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The fabrication and development of the PEFP 1st DTL tank [1)]

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Abstract

The PEFP (proton engineering frontier project) proton accelerator is now in 1st phase of which having a goal of completion of 20 MeV DTL (drift tube linac) manufacturing and the beam test at KAERI site. The DTL will accelerate the 20 mA proton beam from 3 MeV to 20 MeV continued to 3 MeV RFQ (radio frequency quadrupole). The engineering design and the error analysis of the tank consisted of drift tubes with focusing magnets, RF components, vacuum components, and the water cooling channel is completed and we're now fabricating the 1st DTL tank. In this report, we'll represent and discuss the 1st tank fabrication status.

I. Introduction

The PEFP DTL cavity geometry has been optimized for 20 MeV, 20 mA proton beam acceleration. The reasonable number of drift tubes (DT) per tank was considered around fifty, so we divided the DTL to 4 tanks. The DTL design parameters are reported at previous papers in detail [1-3].

A DTL tank is divided two sections take account of the fabrication convenience, and will be bolted together with RF and vacuum seals. It is preferred that the material for DTL tank has to have high mechanical strength and machining easiness. On the other hand, the inner surface of the tank is required the high electrical conductivity to reduce the RF power loss and thermal conductivity to cool the cavity efficiently. In addition, the surfaces exposed to the vacuum have low outgassing rate because the pressure of the cavity should be less than 3×10^{-7} mbar to minimize the beam loss during beam operation. Considering these factors and tank size, low carbon steel pipe of copper plated inside will be used as a base metal, and OFHC copper will be used as the most accelerating components material.

A first tank includes 50 stem holes, 17 holes for post couplers, 8 holes for slug tuners, 4 grilled holes for vacuum components, 5 holes for pick ups, and a hole for RF coupler. And also contained 18 cooling channels and 20 bolt holes. The perturbation effects due to these inserted components were calculated and considered in the cavity design. Therefore structure for compensating the half stem effect at the end walls was considered as shown in figure 1 and table

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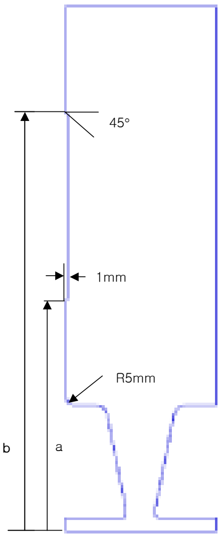
1.



tank #	endwall side	a (mm)	b (mm)	delta (mm)
tank 1	low energy side	202.0	250.0	48
	high energy side	188.0	250.0	62
tank 2	low energy side	190.0	250.0	60
	high energy side	180.0	250.0	70
tank 3	low energy side	180.0	250.0	70
	high energy side	170.0	250.0	80
tank 4	low energy side	170.0	250.0	80
	high energy side	162.0	250.0	88

Table 1. Dimension of tank end wall half stem geometry

Figure 1. Tank end wall half stem geometry.

II. Design and Fabrication

1. Tank

The inner diameter and the length of the 1st tank are 544.28 mm and 4429.57 mm (2153.38 mm and 2276.19 mm, respective section) at 20 ℃. The designed DTL operating temperature is 40 ℃, so the dimensions of the tank are modified consider the ambient temperature during tank machining. A tank is divided with 2 sections as mentioned above, and they're bolted together with fluorocarbon (viton) o-ring and canted coil spring as the vacuum and RF seal. The force for compression for viton is higher than the coil spring, so we considered to this point when designing the groove.[4]

Ports for vacuum components are slotted to prevent the RF attenuations. Grill geometry is designed to reduce the attenuation as well as increase the gas conductance. The slot number of each grill is 4, two of L120 mm × W16 mm and two of L100 mm × W16 mm. The depth of slots is about 13.5mm and 17 mm. Due to these slots the frequency perturbation of each tank is calculated as - 7 kHz, and the reduction of the pumping speed is about 20 %.

