RFQ DEVELOPMENT AT KEK

T. Kato, E. Takasaki, Z. Igarashi, C. Kubota, T. Takenaka and S. Fukumoto

National Laboratory for High Energy Physics
Oho-machi, Tsukuba-gun, Ibaraki-ken, 305, Japan

Introduction

A four vane 201.08 MHz RFQ is being made to accelerate H^- and polarized H^- from 50 keV to 750 keV, the injection energy of the 20 MeV DT linac. It has square cross section with frames instead of conventional circular one[1] for precise alignment of the vanes. All joints are to be electron-beam welded to achieve good electric contact. The vanes were already machined and the surface treatment of the vanes are being done. Before the final design, a shorter cold model of the same frequency was made to develop a detailed electrical and mechanical design[2]. It corresponded to acceleration from 50 keV to 153 keV. Its electrical characteristics were measured. As they were good, a vacuum vessel was prepared for the cold model and acceleration of electrons was observed with suitable shielding of terrestrial magnetic field[3]. Since our RFQ is made of copper, we adopted electrolytic polishing as final surface treatment. In this report we mainly describe the surface preparation by electrolytic polishing and the improvement of the breakdown voltage due to the electrolytic polishing.

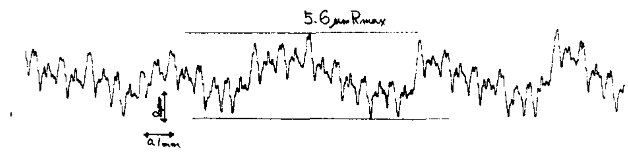
Surface preparation

Electrolytic polishing was chosen as final surface treatment to obtain good electrical conductivity and high breakdown voltage. Since the optimum condition for electrolytic polishing of copper has not yet been established, we at first looked for the best condition in our case for every related factors. The final results obtained are as follows:

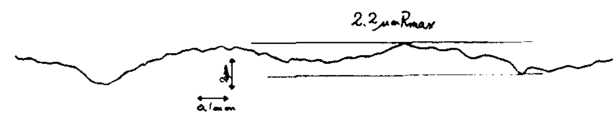
composition of electrolyte	
phosphoric acid	78.3 wt%
chromic acid	7.2 wt%
water	14.5 wt%
temperature	30 - 35 °C
current density	35 A/dm^2
material of cathode	lead

During the polishing, the bath was cooled to keep the temperature constant and the mixture was circulated by a pump to achieve homogeneity of acid density. A cathode of stainless steel was examined. In this case, a slightly higher voltage is necessary compared with lead one and moreover, copper eduction was seen on the cathode. The estimation of the surface flatness was performed in several ways such as thickness measurement by a micrometer, roughness measurement by the stylus method, surface observation by a metallographic microscope and gloss measurement by a glossmeter. Test pieces were machined to make the same cutter trace as the vane.

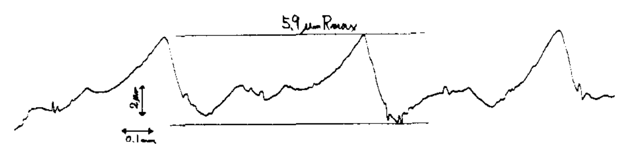
Figure 1 shows the results of roughness measurement by the stylus method in both parallel and perpendicular directions relative to the cutter path before and after electrolytic polishing of 25 μm. The cutter path in the vane fabrication is shown in Fig. 6. Great improvements were seen in both directions, especially, in the parallel direction. A lot of small notches were smoothed out with polishing of less than 25 μm. We show the cross-sectional view of the surface in Fig. 2. With the polishing of 50 μm, a cracked part on the surface was completely removed. However, the surface became somewhat rough again with the polishing of 100 μm since the selective polishing dug many small holes on the surface. Figure 3 shows surfaces taken by a metallographic microscope after polishing of 50 μm for three kinds of copper, OFHC (oxygen free high conductivity copper), tough pitch copper and VMC (vacuum melted and oxygen free high conductivity copper). A test piece of 140 cm, the same length as the vane, was polished about 40 μm, finding that the fluctuation of polishing thickness was



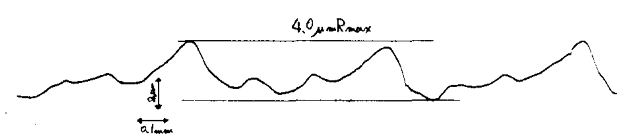
a) Parallel direction to the cutter path before polishing.



b) Parallel direction to the cutter path after polishing of 25 μm.



c) Perpendicular direction to the cutter path before polishing.



