a) Mechanical design and (b) photograph of cold button BPM .(c) Photograph of 20.8mm arc cold button BPM feedthrough made by Kyocera.

CHARACTERISTIC TEST

The capacitance measuring is the first and the important test for capacitive BPMs. Figure 7 shows the measured capacitance of mounted cold button BPM with R&S ZVA8 network analyzer. The measured result indicates the capacitance of one button is 4.96pF. Using the same method, the other button capacitances are 4.98pF, 4.95pF and 4.94pF. The biggest difference is 0.8% which means good mounted process to ensure four electrodes being in the same position.

Secondly, the cold button BPM must pass the cryogenic test. After the cool down (330K to 4K) and warm up (4K to 330K) cycling, the cold button BPM keep the hermetic leak tightness to 1E-10 (mbar*l/s) before and after the cryogenic tests. The test set-up is shown in Fig. 8

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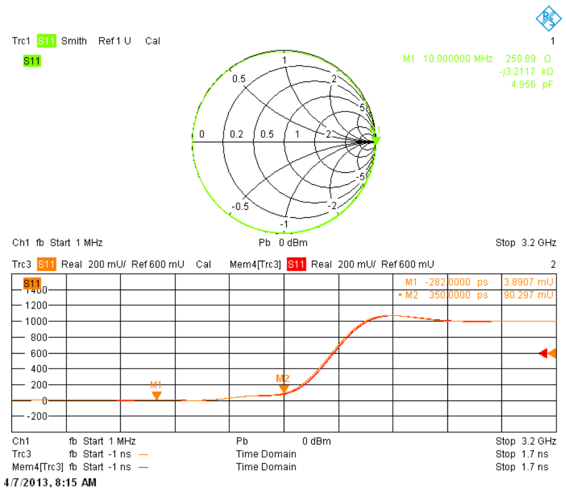

Figure 7: Measured capacitance of mounted cold button BPM using R&S ZVA8 network analyzer. Choosing Mark 1 of 10MHz for S11, the capacitance is 4.956pF.

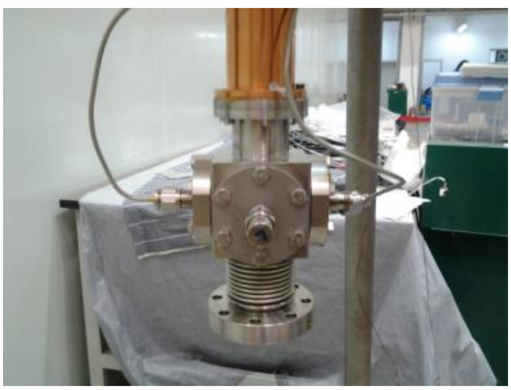

Figure 8: Cold-warm cycling test .

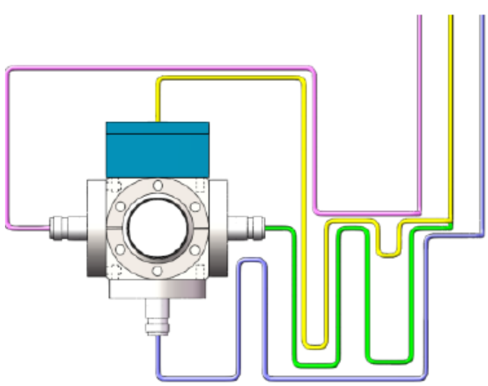

Figure 9: Semi-rigid cable shapes. These cables will be made by Meggitt.

The button feedthroughs are connected to the cryostat feedthoughs via semi-rigid, 50ohm coaxial cables capable of coping with a high radiation environment and the temperature gradient from cryogenic to room temperature. These semi-rigid cables are constructed from copper clad stainless steel inner and outer conductors to give good electrical conductivity and poor thermal conductivity, and use a silicon dioxide foam dielectric. The cables work in a frequency range up to 4GHz, with the electrical length small difference in each cable, which means the four cables associated with a single BPM being less than 10ps.The semi-rigid cables shapes are shown in Fig.9.

SUMMARY

BPM are essential devices for the beam-based alignment and diagnostics of the ADS Proton LINAC accelerator. The cold button BPM have been designed and tested for cold temperature. By the 3D numerical simulator, the size and sensitivity of BPM can be optimized to meet the requirement of beam diagnostics. The cold button BPM can be suffered the cycling test from the cryogenic to the room temperature. The follow problem is how to calibrate the cold button BPM in the cold temperature.

ACKNOWLEGEMENT

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[1] Maurice Cohen-Solal, “Design, test, and calibration of an electrostatic beam position monitor,” Physical Review Special Topics-Accelerators and Beams 13, 032801, 2010.
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