A.1: Development, testing and installation of new 31.613 MHz RF cavity for Indus-1

A new RF cavity operating at 31.613 MHz has been designed, developed and installed in Indus-1 after moving the old cavity to Booster Synchrotron. The cavity compensates for the power lost by the beam due to synchrotron radiation.

The electromagnetic design, design of engineering features including coarse and online fine tuning mechanisms, thermal and structural analysis, design for manufacturing, assembly, testing and integration of the new RF cavity in the Indus-1 ring were done. Low RF frequency results in a large size and complex shape of the cavity.

The internal diameter of the cavity is 840 mm and the axial length is 900 mm. The cavity structure is *re-entrant* type and there are big “capacitor disks”, having a diameter of 614 mm, at 10 mm from the median plane which are attached to the end plates through 290 mm long “drift tubes”. The cavity operates in ultra high vacuum. The power deposited on the walls is cooled in such a way that the thermal detuning, resulting from thermal distortions, is minimized.

A well thought out manufacturable and robust design scheme to meet the multiple requirements of RF frequency, RF surfaces, coarse and fine on-line tuning, and ultra high vacuum, was made. The basic cavity geometry, frequency sensitivity of the surfaces to the deformations and resistive power-loss on the surfaces is calculated in many interactive sessions using SUPERFISH and ANSYS. Mechanical and thermal effects were analyzed using analytical and FEM based numerical techniques (see Fig.A.1.1). The geometry, materials and methods of manufacture have to be truly refined to meet the requirements of RF cavities.

The material requirements form a crucial part of the design. High thermal and electrical conductivity, low multipactoring coefficient, high yield point at baking temperature of 200 °C, hardness of the sealing surfaces, high percentage elongation for metal forming operations, good corrosion resistance in electroplating operations and operational cooling through the lifetime, low vapour pressure and low out-gassing rate, low magnetic permeability (due to proximity to the magnets in the ring), manufacturability, manufacturing facilities and availability are considered in the design.

The cavity is made from SS316L confirming to ASME SA-240 and it is internally electroplated with copper. It is difficult to procure high quality material in small quantities with a proper quality control and considerable efforts were made on the testing of materials, before their use.

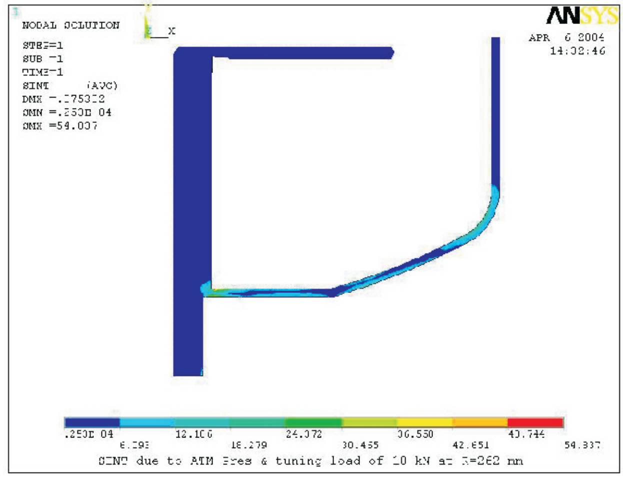

Fig.A.1.1 : Stress intensity contour of RF cavity due to atmospheric pressure and tuning load

The cavity structure is designed to take the forces of atmospheric pressure, mounting devices, support and handling, in addition to the thermal stresses. Since the frequency is sensitive to dimensions, an accurate estimate of deformed geometry is done using finite element method.

Considering very high cost of the Helicoflex and its storage problems, the large diameter is sealed using a lip weld. Before making the final seal welding, RF and UHV qualification of cavity requirements was done. Special clamps were designed to provide high contact pressure across the joint to make good RF contact.

Electroplating of the cavity internal surfaces with copper was done using the in-house facilities and very good quality of plating in terms of adhesion and surface finish was obtained. A thickness of 100 μm was plated on all internal surfaces. The out-gassing rate of the plated surface was measured to qualify the plating process and an out-gassing rate of 10^{-11} mbar.L/s-cm^2 after a baking cycle at 200°C was obtained. Good surface finish and removal of sharp corners is achieved by a combination of machining and painstaking hand-polishing operations. The final cleaning of the cavity was done using vapour degreasing.

