ELECTRON BEAM WELDING OF NIOBIUM RESONANT CAVITIES AT IUAC

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Abstract

The Electron Beam Welding facility at IUAC was commissioned in February '2002. Subsequently parameters were developed for welding niobium material, which were used for fabricating resonators. In addition, several existing resonators were reworked and restored successfully. IUAC in collaboration with RRCAT has built two single cell cavities. Two single spoke resonators for Fermi Lab are also presently under construction. This paper will report the electron beam welding activities at IUAC.

INTRODUCTION

The Electron Beam Welding (EBW) machine at Inter-University Accelerator Centre (IUAC) is a model LARA 52 supplied by M/s Techmeta, France (see figure 1). The total beam power available is 15 kW at a maximum operating voltage of 60 kV. The welding chamber is 2500 mm × 1000 mm × 1000 mm in size. It is pumped by two diffusion pumps, each of capacity 8000 l/s, having water cooled baffles. The diffusion pumps are backed by a rotary pump and roots blower combination. The electron gun is separately pumped by a turbo molecular pump. The diffusion pumps use silicon free oil and the operating vacuum of 5×10^{-5} mbar in the welding chamber is achieved in about 30 minutes time.

Figure 1: Electron Beam Welding machine at IUAC.

A table of size 1400 mm × 900 mm provides a total travel of 1000 mm in one direction. The electron gun moves in the perpendicular direction and travels ±250 mm. For circular welds, a tilting rotary manipulator with matching tailstock is provided. Control in the z-axis is achieved through the focusing coil, which can focus the beam over 450 mm. For optical viewing a camera is provided, which is used for setting up the job and for witnessing the actual welding. The complete electron gun system can also be mounted horizontally.

The overall machine and beam parameters are CNC controlled. The welding programs are created, executed and stored on the CNC TERA-S system. The control system runs on a PC which is interfaced with the CNC. The PC operates through a touch screen. An oscilloscope is provided on the console to view the beam pattern during beam vibration/oscillation.

IMPORTANT FACTORS FOR EBW OF NIOBIUM RESONATOR PARTS

For a cavity to perform at high accelerating gradients, the RF surface is critical. The electron beam welds should be full penetration with smooth and uniform bead. They must not have any cracks, undercut, underfill or porosity. The welding parameter must be carefully chosen so that the welds exhibit all these qualities. Pre-weld cleaning is an important component of the welding procedure. After the niobium parts are machined, they must be mechanically polished to obtain square edges without any burr and folds. Subsequently the components are cleaned and degreased in an ultrasonic cleaner. Just before the welding, they are chemically cleaned to remove 2-3 μm material using an acid etching solution. The parts must be carefully packed in clean dry bags.

PARAMETER DEVELOPMENT AND QUALIFICATION

After the machine was commissioned at IUAC, we developed the welding parameters on niobium material. The parameters were developed for two different thicknesses, namely 1.6 mm and 3.2 mm that are predominantly used in fabricating niobium resonators. A number of trials in key hole and conductance mode were carried out. The parameters were chosen based on full penetration with smooth face and root, no undercut or underfill.

Using the qualified parameters, welding samples were prepared, which were subjected to the following tests. The final parameter was chosen based on the reports.

A. Visual inspection to ensure full penetration, smooth and uniform bead on the face and root of the weld, minimum weld spatter, no undercut or underfill.

B. Thermal shocking from room temperature to LN_2 atleast half a dozen times followed by leak testing at leak rates $< 2 \times 10^{-9}$ mbar l/sec.

C. Die penetrant test to inspect cracks on the surface.

D. Radiography to detect weld porosity and internal cracks.

FABRICATION OF QWRS

There are thirty five electron beam welding joints in the quarter wave resonator (QWR) used in IUAC linac [1]. They can be classified into three categories: linear, circumferential and saddle shaped. Although the basic parameters for the two thicknesses of niobium had been developed, they had to be fine tuned for each joint to account for their size and the associated fixturing with it. In fact, this is the most difficult aspect of electron beam welding and is non-trivial to assess. Less power can result in lack of penetration and more power can easily lead to blow throughs. Both are difficult to fix. The trick therefore is to get the parameter just right for welding a component of a given thickness. Substantial amount of effort has been devoted in fine tuning the parameters for the different welds on the IUAC-QWR.

