5th International Particle Accelerator Conference IPAC2014, Dresden, Germany JACoW Publishing
ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPRI062

CW ROOM TEMPERATURE RE-BUNCHER FOR THE PIP-II LINAC FRONT END*

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Abstract

At Fermilab there is a plan for improvements to the Fermilab accelerator complex aimed at providing a beam power capability of at least 1 MW on target. The essential element of the plan (the Proton Improvement Plan II – PIP-II) is a new 800 MeV superconducting linac. The PIP-II linac consists of a room temperature front-end and a high energy part that uses five types of superconducting cavities to cover the entire velocity range required for beam acceleration. The room temperature front end is composed of an ion source, low energy beam transport line (LEBT), radio frequency quadrupole (RFQ), and medium energy beam transport line (MEBT). The paper summarises design of a re-buncher cavity used in the MEBT section.

INTRODUCTION

The Proton Improvement Plan-II [1] is structured to deliver, in a cost effective manner, more than 1 MW of beam power to the Long Base Neutrino Experiment (LBNE) while creating a flexible platform for longer-term development of the Fermilab complex aiming to gain multi-MW capabilities in support of a broader research program, as resources become available in future. The central element of PIP-II is a new 800 MeV superconducting linac, injecting into the existing Booster. The linac with continuous wave (CW) capable cavities and cryomodules is a partial implementation of Stage 1 of the Project X [2]; it offers a straightforward future upgrade path with minimal additional up-front costs.

Conceptual RF design of a cavity that can serve as a buncher in the MEBT section of the linac was made early in 2012 and reported to the Project X collaboration meeting at LBNL [3]. At this stage, the design was configured to respond to the beam dynamics requirements by providing accelerating voltage of sufficient amplitude in the gap space defined by the velocity of charged particles (H^-). From several options that were analysed, a quarter-wave coaxial resonator with the frequency of 162.5 MHz was chosen for implementation as this approach promised modest space occupied by the cavity in the beam line and moderate power loss. Possible steering effect and multipacting were studied at that point and found not to be a serious obstacle. It was also demonstrated by modelling that power couplers and tuners previously designed and built for HINS project [4] can be re-used in the buncher.

Two major questions of the cavity design remained after the conceptual RF design was suggested in [5]: details of how the cooling of the central stem could be effectively arranged, and how to make flange to flange size of the cavity in the MEBT beam line smaller to allow installation of additional diagnostics. Both issues were addressed during preliminary design study, the goal of which was to come out with a mechanical design concept and fabrication scenario that would results in building a cavity with RF properties close to those described in [5]. This paper summarizes results of this study.

CAVITY DESIGN

The QWR dimensions, shape of stem and drift tubes have been optimized using CST MicroWave Studio (MWS) to meet the requirements and avoid excessive losses and peak surface fields. The power coupler and plunger tuner designs have been borrowed from the re-buncher cavity design for HINS [4]. Matching, preliminary thermal analyses for the power coupler and estimation of the plunger tuning range have been also performed using CST Studio Suite. The main parameters of the re-buncher are presented in Table 1.

Table 1: Main RF Parameters

Frequency f, MHz	162.5
Q factor	>10000
Aperture radius, mm	20
Gap, mm	2x23
Effective voltage (β=0.067), kV	70
Power loss in copper, kW	0.92
Effective shunt impedance, Ohm	5.3e6
Max. electric surface field, MV/m	4.2
Tuning range, kHz	440

Beam steering effect and probability of multipacting have been evaluated with CST Particle Studio simulations. It was found that steering effect is weak and can be ignored. But one or two multipacting barriers at lower power should be expected.

To simplify cavity fabrication, it was suggested (and found possible by corresponding RF modelling) to use the central stem with the round cross-section instead of elliptical one that was assumed in [6]. To ensure proper alignment of beam line elements and to save the longitudinal real estate occupied by the cavity, special shape of the central block of the cavity was proposed; corresponding RF modelling indicated no significant changes in the cavity RF properties. Main components of the BC assembly are shown in Fig. 1.

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*Work supported by US Department of Energy
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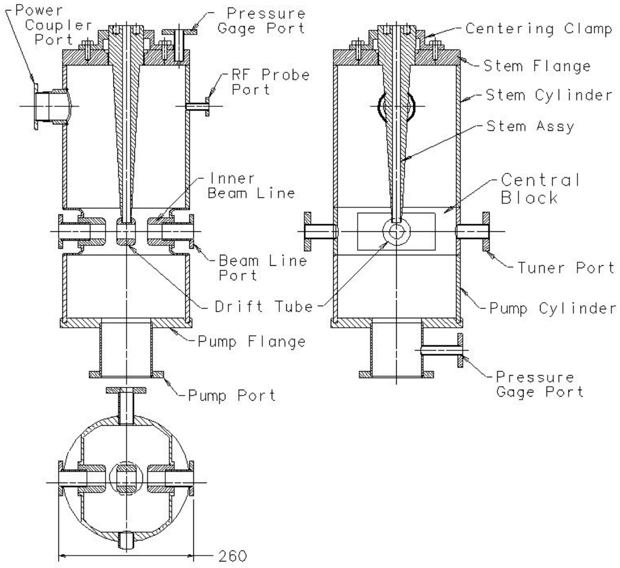

Figure1: Buncher cavity: main components.

