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RF BUNCHER CAVITY FOR POLARIZED He-3 BEAM AT BNL*

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Abstract

A 100.625 MHz quarter wave resonator type rf buncher cavity was fabricated for polarized He-3 spin rotator beam line at BNL. This cavity will be installed in the existing EBIS-To-Booster beam line to provide effective voltage of more than 40 kV for 2 MeV/u $^3He^{2+}$ beam. This cavity has a large drift tube inner diameter of 80 mm and small gap length of 5 mm. The buncher consists of 3 sections, which are a cavity main body including drift tube, stem, and inner wall, a lid with a power coupler, and a lid with an inductive tuner. The main body was machined from a bulk copper only by CNC machining. The result of low power test agreed well with rf simulation without any alignment. The difference between measured and calculated resonant frequency was <0.1 %, and measured Q value was 92 % of that in simulation. The cavity rf design and test results will be shown.

INTRODUCTION

Polarized ^{3}He beam will be used for the Electron-Ion-Collider science program at BNL to study dynamic internal structure of protons, neutrons, and nuclei, and how quarks and gluons contribute to the spin of fundamental particles [1]. EBIS pre-injector with the Extended-EBIS (under development to replace the existing RHIC-EBIS) will provide 5×11^{11} particles of 2 MeV/u polarized $^3He^{2+}$ beam with about 80% polarization. The Extended-EBIS will provide longitudinally polarized $^3He^{2+}$ beam. A RFQ linac and an IH-Linac will accelerate the beam to 2 MeV/u. [2] The polarization must be rotated to vertical direction before transported to AGS-Booster synchrotron. New He-3 spin rotator beam line is being developed [3] to be added in the existing EBIS-to-Booster (EtB) line as shown in Fig. 1. Existing components in the EtB line will be re-arranged and a new RF buncher described here will be installed.

BUNCHER DESIGN

The buncher cavity is a quarter wave resonator type rf cavity. The resonant frequency is 100.625 MHz as same as other rf cavities in EtB line. Required effective voltage is 40 kV for 2 MeV/u $^3He^{2+}$ beam. Distance between gap center ($\beta\lambda/2$) is 97.46 mm. This cavity has a large drift tube inner diameter of 80 mm and short gap length of 5 mm. Operational duty factor is less than 0.1 % and there is no water cooling. There are 3 sections, which are a main body including drift tube, stem, and cavity wall, a lid with a power coupler, and a lid with an inductive dynamic tuner. The main body is made from bulk oxygen free copper using only CNC machining. Drift tube alignment only depends on machining accuracy. The lids are aligned with precisely machined and positioned alignment pins on the main body near drift tube so that the lids are used as a structure to prevent from cavity deformation. The inductive dynamic tuner is located near a stem. The tuner is made of a φ50.6 mm copper cylinder. The tuner will be mounted in horizontal direction. There are blinds holes made from cavity wall side to reduce the weight of the tuner. A ring made by Vespel is mounted inside of a tuner assembly to support the tuner cylinder for accurate positioning. The ring is split-ring shape for evacuation. The location of the tuner is found in Fig. 2 as a cylinder. RF power is fed by a loop coupler made of φ3 mm solid copper conductor. The coupler is located on the other side of lid at similar location as the tuner. Machining, fabrication, and low power test were performed by TIME Co., Japan.

The RF design was optimized with CST Microwave Studio. The optimized cavity Inner dimension is 274.92 (L), 285 (W), and 518 (H) in mm as shown in Fig. 2. The effect of drift tube alignment (for this cavity machining accuracy) was investigated. The dependency is +408 kHz as 0.1 mm longer distance between drift tube. Longer gap length decreases capacitance and increases resonant frequency