The size of the cooling channel is W30.0mm × D5.0mm, and the lengths are 2130.0 and 2257.0 mm for individual sections. We designed that each section has respective 20 cooling channels, and channels are at a distance of 20 mm from the inner tank surface. The calculated temperature rise of the inner surface of the tank is about 1.7 ℃, when heat load on the tank wall is 0.8 W/cm^2, total flow rate is 10 L/sec, and initial cooling water temperature is 35 ℃. But there are ports for slugs and vacuum components at the bottom of the tank so two cooling channel reduction is unavoidable. In figure 2, modified cooling channel location and size are showed. The inner surface of cooling channel will be plated by Cr about 30 ~ 40 ㎛ to prohibit the corrosion. And finally the stainless steel bars will be TIG welded as channel covers.

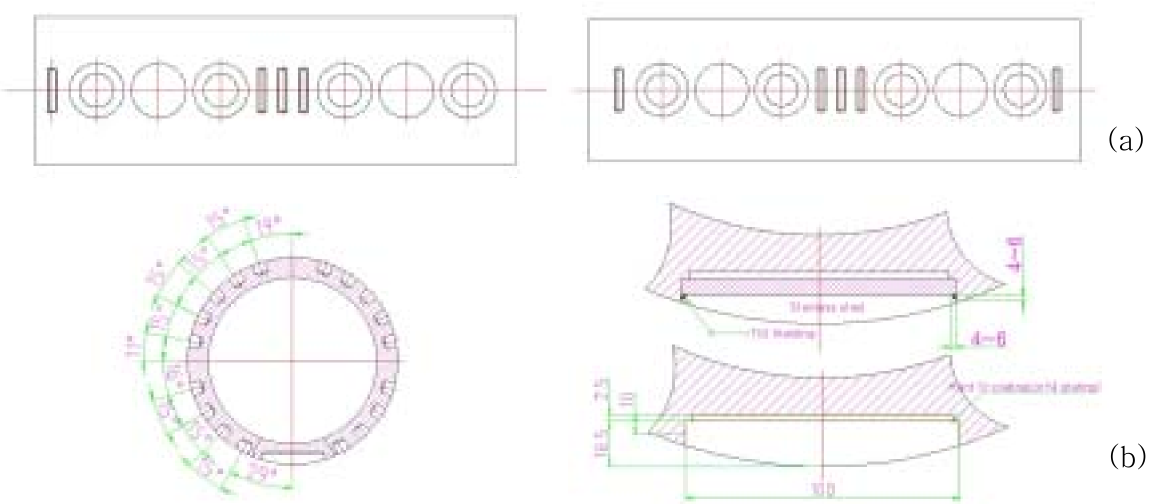


Figure 2. (a) The modified cooling channel configurations of respective section and (b) the sectional view of the channel

2. PR plating

The copper plated inner surface of tank has to satisfy the required RF and vacuum performances. So we choose the PR (periodic reverse) plating method for raising the quality factor and reducing the surface outgassing. Before the plating, the inner surfaces will be basically machined by honing method to satisfy the plating surface conditions [5].

We fabricated the PR plated pipe sample having inner diameter of 150 mm and the length of 750 mm to evaluate the RF and vacuum performances. The plated thickness is 100 ㎛, and polished mechanically as the final surface treatment. The roughness of the sanded surface is generally favorable but it's not attainable to the recommendation. We attempted the electro polishing of the plated copper, but it also not succeeded. Therefore we're trying to find the suitable treatment method applicable to the main tank. The conflat type of vacuum flanges of O.D 8" were welded at pipe ends, and a extra port having I.D 35 mm was welded at pipe for installing the pick up and vacuum gauge. The plating processes for sample preparation were as followed in table 2, and the completed sample is showed in figure 3.