Subassemblies of the cavity are joined together by furnace brazing. Having in mind high accuracy of RF modelling, the accuracy of fabrication was proposed that would ensure that the cavity frequency falls within the range that could be handled by tuners used as a part of the cavity final assembly. The distance L_{dr} between the mid-planes of the two accelerating gaps of the cavity is defined by the speed of particles $\beta = 0.0668$ and equals $L_{dr} = \beta c/2f = 61.66$ mm.

The cavity has two accelerating gaps, each 23-mm long, and a 38.66 mm long drift tube. While choosing the length of gaps in the beam transport section, magnitude of the electric field on the drift tube must was taken into account. 240 mm inner diameter of the cavity was chosen as a compromise between the overall size of the cavity and its shunt impedance (and hence power loss in walls of the cavity). This choice mainly defines the length of the stem. As addition of each ports to the cavity changes its resonant frequency, corresponding changes in the stem (and the stem cylinder) length must be made to compensate for the change.

For each of the two tuners installed in the cavity, the diameter of the tuner rod is 20 mm, and the range of the movement is 25 mm. Tuning diagram is shown in Fig. 2. The range of the tuning by the two tuners is ~600 kHz.

At 80 kV of the effective voltage, the maximum electric field on the surface of the tuner's rod is ≈2 MV/m; this is well below the maximum field on the surface of the drift tube (3.3 MV/m); field map in Fig. 3 illustrates this. The power dissipation in the tuner rod in nominal position is evaluated to be less than 0.5 W.

Major components of the cavity that geometrically define RF properties must be made of C101 copper. All ports must be equipped with stainless steel CF-type flanges, which must be welded after the cavity is fully assembled and the working frequency is verified. This requirement is due to a possible softening of stainless steel flanges during the final brazing step at about 800°C.

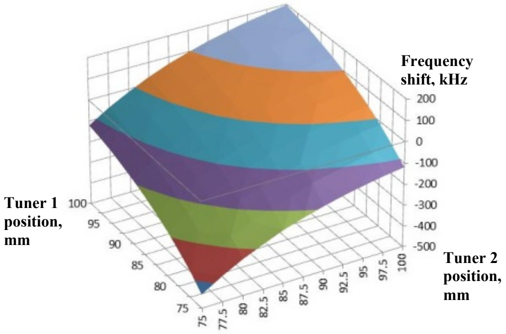

Figure 2: Tuning diagram; zero frequency shift corresponds to the 87.5 mm tuner position.

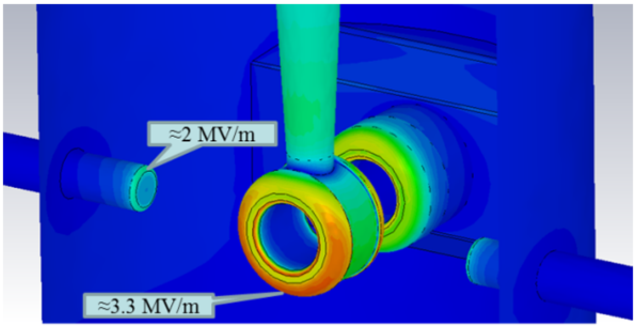

Figure 3: Surface electric field map.

COOLING THE CAVITY

Total power loss in the cavity walls at effective voltage of 80 kV is ~1200 W with ~850 W dissipated in the central stem. As a traditional cooling approach can be used for cooling the body of the cavity to remove the power deposited in the central stem, a different cooling scheme was needed for the stem so that the temperature doesn't rise too high. After several ways of making cooling channels were studied, and the issue of the channel blockage by lime deposits was identified, a coaxial counter-flow cooling scheme was proposed. In this scheme the cooling circuit was configured so that it could be easily disassembled for cleaning or replacement of the cooling insert. A simple sketch that exemplifies this approach is shown in Fig. 4.

Cooling water is delivered to the drift tube of the cavity by a pipe that is inserted in a bore drilled in the central stem. Cooling water returns in the gap between the inlet pipe and the wall of the bore. The assembly can be easily removed for cleaning, if necessary, and re-installed after cleaning. In this scheme, there is no direct interface of the cooling channel with the active part of the RF cavity, so elastomeric gaskets (e.g. Viton) can be used to insulate the hydraulic circuit. This makes the channel cleaning procedure simple and allows making the cleaning on a regular basis during maintenance periods.