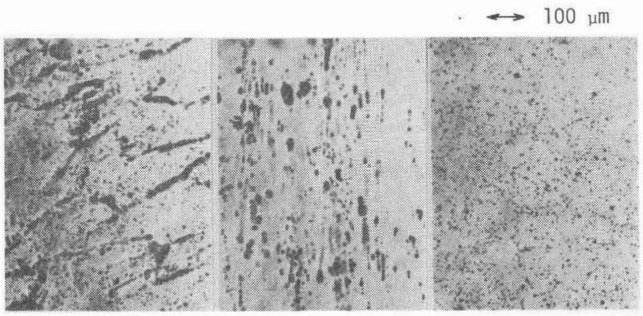
d) Perpendicular direction to the cutter path after polishing of 25 μm.

Fig. 1 Traces of roughness measurement by the stylus method.

less than 10 %. The equipments required for polishing of the vanes and the cavity, that is, a DC power supply of 20 V - 10000 A, an electrolytic cell of 1000 x 1000 x 1800 mm and lead cathodes of 40 mm in diameter, are being prepared.

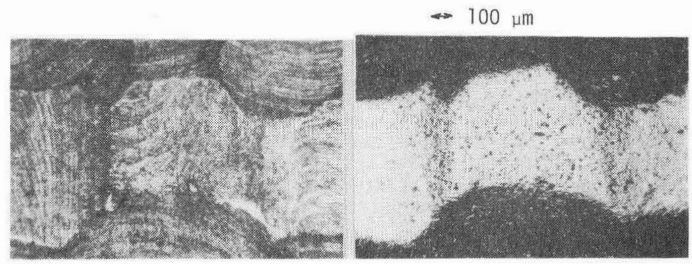
a) Before polishing. b) After polishing of 25 µm. c) After polishing of 100 µm.

Fig. 2 Cross-sectional view of the surface perpendicular to the cutter path. Nickel was plated on the surfaces to keep sharp edge during cut.

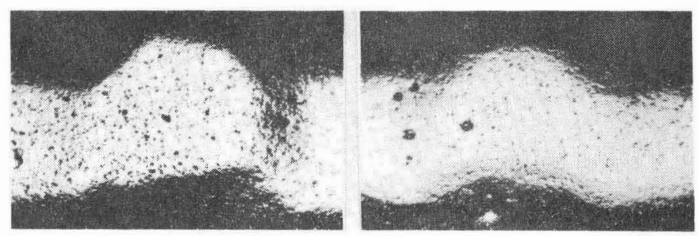


a) OFHC b) tough pitch copper c) VMC

Fig. 3 Photograph of the surface after electrolytic polishing of 50 µm.



a) Cutting only, before polishing. b) After polishing of 25 µm.



c) After polishing of 50 µm. d) After polishing of 100 µm.

Fig. 4 Surfaces of OFHC pieces for DC breakdown voltage test.