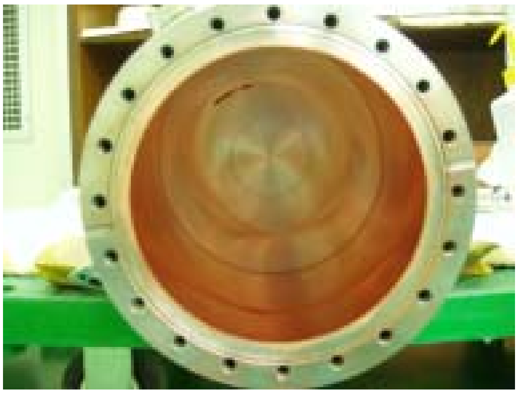


Figure 3. Fabricated PR plating sample. (Vitzrotech. Co.)

We measured the quality factor of this plating sample using network analyser (Agilient 8753ES) as increasing the tightening torque of end walls. The measured result is shown in figure 4. The calculated resonant frequency is 1529,8849 MHz and the measured is 1531,7150 MHz. The temperature and humidity during the measurement was 23 ℃ and 55 %, respectively. The Q_0 increases with respect to the increasing the torque, and nearly saturated to 28,662. The calculated value for this sample is 40,341 but the measured value is about 71 % of calculation. The main DTL tanks need over 90 % of calculated value at 350 MHz. The measured value is not come up to the recommendation. So we're going to remake the RF input coupler and insert the RF seals between the flanges and end walls. We're intending to measure once more after that, we will confirm the plating quality finally then.

Table 2. Plating processes for sample preparation

Pre treatment	- Honing and cleaning
Ni strike plating	- 100 A, 10 V, 2 min.
Ni plating	- 15 A, 3.5 V, 10 min.
Cyanide Cu plating	- Anode : electrolytic copper ball - 10 A, 2.5 V, 30 min.
Cu sulfate plating	- Anode : oxide free, phosphorized copper ball - Sulfuric acid : 135 - 145 g/L - Copper Sulfate : 138 - 148 g/L - Cl ion : about 15 ppm - Current density : 1 ~ 5.5 A/dm^2 - PR pulse duration : 20 sec forward, 4 sec reverse, 1 sec interval - Time : 600 min.
Surface treatment	- Papering (sand paper : #2000) - Cleaning

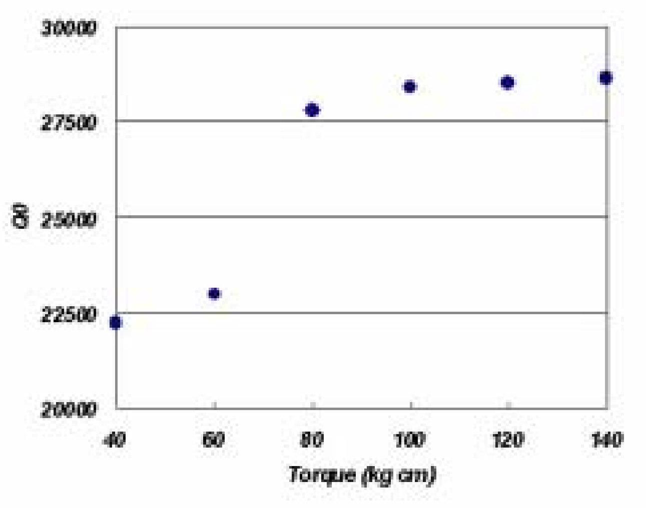


Figure 4. Results of quality factor measurement of the plating sample.

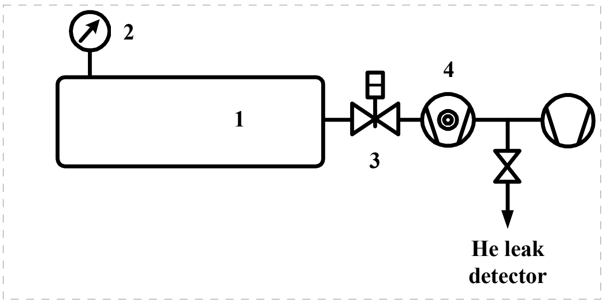


Figure 5. The system diagram of surface outgassing rate measurement. (1. Plating sample, 2. Ionization gauge, 3. Gate valve : Stainless steel, Metal gaskets, 4. TMP with Scroll pump)

