Design of High Current Bunching System and Fast Faraday Cup for High Current LEBT at VECC

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Abstract. A high current 2.45 GHz microwave ion source is currently operational at VECC. We are able to transport 6.4mA of proton beam current in the transport line of the ion source. This high current beam will be bunched and characterized by a fast faraday cup. The high current buncher described here is unique in its kind as it has to handle high beam loading powers upto 400W and is designed to bunch cw beam to produce 5mA average proton current at 80KeV in a bunch width of 30 deg. of rf cycle. This paper highlights the design, development and current progress of high current bunching system and a high power fast faraday cup to measure the phase width of bunched beam.

Keywords: buncher, fast faraday cup, ion beam.
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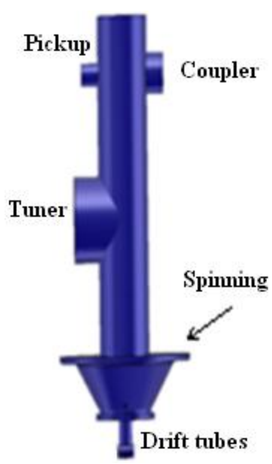
INTRODUCTION

At the Variable Energy Cyclotron Centre, we are developing a 10MeV, 5mA four sector compact proton cyclotron. The main objective of this project is to understand and settle various physics and technological issues associated with the production, bunching, injection, acceleration and extraction of the high intensity beams. A 2.45 GHz Microwave ion source and ~3meter long solenoid based beam transport line along with various diagnostic elements such as DCCT, faraday cup, fixed and movable slits, beam viewer etc. have been developed to study the high current beam bunching and beam inflection. The ion source is producing regularly 8.5mA beam current as measured at DCCT. A well collimated beam of 6.4mA proton has been transported and optimized at a faraday cup located 3m away from the ion source [1, 2]. It is well known that a cyclotron accepts only a fraction of continuous ion beam coming from the ion source. The beam current in the phase acceptance can be increased by a using a suitable buncher in the injection line. In the case of low beam current the drift length of time focus from the buncher remains a free parameter and can be chosen as per the convenience. However, in the case of high beam current there is a restriction on the drift length and bunching efficiency decreases sharply with increase in the drift length. Use of a shorter drift length requires generation of high bunching voltage. Therefore, a high current beam bunching system calls for special attention in terms of handling of beam loading as well as generation of high gap voltages. The buncher system chosen is a normal conducting quarter wave resonator with two 5mm acceleration gaps separated by a drift tube of length $\beta\lambda/2$. The fabrication of buncher has been completed and assembling is being done for low power tests. In order to measure the phase width of the bunched beam and to understand and establish bunching efficiency in case of high current beams, we have also designed and fabricated a coaxial water cooled fast faraday cup, which will be located at a distance of 80 cm after the buncher. This paper describes the special features, electromagnetic design and developmental progress of the high current beam bunching system and fast faraday cup.

HIGH CURRENT BUNCHING SYSTEM

The Physics design of high current buncher requires a gap voltage of ~5 kV for 80 keV proton beam as described in ref. [3]. Since a non-resonant buncher will need a large amount of power [4], we have selected a quarter wave resonator as buncher due to its better thermal stability and high qualiy factor against helical or spiral resonators [5,6]. Figure 1 shows the model of $\beta\lambda/2$ rf structure designed to bunch 80 KeV proton beam at 42 MHz in eigen mode solver of CST MWS 3D code [7]. We started the initial design of the buncher resonator by choosing inner conductor radius r equal to 1cm (minimum) and outer conductor radius R to 10 cm (maximum) because of limited space, mechanical stability and cooling constraints. We then studied the variation of shunt impedence with changing the values of these radii. We observed that shunt impedance degrades with increase in inner conductor radius (keeping out radius fixed at R=10cm) and improves with increase in outer conductor radius (keeping inner conductor radius fixed at r=1cm) as shown in Fig. 1. Finally, the taper length near the short end of resonator was varied keeping R=10cm and r=1cm, an optimized value of 3cm was chosen for ~300kΩ shunt impedance as shown in Fig. 1. The chosen values of R=10cm and r=1cm are the best possible values within the limited available space. The calculated length of resonator from the beam axis turns out to be equal to1.7m due to low capacitance provided by drift tubes, which is very near to the free space quarter wavelength of 1.78m at 42 MHz.



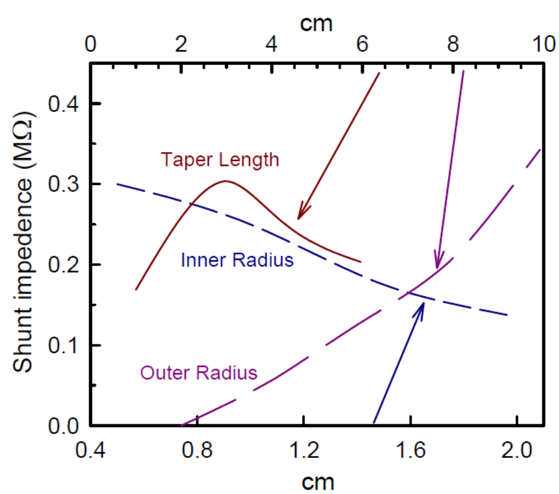


FIGURE 1. CST Microwave studio model of buncher resonator (left). Variation of shunt impedance with inner conductor radius, outer conductor radius and taper length (right).