DC voltage breakdown test

Three pairs of test pieces were prepared for evaluation of electrolytic polishing of the vane surface on breakdown voltage. Their shape is similar to a unit cell, from a valley to the next one of a vane, near the RFQ exit. For simplicity, a DC voltage was applied between two pieces separated by 6 mm or 3 mm at the tops. They were made of OFHC and machined following the same procedure for the vanes. A part of the spare high gradient accelerating column was used as a vacuum vessel and was evacuated by a 1000 l/s vac-ion pump with a 1000 l/s turbo-molecular pump. The pressure was 4 - 10 x 10^{-7} Torr and no special pattern was observed by a quadrupole mass analyzer. The following surfaces were tested: cut by a CNC milling machine and no polishing, electrolytic polishing of 20 µm, 50 µm and 100 µm (Fig. 4). Polishing with $A\ell_2O_3$ powder or emery paper was avoided. There were big differences in breakdown characteristics among three pairs as usually observed in such tests. For cutting only, the lowest breakdown voltage was 60 kV with 6 mm gap spacing (1.1 Kilpatrick) whereas the highest was more than 84 kV with 3 mm gap (2.3 Kilpatrick) [4,5]. For 25 µm electrolytic polishing, the worst pair was improved to 87.5 kV with 3 mm gap (2.4 Kilpatrick). As the voltage was limited by the power source capacity, more improvement may be expected. No deterioration was found for the best pair while the other showed some peculiar behavior. There was no current up to 77 kV for increasing the DC voltage. Then abruptly a current started to flow. It was 7 µA at 87.5 kV and unchanged for 10 minutes. X ray was observed. It decreased gradually with decreasing the voltage and ceased at 42 kV, but it began to flow when the voltage was increased from this level. As the current was reproducible, it seemed that a "cathode" was produced. The current vanished for 50 µm polishing. Thus all pairs attained to 87.5 kV with 3 mm gap for 50 µm polishing and no bad effect was observed for 100 µm polishing. As a whole, the electrolytic polishing is promising. On the basis of the fundamental experiments above, polishing thickness of 35 µm for the vanes, 25 µm for the flat cavity plate and the final polishing of 5 µm for the cavity were chosen.

750 keV proton RFQ

The RFQ of 750 keV output energy was calculated and mechanically designed on the basis of the experience of the first model RFQ . Table 1 shows the design parameters. Figure 5 shows mechanical design. Limiting current of 98 mA was chosen considering the planned H^- injection into the Booster synchrotron. The features of mechanical design are copper-made, square cross section

Table 1

Parameters of the 750 keV proton RFQ

Frequency	201.08	MHz
Injection energy	50	keV
Final energy	750	keV
Vane voltage	89	kV
Number of cells	118	
Vane length	136.4	cm
Initial radius	2.4	cm
Minimum radius	0.4	cm
Initial modulation	1.0	
Maximum modulation	2.0	
Initial phase	-90.0	
Final phase	-30.0	
Normalized acceptance	0.41	πcm mrad

with frames instead of conventional circular one, electron-beam welding between the vanes and the flat cavity plates and no rf joints except for rf coupling ports. The cavity is strong enough for evacuation. The deformation is expected to be less than 10 μm, and if necessary the vane alignment might be confirmed from the outer surface. The machining of the vane was done three times. Figure 6 shows the trajectories of the center of a ball end mill projected on the three planes in the Cartesian coordinate. In the finish cut the pitch of a ball end mill changes linearly from 0.68 to 0.79 mm to save machining time. The overall mechanical tolerance of the vane is expected to be less than 50 μm.

The authors are deeply indebted to Mr. Iino and his group of Mitsubishi Heavy Industries for skillful work of the vane fabrication and Nomura Plating Company Limited for elaborate electrolytic polishing study. They would like to express their gratitude to Dr. T. Nishikawa, the Director General of KEK, Prof. T. Kamei, the head of the Accelerator Department and all members of the Injector group.

References

1. L.D. Hansborough, J.M. Potter and N.G. Wilson, "Mechanical Design of RFQ Resonator Cavities in the 400 MHz Frequency Range", Proc. 1981 Linear Accelerator Conf., p.329 (1981).
2. T. Kato, Z. Igarashi, C. Kubota, E. Takasaki, T. Takenaka and S. Fukumoto, "Development of an RFQ Linac at KEK", Proc. 1983 Particle Accelerator Conf., IEEE Trans. Nucl. Sci., 30, No.4, p.3569 (1983).
3. T. Kato, E. Takasaki, Z. Igarashi, C. Kubota, T. Takenaka and S. Fukumoto, "An RFQ Linac for Proton Acceleration", Proc. 7-th Symp. on Ion Source and Ion Assisted Technology, (ISIAT '83), p.629 (1983).
4. W.D. Kilpatrick, "Criterion for Vacuum Sparking Designed to Include Both rf and dc", Rev. Sci. Instr., 28, p.824 (1957).
5. S.W. Williams, R.F. DePaula, D.R. Keffeler and G.R. Rodenz, "Voltage Breakdown in a 420 MHz RFQ Structure", 1981 Particle Accelerator Conf., IEEE Trans. Nucl. Sci., 28, No.3, p.2976 (1981).

