RESTORATION OF RF CAVITY FOR SYNCHROTRON STORAGE RING INDUS-1

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Abstract

RF Cavity for Synchrotron Storage Ring, Indus-1, is made of Stainless steel and it is internally electroplated with copper. The cavity is designed for 31.613 MHz operation and has an internal diameter of 840 mm & length of 600 mm. The cavity structure is re-entrant type and there are big “capacitor disks” at 10 mm from the median plane which are attached to the end plates through 290 mm long “drift tubes”. Vacuum in the RF Cavity for Synchrotron Storage Ring, Indus-1, started deteriorating in the month of June 2001 and within few weeks time the vacuum level deteriorated by 3 orders from $5X10^{-9}$ mbar. The leak check, which became quite complicated due to the location & internal electroplated surfaces, showed a leak in the drift tube. This paper describes the work done to analyze the problem, design of alternative structure & the cooling circuit, FEM analysis of temperatures & thermal deformations, RF analysis, coarse & fine tuning and manufacturing, electroplating, assembly, vacuum testing, RF testing and integration in the ring. The cavity is now working in the ring, with a vacuum level of 1.0E-8 mbar with beam. Thermal time constant & thermal detuning have improved after the repair. The total thermal detuning is now less than 50 kHz at 22 kV, which is well within the on-line tuner range, and start-up time is 10 minutes.

INTRODUCTION

Indus-1 is a 450 MeV, 100 mA electron storage ring, constructed at Centre for Advanced Technology, Indore, India. The ring requires one radio frequency cavity operating at 31.613 MHz. Considering the relatively low frequency of the cavity and the limits suggested by mechanical design, a re-entrant type of structure was designed. The resulting inside diameter of the cavity was 840mm and inside length was 600 mm. The cavity should maintain a vacuum of the order of 10^{-9} mbar. The cavity developed a vacuum leak and the vacuum deteriorated to unacceptable level. Considerations of geometry of the structure, location and type of defect and the fact that it is an RF structure, dictated that the solution couldn’t be achieved by local repair of the leak. The problem has been solved by executing a re-design and fabrication of the defective part of the cavity structure.

The cavity is made by internally electro-plating copper on stainless steel Type 304L substrate. The original structure, worked successfully for five years. Figure 1 shows the photograph of the defect on the drift tube and one symmetrical-half of the cavity after opening the large central joint. The cooling circuit provided on the original structure for the cooling of capacitor disks and the drift tube is shown in Figure 2.

The cavity is made in two halves having a large joint at the median plane (normal to the axis) sealed by a Helicoflex® seal. This seal has a sealing lining of aluminium, inner lining of Inconel 600 and elastic core spring of Inconel X750 (HN200 seal). Visual inspection on the removed drift tube showed that the crack was oriented longitudinal to the tube along the brazing line of the cooling coil to the drift tube.

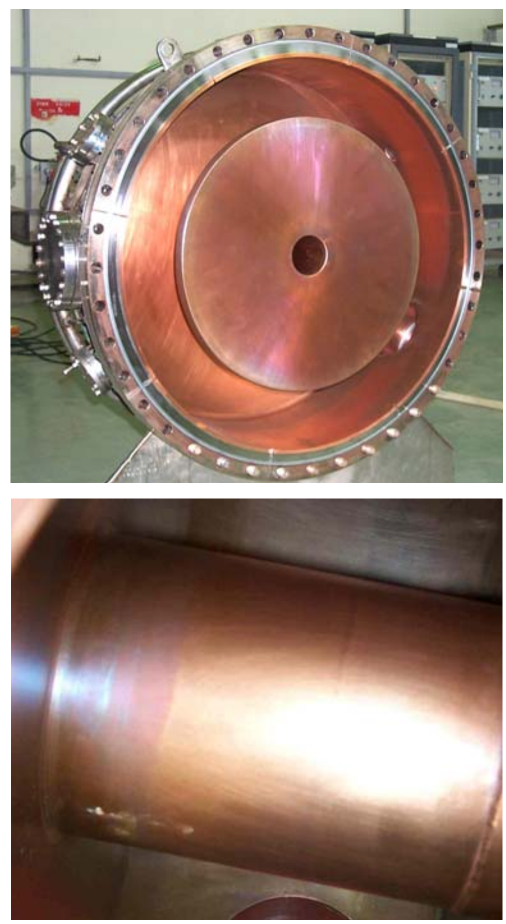

Figure 1: The original cavity structure after opening, a large Helicoflex seal, in place for many years, can be seen on the flange (Top). The defect can be seen in the picture at bottom.