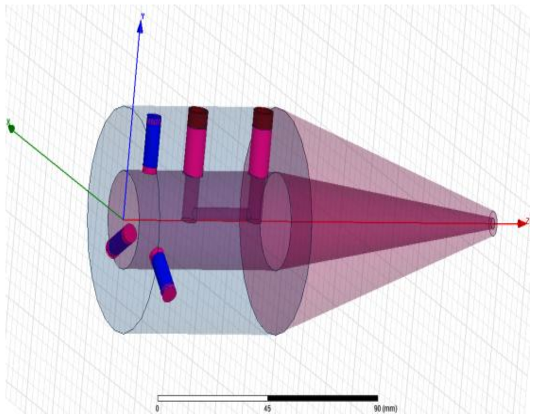
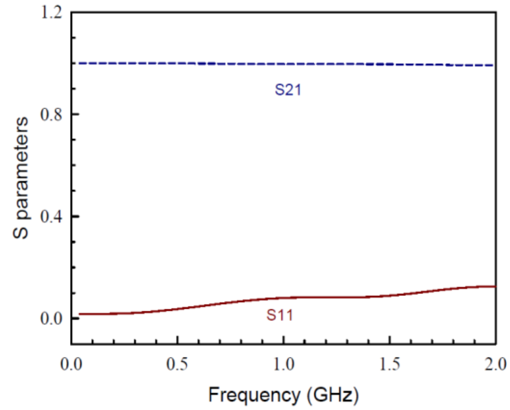
 

FIGURE 2. The HFSS model (left) and the optimized reflection and transmission characteristics of Faraday cup (right).

Since the length of the buncher resonator is comparatively large (1.7m) therefore, during the design we have taken care that the volume under vacuum should be as minimum as possible to prevent any local discharges in the length of the resonator. A cylindrical alumina ceramic vacuum window has been used to isolate vacuum and air regions of resonator. We have optimized the rf window in CST MWS to achieve maximum shunt impedance of 300kΩ, along with voltage withstanding capability of ~10kV. An input coupler with adequate coupling is needed to transfer power to the cavity. The rf coupler in this design is a rectangular loop located near the short end of the resonator. The coupler size of 40mm × 62mm and a distance of 20mm from the centre of inner conductor resulted in 50Ω feeder impedance. An rf tuner is needed to maintain the cavity at resonance against different sources of frequency drifts. A capacitive tuner with a stroke of 30mm for a maximum frequency shift of 200 kHz was designed for this resonator.

FAST FARADAY CUP

In order to avoid the beam loss and hence the damage of the components during injection it is necessary that the phase width of the bunched beam should be measured before injection into the cyclotron to ensure that it is within the acceptance region of the machine. A fast faraday cup is the most suitable diagnostic device for bunched beam characterization at low energies due to its better signal to noise ratio. This faraday cup was designed to handle approximately ~600W of beam power. The configuration of the faraday cup was chosen to offer a characteristic impedance of 50Ω to transmit high frequency content of the beam bunch with minimum reflected signal. The design of the coaxial part of the cup takes care of impedance discontinuities offered by support rods and water feed-through. The bi-conical transmission line transforms 50Ω coaxial line to 50Ω SMA feed-through dimensions as shown in Fig. 2. The complete design of fast faraday cup was optimized in ANSYS HFSS™ [8]. We have achieved a bandwidth of 1.75 GHz ($S11 < 0.1$) and full transmission as shown in Fig. 2.

STATUS OF BUNCHER AND FAST FARADAY CUP

The fabrication and assembly of various parts of the buncher system has already been completed as shown in Fig. 3. An automated bead pull measurement set up is in advanced stage of completion. We have planned to perform low power measurements of quality factor, shunt impedance, and resonance frequency. The buncher will be coupled to the beam line for online performance tests with the beam after offline rf measurements and characterization of the buncher resonator parameters. We are fabricating two sets of faraday Cups; cooled one and single piece un-cooled one. The main objective is to experimentally establish the effect of welding, brazing joints on the 50Ω impedance of the fast faraday cup. Figure 5 shows the fabricated aluminum and copper prototypes of inner conductor. The S-parameters measurement of the faraday cup will be performed before the beam test.

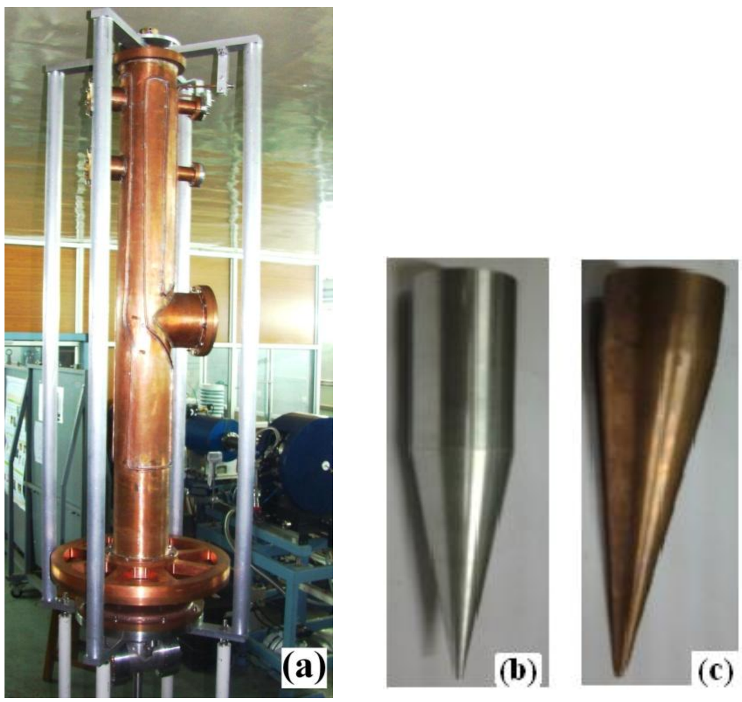


FIGURE 3. (a) The assembled buncher resonator at ion source test stand. (b)The inner conductors of un-cooled fast faraday cup and (c) cooled faraday cup.

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