Of all the welds, the most critical is the closure welding that joins the two major sub-assemblies, namely the outer housing and the inner central conductor. This weld lies in the crucial high magnetic field region. The rf surface here is the root of the weld, which is difficult to access for any mechanical polishing. The requirement is to have a full penetration weld with no spatter and smooth uniform bead. Also, since the sub-assemblies have substantial mass, developing a good parameter took several trials.

We have so far fabricated around eighteen QWRs. In addition, several critical repairs have been successfully performed on the existing resonators. On three resonators, the upper caps on the central conductor assembly were replaced. For this the resonators had to be cut open. On several resonators the leaking coupling port bellows assemblies have been replaced with an in-house developed design. The replacement work involves machining out the leaking port, fitting a new port in its place and welding it. The total number of welds performed on the all QWRs, including the initial parameter development, is around one thousand. In figure 2, a typical setup is shown. The indigenously built QWRs [2] have performed very well. They have substantially exceeded the design goal, thus validating the welding procedures adopted at IUAC.

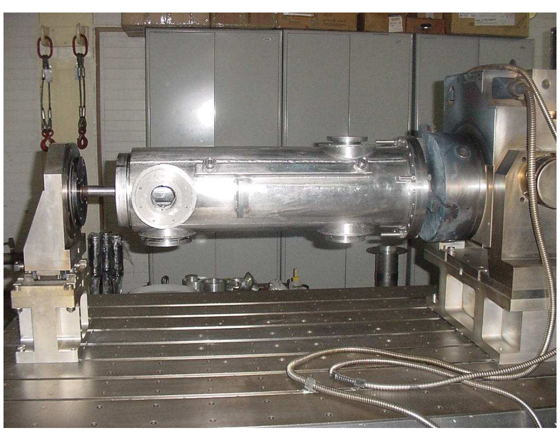

Figure 2: Typical electron beam welding setup.

1.3GHZ SINGLE CELL CAVITIES

This is a collaborative project between IUAC and Raja Ramanna Centre for Advanced Technology (RRCAT), Indore under the Indian Institutions and Fermi Lab collaboration (IIFC). The cavities were formed and machined at RRCAT and the electron beam welding was performed at IUAC. In the first stage, two single cell cavities were fabricated. They were sent to Fermi Lab for testing. In cold tests at 2 K the first cavity produced 19 MV/m and the second cavity achieved 23 MV/m accelerating gradient. The most critical welding in the single cell cavities is the equator joint where the magnetic field is maximum. Due to shortage of niobium material, this welding was performed after only two trials on a niobium ring of the equator diameter. After welding the first cavity, the parameter was further tuned to improve the weld quality, which is indicated in the slightly better performance of the second cavity. We are now building two improved single cell cavities incorporating all the lessons learnt from the earlier fabrication. For the equator weld, trials are being made on actual size dumb-bells to obtain a good parameter.

Apart from the equator joint the single cell cavity also has Nb-Ti to niobium joints. Due to the difference in the physical properties of the two materials, this welding also needed several trials. We have successfully developed a good parameter for this weld.

SINGLE SPOKE RESONATORS

This is a collaborative project between IUAC and Fermi National Accelerator Laboratory, USA, for fabricating two single spoke resonators. In addition to developing all the dies, fixtures and other tooling, we had to develop all the EBW fixtures and welding parameters. The Seam welding of both the outer shells and the spoke halves, have been completed. The long seam welding of the spoke halves was non-trivial since the spoke is narrow in the middle and slightly bigger at the ends. Also the gun to work distance continuously changes during this welding. Presently we are getting ready to weld the end wall to the beam port assemblies and the outer shell to its coupling port assemblies.

CONCLUSIONS

The electron beam welding machine at IUAC is being used for fabricating different types of niobium resonators for in-house and collaborative projects. Performance of the QWRs welded at IUAC is excellent, with several of them easily exceeding the design goal. At the same time the performance of the first two single cell cavities is quite satisfactory and we are confident that the next set of cavities will perform even better.

REFERENCES

[1] Prakash N. Potukuchi, Proceedings of 14th Intl. Conference on RF Superconductivity - SRF2009, Sept. 20-25, 2009, Berlin, Germany, p502

[2] Prakash N. Potukuchi, in this conference