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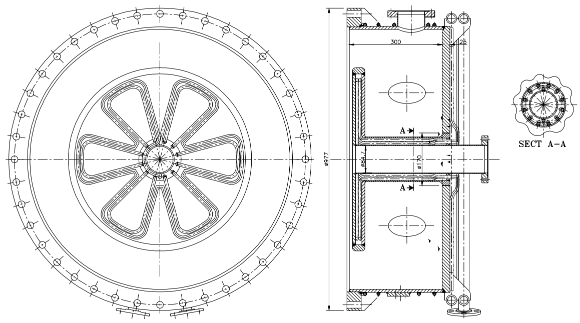

Figure 2: Cooling circuit of original cavity structure (One Half of the cavity is seen).

Considering that the operation of the ring depended on this cavity, the cavity had to be restored in a short period.

DESIGN DETAILS OF MODIFIED CAVITY

The modified cavity structure as shown in Figure 3. The capacitor disks with inter-space are replaced with solid stainless steel disks, relying on cooling by conduction through solid. The heat loss on various cavity surfaces, temperatures and resulting detuing were calculated for modified geometry. The choice of solid disks removes the multiple machining requirements, long length brazing of cooling coils and also reduces the weld length to a very minimum. In addition the four vacuum boundary joints are eliminated. The drift tube was designed to be single thick tube with long holes drilled for cooling water flow. The cooling water enters through the smaller inner tubes and returns through the annular space as shown in Figure 4, thus providing flow directly on internal surfaces of the holes of the drift tube on a large area.

The scheme also provides a high coefficient of heat transfer at the end of the hole, where water impinges on the bottom of the hole. This provides vigorous cooling in the drift tube, reducing the variation of the frequency sensitive capacitor plate gap, which is important for controlling the thermal frequency shift. Such construction of drift tube has inherent advantage of better thermal performance and robust manufacturing compared to brazed and welded coils. Water cooling from the end plates and shell of the original cavity were removed, due to frequent leakage problem, and blast air cooling using 16 Nos. of 4.5” instrument cooling fans was provided.

Temperature distribution and thermal deformation were calculated using software COSMOS/M and ANSYS (Figures 5). These values were then used to calculated the frequency shift of the cavity from no power to full power using software SUPERFISH.

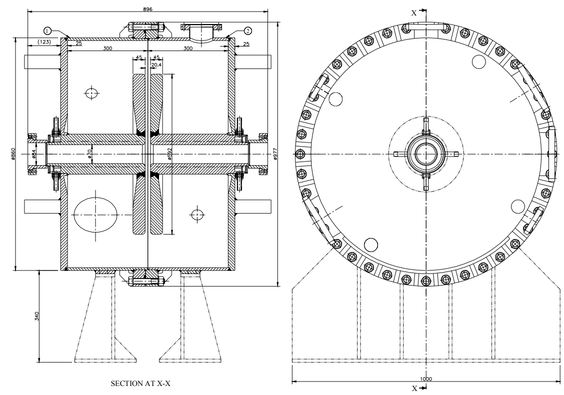

Figure 3: The modified cavity structure

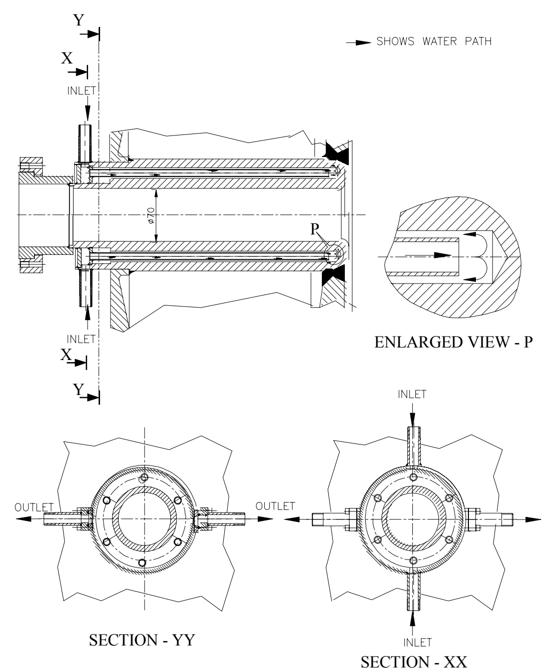

Figure 4: Cooling circuit of the modified cavity structure, note that the cooling coils are not welded to the drift tube yet its rigorous cooling is available. There is no joint on water to vacuum boundary.