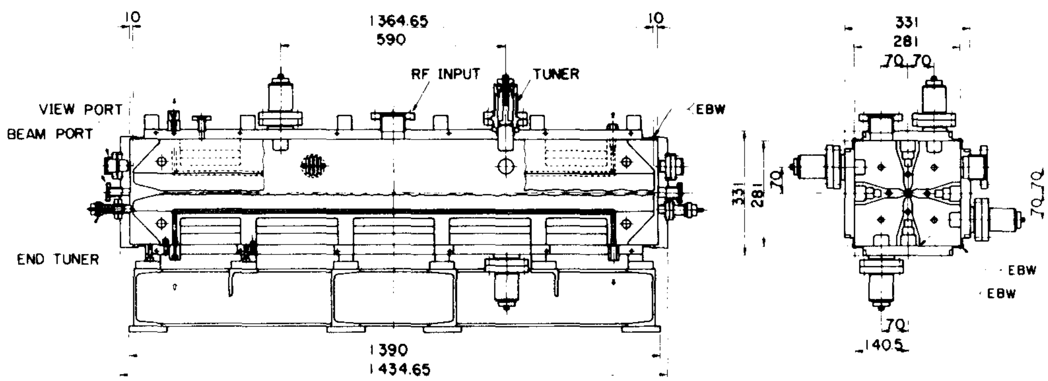
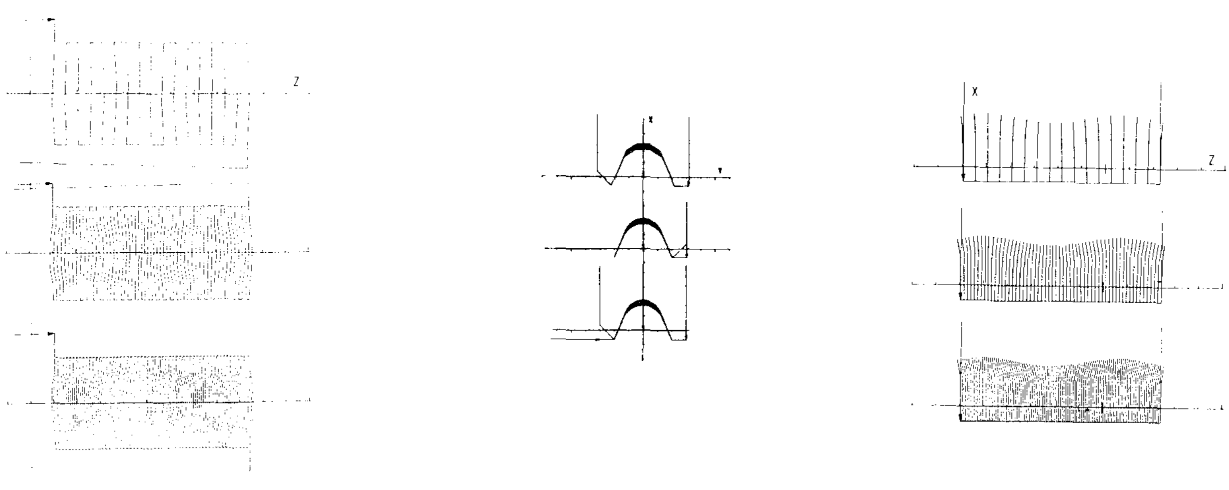


Fig. 5 Mechanical design of 750 keV proton RFQ.



a) Accelerator section projected on the y-z plane.

b) Accelerator section projected on the x-y plane.

c) Accelerator section projected on the x-z plane.

Fig. 6 Trajectories of the center of a ball end mill projected on the three planes. Three kinds of trajectories represent rough, semi-finish and final cut.