Also we measured the outgassing rate of this sample using a pressure-rate of rise method (build-up test). In figure 5, the diagram of test system for measurement of the outgassing rate is presented. The pressure variation after the valve close is given as dP/dt = (QL + QS) / V, here QL is load from leaks, QS is load from outgassing, and V is the total volume of the sample. The total surface area of plated copper is 3532.5 ㎠ and the surface of stainless steel used for flange adapting is 1359 ㎠. And also we measured the He leaks at the welded and copper sealed joints as ~ 5× 10^{-10} mbar L/sec (figure 7).

We first evacuated the sample chamber 56 hrs as shown in figure 6 and record the pressure vs. time after close the gate valve. The outgassing rate is measured as 2.74× 10^{-10} mbar L/sec cm^2. This value is a little higher than the designing, but we're expecting to get the better surface condition as performing the RF conditioning.

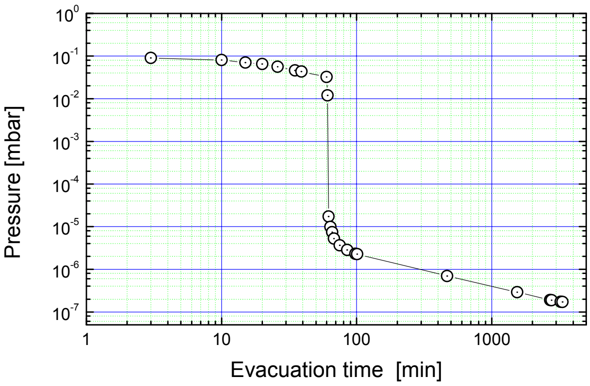


Figure 6. The evacuation curve of the sample.

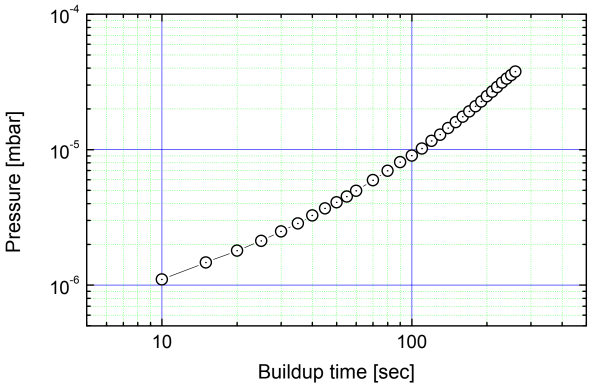


Figure 7. The pressure build up after the valve close.

3. Drift tube and Quadrupole magnet

The number of drift tube installed in the 1st tank is 50. The outer and the bore diameter are 130 mm and 14 mm respectively, and the nose cone angle is 10°. All drift tubes have same nose cone geometry, and the length increases according to the variation of the acceleration energy. The quadrupole electro magnets will be inserted into the drift tube and fixed. We're not completed yet the precise inner drift tube designation including the quadrupole magnet. We fabricated and completed the machining and e-beam welding test of the first and the last drift tube samples having no quadrupole magnet. In figure 8, the picture of the fabricated sample is presented. A DT is parted to 4. The machined OFHC copper body and the two end-cap covers are e-beam welded together, and then the stem was brazed with this drift tube for convenient sample fabrication. Last a DT was electro polished to satisfy the surface quality. We confirmed the surface roughness about Ra <0.3 ㎛ and the vacuum tightness of welded parts by measuring the He leak rates as under 1×10^{-10} mbar L/sec.