Thermal modelling of the cooling circuit showed that the expected heating of the stem can easily be compensated; Figure 5 shows corresponding temperature map. With 1100 W deposited on the stem surface, the maximum surface temperature rise is ~10°C, and the temperature rise in the cooling water is only ≈4°C.

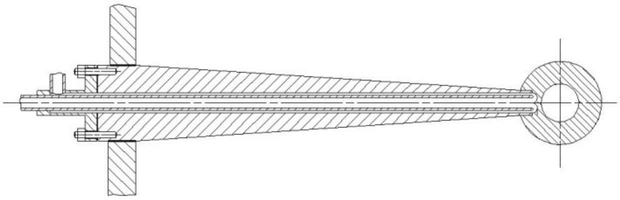

Figure 4: Concept of a counter-flow cooling scheme.

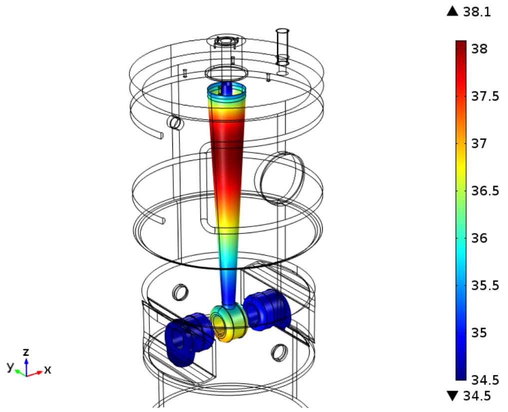

Figure 5: Temperature map from 3-D thermal study.

To verify predictions of the modelling, a mock-up of the cooling arrangement in the central stem was fabricated and tested [7]. The mock-up was assembled using pieces of standard copper tubing; the cooling geometry is quite close to what is planned to use in the cavity and what is shown in Fig. 6.

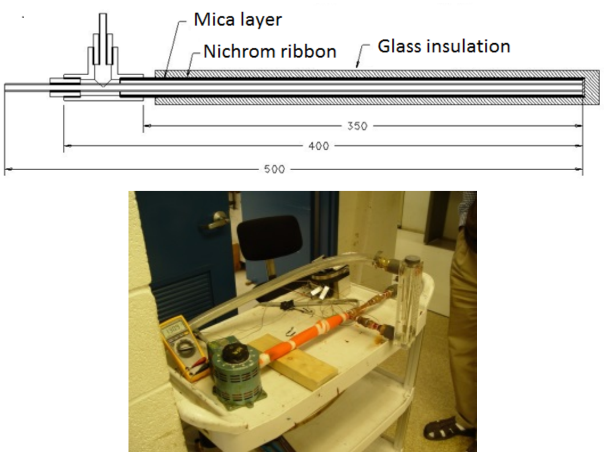

Figure 6: Mock-up of the central stem cooling circuit (above); testing the mock-up.

As the geometry of the measurement setup differed (although just slightly) from what was shown in Fig. 4, the performance of the mock-up device was verified by modelling using 1 GPM water flow. The measured output temperature compares well with what is predicted by modelling (Fig. 7).

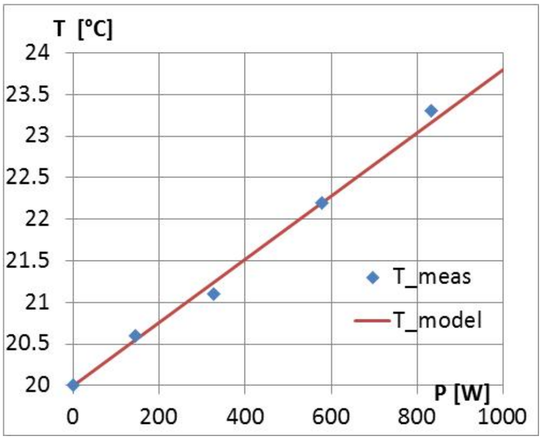

Figure 7: Temperature of cooling water as a function of the heating power in the mock-up.

The mock-up of the cooling system was also tested in for the flow obstruction in a long term (four months) experiment with 2.5 GPM flow and 8 PSI differential pressure. No change of water flow was observed. After the system was disassembled, some discoloration of copper surface by copper oxide was noticed though.

CONCLUSION

The RF and mechanical design of the CW re-buncher for PIP-II linac is completed with all functional requirements met. The proposed cooling scheme was tested for cooling efficiency and for possible long term flow obstruction. The tests have demonstrated that the hydraulic and thermal performance of the cooling scheme is quite adequate.

ACNOLEDGEMENTS

Authors thank M. Ball and J. Czajkowski for their help in conducting the long term water flow test.

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