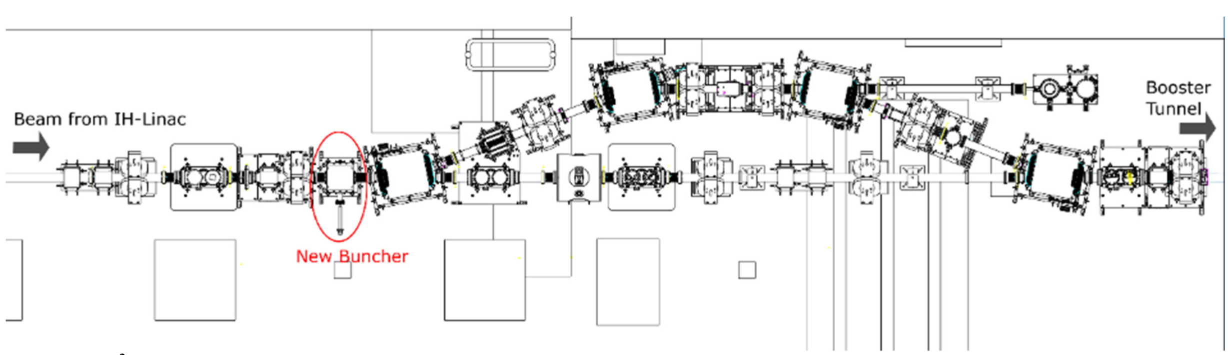

Figure 1: ^{3}He spin rotator beam line being constructed at the existing EBIS-to-Booster (EtB) beam line at EBIS.

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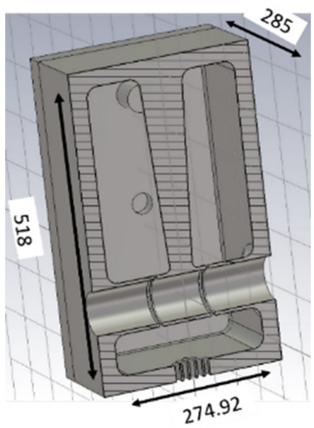

Figure 2: Cavity inner dimension.

based on the simulation with 5.0 mm and 4.5 mm gap length. The dependency on the drift tube thickness is about -363 kHz per 0.1 mm thicker drift tube thickness based on the results of 5.6 mm, 5.8 mm, and 6.0 mm thickness. The cavity RF properties are mainly determined by the structure near drift tube gap. Actual deviation from the simulation after machining is unknown until the machining and low power test is finished. We used width of the main body and inner side of the lids to adjust the resonant frequency after drift tube machining is finished.

The resonant frequency can be increased by machining the width of main body. Minimum width to machine was 250 mm due to technical reason. Figure 3 shows the effect of main body width calculated for the width of 270 mm, 285 mm, and 300 mm. With linear fitting, the resonant frequency changes +35.9 kHz per 1 mm narrower width (0.5 mm machining on each side of the main body).

The inner wall of lids can be machined to decrease resonant frequency. The same area as inner volume of the main body is machined as keeping the surface touching to the main body unchanged. The effect of the lid machining is -32.9 kHz per 1 mm depth on a lid. The lid with a tuner was planned to be machined first as an effort to increase tuner insertion distance.

We planned to adopt the following 3 steps to achieve the target frequency safely to accommodate uncertainty related to the condition after the machining around drift tube.

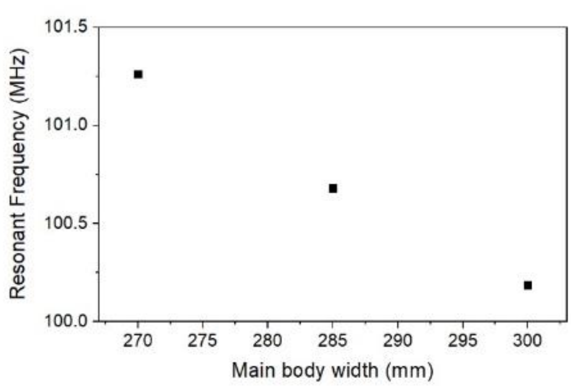

Figure 3: Main body width and resonant frequency.