Besides, we also fabricated the cooling assembly and stem holder. The drift tube must arrayed with ± 50 ㎛ error range, so that we fabricated the holders that have the adjusting function of the drift tube. It has to adjust the stem's position and direction, and also sustain the whole drift tube weight [2]. The stem is designed having coaxial cooling channel system as shown in figure 9. Water flows into the inner drift tube through between the stem and inner pipe, and flows out through the inner pipe. And also the enameled copper coils come out together and cooled by these water.

Figure 8. The shortest drift tube sample (without QM)

The focusing quadrupole magnet is a pool-type electromagnet as mentioned above. The designed external and bore diameter are 110 mm and 20 mm respectively, and the pole length is 30 mm [2]. The magnet is fully inserted in the cooling water, so the steel iron core must be plated to prohibit the scale. We fabricated the iron core and performed the Cr plating. The pole shape was formed by electric discharge machining of 1010 low carbon steel. The machined core was plated about 10 ㎛ of Cr. First sample was failed due to the non-uniformity of plating. The second sample is almost covered with Cr, but there are still imperfections at sharp edges. So we're planning to round off the edges about R1 mm. With second core sample, we winded the enameled solid copper coils as shown in figure 10. The gap between each pole is 7.59 mm, so the stiff copper coil was not easily bended. We winded 3.5 turns of 3 mmϕ coil on behalf of square coil and ran through the current up to 250 A. The voltage was 3.3 V and a magnetic field strength near the pole tip was 2.2 kG then. The QM was totally drowned in water during the test - about 40 hrs -, the corrosion problem of the enameled copper coil due to the cooling water was not occurred. But there were some corrosion spots at scratches caused by the carelessness during the winding. We're now modifying the pole shape considered to the easy coil winding and going to complete the drift tube design.

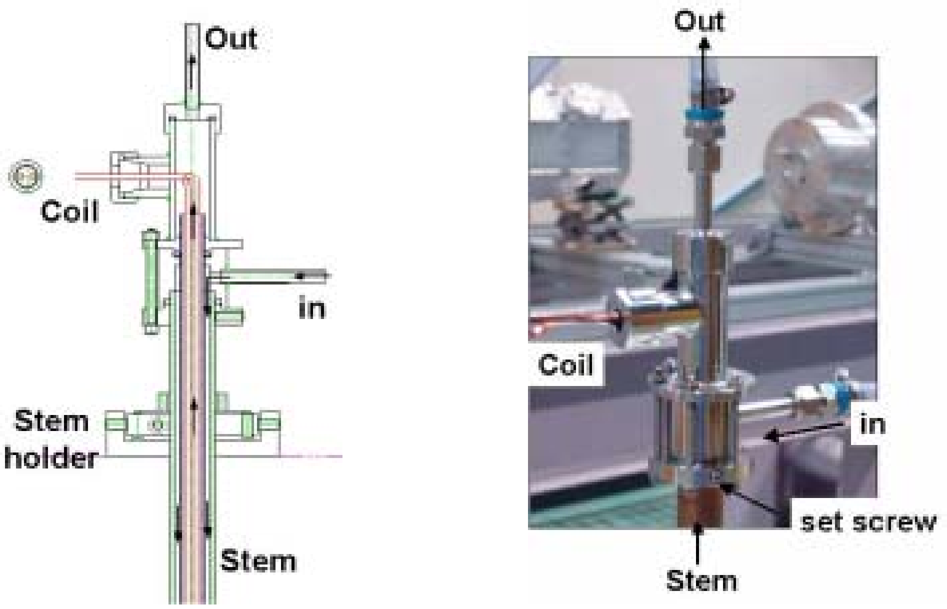


Figure 9. The cooling water adaptor of the stem design and sample test.

Figure 10. (a) Fabricated iron core sample and (b) coil test

III. Summary and further works

The engineering design for 20 MeV PEFP DTL cavity and the other components has been almost finished. And the 1st tank fabrication is scheduled to complete at the end of this December. We still have some problems to solve, such as the QM modification and the establishment of the PR plating conditions and processes, and so on. We will proceed to the tank fabrication and prepare the RF tuning gradually.

Reference

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