MANUFACTURING DESIGN AND STATUS OF LEHIPA RFQ

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Abstract

The LEHIPA RFQ will accelerate the 30 mA (average/cw) proton beam from ECR ion source to the energy of 3 MeV. Manufacturing RFQ is highly challenging task due to its stringent geometric tolerances. To achieve such tolerances, manufacturing design that includes RFQ manufacturing scheme, mechanical tolerancing of the vanes, brazing design, and mechanical inspection scheme was conceptualized. Trials were done on a few prototypes to establish the design. This paper discusses salient features of manufacturing design, results of the trials, and a few possible modifications in the design to achieve better precision levels.

INTRODUCTION

BARC has initiated the development of Low Energy (20 MeV) High Intensity Proton Accelerator (LEHIPA) as front-end injector of the 1 GeV accelerator for the ADS program. The RF and accelerating parameters of LEHIPA are described in [1]. Its Radio Frequency Quadrupole (RFQ) consists of four mechanically joined one-meter long modules (fig. 1).

Figure 1: First module of LEHIPA RFQ with its support structure.

The 3MeV RFQ is being manufactured at Brahmos Thiruvananthapuram Ltd., Trivandrum (BATL). In the view of complexities involved in its manufacturing, manufacturing activities were divided in five stages. First three stages were dedicated to various trials; in stage-4 we are making a one meter long 400 keV Deuteron RFQ. Manufacturing of 3 MeV RFQ will begin in stage-5.

MANUFACTURING SCHEME

LEHIPA RFQ is a approximately 4 meter long structure. Four modules of approximately one meter length will be mechanically joined to make the RFQ. Each RFQ module will be made of four OFE Copper vanes; two of them are major vane and remaining two minor vanes. These vanes are joined together in first vacuum brazing step to make RFQ cavity assembly. Various ports and flanges are then brazed on this assembly in a second brazing cycle at marginally lower temperature.

MECHANICAL TOLERANCING

We are targeting to control the RFQ internal surfaces within ± 70 μm with respect to their nominal position. To get these tolerances, individual vanes are being machined within ± 40 μm. Vane tips are being machined within ± 20 μm. Brazing surfaces and all the datum features are asked to have flatness of ± 10 μm. We expect total error due to vane alignment and brazing deformations to be of the order of ± 30 μm.

MANUFACTURING PROCESS

For fabrication of the 400 keV RFQ, following procedure is being adopted: rough machining of all four vanes leaving a stock of 4 mm, gun-drilling to make vane coolant channels, stress relieving at 600^0C, finish machining of vanes, geometric inspection of individual vanes, RFQ assembling and aligning, first round of brazing, repeat of dimensional inspection and RF tests, second round of brazing, final inspection including RF tests.

BRAZING

RFQ brazing procedure consists of two steps- the first step involves the brazing of the four vanes to form RFQ cavity in horizontal position. After brazing, both the octagonal ends of the RFQ cavity are machined in order to fit the circular stainless steel end-flanges. In second step brazing, these flanges are brazed on to the RFQ cavity a vertical furnace. Vacuum ports, RF ports, tuner ports, and coolant channel connectors are also brazed during this step.

Brazing fillers used for joining OFE copper vanes were (a) PalCusil-5 (B-Ag68CuPd- 807/810, brazing temperature 830^0C) is used for the first step and (b) Cusil (B-Ag72Cu-780, brazing temperature 790^0C) is used for the second step.

To qualify the brazing procedure, trials with small length, 20 mm wide coupons were done to simulate vane-to-vane joint. Various combinations with changing no. of grooves, their proximity with outer surface, capillary gap (including zero gap), orientation of groove with respect to gravity were tried. Finally, we decided each brazing joint to have nominal capillary gap of 50 microns and two grooves of approximately 1.6 mm width (fig. 2) on one of its two surfaces. Brazing surfaces don't have any steps to give extra flexibility. Care is taken to design and orient the grooves (during brazing) in such a way that gravity assists in spreading molten filler alloy during brazing. One of the major vanes of each RFQ module has grooves on both of its brazing surfaces; the other one has no brazing grooves. Both the minor vanes have grooves yet they are on opposite brazing surfaces.

In initial brazing trials, foil type of brazing fillers were used. In this case, vanes had to rest directly rest on the foils. It resulted in poor performance both in terms of leak-tightness and precision point of view. Now we are using wire type of fillers. It is advantageous because vanes can rest on shims that do not melt during brazing, which in turn gives better precision after brazing. In addition, shims give us flexibility to alter the assembly by 20-30 microns to get desired RF characteristics.

Figure 2: A short length major vane showing brazing arrangement.

Fixturing

During the initial trials, an independent fixture was used to hold the vanes in their desired position. However, this was found to be inadequate for maintaining alignment through brazing step and the minor vanes were displaced during brazing. The revised fixturing was done with the help of projections provided on the vanes through which bolt were used to clamp the vanes together. After first-step brazing for completing RFQ cavity, these projections are machined off.

Vane Assembly and Alignment

Alignment process for joining of four vanes to make RFQ cavity is as following: place the bottom major vane (the one with brazing grooves) on the coordinate measuring machine (CMM) bed, put the filler wires in the grooves and the shims in their respective positions, place on of the minor vanes on the major vane, align it with respect to major vane, fasten both the vanes with help of the bolts, repeat the process with remaining minor vane and major vane (the one without brazing groove), then conduct geometric inspection (fig. 3) and RF tests. If required, fine tune the assembly by changing the shims of required thickness.

In one of our trials, titanium bolts were used to block the vanes, however they are suspected to be detrimental to vane alignment by putting extra constraints on the vanes. In future, we plan to use bolts made of material having high strength at brazing temperature and matching thermal coefficient of expansion with OFE copper.

Critical dimensions at the entry and exit section of the RFQ vane have been identified, which are inspected to check the alignment of the vanes with respect to each other. All the alignment measurements are referenced from the features on internal surfaces of the RFQ. This reduces requirement of keeping stringent tolerances on the outside surfaces. It results in direct evaluation of the alignment precision as well.

Figure 3: The CMM Inspection of RFQ cavity.

FABRICATION STATUS

All four vanes of 400 keV RFQ have been machined (fig. 4). Following table lists tolerances that were achieved on its vane machining:

RFQ Tolerances	**Value**	**Units**
Machining error	± 20	μm
Vane modulation error	± 20	μm
Vane thickness error	± 10	μm
Vane Flatness error	± 50	μm

Figure 4: A 400 keV RFQ Minor Vane.

FUTURE MODIFICATIONS

Deformations of the order of ± 40 μm due to stress relaxation in the 400 keV RFQ vanes after their finish machining have been noticed. Few modifications in next RFQ module manufacturing is planned to reduce the deformations. Only 500 μm of stock will be left on the vanes for finish machining. And an additional stress relieving treatment will be given to the vanes prior to finish machining. Even distribution of the clamping pressure during finish machining will also help in reducing the deformations.

CONCLUSIONS

It has been possible to machine the vanes within specified tolerances. Brazing process including fixtures has also been qualified as far as vacuum tightness is concerned. However, we need to control the deformations induced due to stress relaxation in the machined RFQ vanes to get better precisions.

REFERENCES

[1] P. Singh *et al.*, Accelerator development in India for ADS programme, Pramana-J.Phys., **68,** 331 (2007).