Firstly, machine the main body to 300 mm width with everything else in optimized dimension. The expected resonant frequency is 100.185 MHz. After low power test with all components assembled, the main body width for second machining is determined based on RF simulation. Minimum width of the main body is 250 mm, which is limited by stem size and machining aspect. The resonant frequency tuning range with main body width from 300 mm to 250 mm is about +1.8 MHz. After second machining to the width determined by the first machining, if the frequency still does not meet the specification, the main body width or inner side of lids is machined. Assuming the main body width after second machining is 285 mm (optimum width in simulation), the frequency can be changed up to about +1.2 MHz by main body width. The thickness of lid is 34 mm and maximum depth of machining is 12 mm (this means that minimum lid thickness is 22 mm), so the maximum tuning range with both lids is about -788 kHz. Table 1 summarizes the optimized buncher parameters with 50 mm tuner insertion into the cavity.

Table 1: Buncher Parameters from Simulation for 3He2+

Frequency	100.625 MHz
Energy	2 MeV/u
Velocity β	0.0654
Max. duty factor	0.1%
Effective voltage	40 kV
Bore diameter	80 mm
Gap length	5 mm
Q	9940
Peak electric field	8.25 MV/m
Kilpatrick factor	0.73
Transit time factor	0.746
Power loss in copper	557 W

LOW POWER TEST AFTER FIRST MACHINING

Low power test using a network analyzer was conducted after the first machining with 300 mm of main body width. Screw holes and holes for alignment pins for lids were designed for minimum width of 250 mm so that only sealing surface of the main body needs to be reworked after the

Figure 4: Buncher main body after first machining and Assembled cavity inner dimension.

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second machining. Figure 4 shows the cavity main body after the first machining. For this measurement, a temporary coupler and pickup loop shpes were used to verify 50 Ω matching. The following measurement was done with the matched condition. The measured resonant frequency well agreed with simulation for all tuner positions from 0 to 75 mm, where 0 indicates zero insertion into the cavity. The difference from simulation is up to -51 kHz or -0.05 %. This means the main body was excellently machined. We found the resonant frequency changes about -13 kHz when pumping down the cavity. Based on the low power test, we decided to machine the main body width from 300 mm to 285 mm as designed in RF simulation.

LOW POWER TEST AFTER SECOND MACHINING

After the main body width was machined to 285 mm, the second low power test was performed. Before the low power test, a power coupler and pickups with loop shape determined from the first low power test were fabricated. Figure 5 shows pictures of the completed power coupler and tuner assembly. Figure 6 shows the fully assembled buncher cavity for low power test after the second machining. The cavity satisfied all specifications, and the third machining was not needed. The resonant frequency of 100.625 MHz was achieved with tuner insertion of 44 mm in vacuum. The frequency difference from simulation was about 0.02 %. The total tuning range with tuner insertion from 0 to maximum 89 mm was measured as 620 kHz. Q value was 9258, which is 92 % of the expected value from RF simulation. With this Q value, it is expected for an RF amplifier to supply 1.2 kW for effective voltage of 40 kV required for the polarized $^3He^{2+}$ operation. This is within the 5 kW solid state amplifier we plan to use. The estimated maximum effective voltage with 5 kW RF amplifier is 81 kV.

Figure 5: Power coupler (left) and tuner (right).

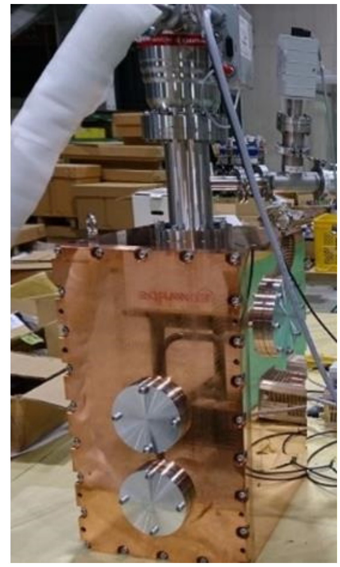

Figure 6: Assembled cavity after second machining.

CONCLUSION

A Quarter Wave Resonator type 100.625 MHz RF buncher was constructed for 3He spin rotator beam line to be installed at EBIS pre-injector at BNL. The main body including drift tube, stem, and cavity wall was machined from bulk oxygen free copper using CNC machining. The drift tube alignment relies on accuracy of the machining. Low power test showed that the fabricated buncher cavity well agreed with the rf simulation results. We are preparing for high power test with a 5 kW RF amplifier.

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