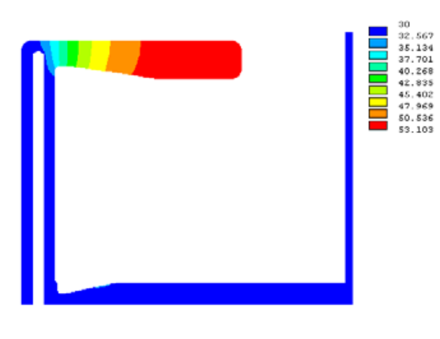

Figure 5: Temperature distribution for power loss corresponding to 22kV with cooling water flow of 50 lpm in the drift tube cooling circuit.

Copper plating

The original plating of the complete cylindrical shell and most of the area of the end plates of cavity was preserved. Capacitor-drift tube subassemblies were welded, finish-machined and electroplated separately, leaving a small area adjoining the weld location. The sub-assemblies were welded to the end plates. Cooling headers were also welded at this stage. After completing all the welding operations, the weld and its adjoining area was electro-plated by using the cavity shell itself as the tank for holding the electrolyte. Copper was deposited to a thickness of 60 microns based on the skin depth calculations. Plating thickness on the cavity surfaces was controlled by adjusting the plating time.

Heat treatment

The electroplated capacitor-drift tube sub-assemblies were heat treated in vacuum furnace to

- remove the gases generated during the plating
- improve the adhesion of the copper plating
- to stress relieve the structure to prevent deformation due to stress relieving during baking.

The heat treatment was done at a temperature of 200°C and a vacuum level of 1.0E-5 mbar. A large vacuum furnace, equipped with a cryo pump with a pumping speed of 10000 liter per second, with a cylindrical hot zone of diameter 750 mm and a length of 2500 mm was used.

Vacuum performance

The individual weld on the vacuum boundary were leak tested by MSLD (He) having a sensitivity of $3X10^{-10}$ mbar.lit/sec. When the cavity was assembled using Helicoflex®, the joint showed a gross leak rate of 10^{-6} mbar.lit/sec. Initially it was suspected that the flange surface may have scratches, however even after re-machining of the flange surfaces and careful centering of the seal in the groove, the leak persisted at the same level. Due to repeated non-sealing of the joint with Helicoflex®, a VITON gasket was used. It is suspected that during a long storage period aluminium lining surface of Helicoflex® has developed a thick oxide layer, which is hindering a proper sealing. It is to be noted that the previously installed Helicoflex® worked for about five years and when the leak in drift tube was found, the seal was still good. The cavity was baked at 120°C for 24 hours using a special oven around it and the cavity is operating at a vacuum of $1X10^{-8}$ mbar with two 270 lit/sec SIPs and two 1000 lit/sec TSPs.

Tuning of the cavity

Coarse tuning was done by changing the axial length of the cavity. A mechanism has been provided on the end plates of the cavity for this purpose. Online fine tuning is done by using three cylindrical tuning plungers, which operate in the cavity volume. The tuning range of the three tuners is 110 kHz.

High power testing

After baking the cavity, initial resonant frequency was adjusted to 31.770 MHz with β of feed loop adjusted to 1.28. RF conditioning of cavity was started without cooling water circulation. Power was increased slowly in pulsed mode. CW power of 200 watts could be fed on the first day and cavity gap voltage of 29 kV was reached on the second day (with considerable multipactoring). With cooling water flow & forced air-cooling, frequency drift of 2 kHz /°C was observed (due to the change in ambient temperature). With three tuning plungers for taking care of beam loading & thermal detuning, auto start of RF system was possible. Resonant frequency of RF cavity was again adjusted to 31.619 MHz (desired Indus-1 RF system frequency) with coarse tuning arrangement mounted at both the end plates of RF cavity. With all these modifications in RF cavity & optimisation of feed back loops for amplitude, phase & frequency of RF cavity for smooth operation, less downtime of Indus-1 RF system was possible since October 2001. With maximum of 100 mA and 150 mA of stored current in the storage ring the detuning observed, due to beam loading, was around 9 kHz and 12 kHz respectively.

FAILURE ANALYSIS

A failure analysis was performed to identify the cause of the failure which revealed intergranular corrosion and extremely coarse grains of the material. There was a possibility that halogen acids used during electro-plating were left in the crevices at braze interface. The cavity was baked about 15 times to 170°C using electrical heating tapes. During the course of operation the cooling water started leaking into the interspace and it is suspected that high temperature combined with the presence of brazing flux & acid residues provided for a favourable conditions for corrosion.

REFERENCES

[1] Thermal design of modified Indus-1 RF cavity - Abhay.Kumar, Jishnu Dwivedi,SG Goswami, RS Sandha & HC Soni, CAT internal report CAT/2002-25

[2] Internal Report on failure analysis of drift tube of RF cavity – Rakesh Kaul, P.Ganesh, AK Nath, CAT.