On-line fine tuners with short overall length were also developed. The tuners have a stroke length of 100 mm and provide a tuning range of ± 40 kHz per tuner. The tuner consists of a copper plunger that moves inside the cavity

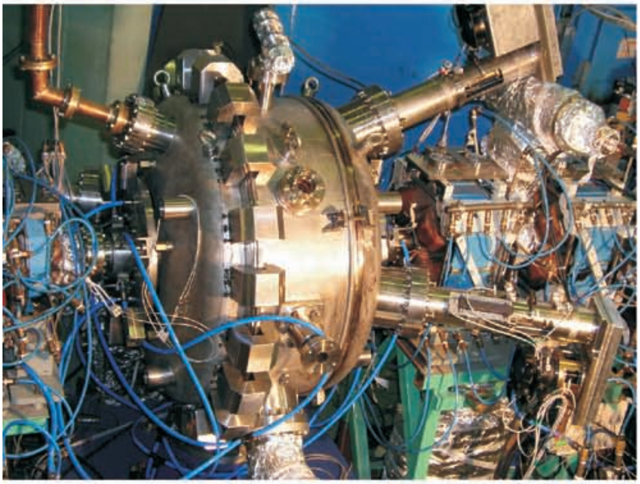

Fig.A.1.2 : Photograph of the RF cavity

volume on a linear path, changing the inductance of the cavity, and thereby its resonant frequency. Movement is transmitted inside vacuum using edge-welded bellows. Its actuator unit consists of ball screw, linear slide, timing belt drive, stepper motor, and electromagnetic brake. Linear potentiometer is used for taking feedback of its position. An integrated mounting table for the cavity and its sub-systems with provision for alignment is made. Thermocouples are mounted on the cavity for knowing temperature during baking.

A power of 1200 W is fed to the cavity to generate a gap voltage of 25 kV. Its thermal detuning is 80 kHz and it can be tuned to required frequency with an accuracy of 10 Hz using the on-line tuners. The cavity is cooled using a dedicated chiller system. The system supplies the low conductivity water at any constant temperature in a range from 10°C to 35°C and with a stability of ± 0.5°C. The usual input cooling water temperature is 27°C.

The installation of the cavity, in Indus-1 SRS ring, was accomplished in May 2007 and it is operating successfully, at a vacuum of 2×10^{-8} mbar. A photograph of the installed RF cavity is shown in Fig.A.1.2

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A.2: TL-2 optics design for the CTF-3 (CERN)

Compact LInear Collider (CLIC) is an upcoming project at CERN, Geneva. CLIC Testing Facility 3 (CTF3) is a sub-project to demonstrate the generation of high power RF at 12 GHz by means of an electron beam. The RF generation scheme developed at this facility will be used for electron acceleration in the CLIC.

In CTF3, a 150/300 MeV electron beam with a bunch length of 8.3 ps and normalized emittance of 100 π mm-mrad (both planes), after the extraction from the Combiner Ring (CR), will be transported to the CLIC experimental (CLEX) area with a compressed bunch length of ~1.6 ps. This beam transport, accompanied by bunch compression keeping the emittance dilution less than 10%, will be done in a transfer line named as TL-2. The optics design of this line has been done at Indus Operations and Accelerator Physics Design Division of RRCAT under DAE-CERN collaboration.

This line will be installed in the existing LEP pre injector complex, CERN. An additional constraint was that the TL-2 was to be designed using some spare quadrupole and sextupole magnets available at CERN. CTF3 being a test facility, this line is also required to have a capability to vary the bunch length over a wide range. Designing a line to meet the stringent requirement of bunch compression over a wide range, keeping very low emittance dilution, using the magnets with pre-defined specifications, and its installation in the existing building geometry was a major design challenge.

In magnetic optics, the path length of a particle depends on its momentum. The R_{56} parameter connects the deviation in the path length of a particle with the relative deviation of its momentum with respect to the central value. Therefore by controlling this parameter, a bunch with a certain momentum spread can be compressed. R_{56} is a function of the dispersion, which is a measure of the displacement of an off momentum particle from the design trajectory. Therefore by shaping the dispersion function along the line, R_{56} can be controlled. The TL-2 line is capable of tuning the R_{56} parameter from -0.30 m to +0.30 m.

Besides R_{56}, the second order aberration known as T_{566} can also have a large effect on the bunch length. In the design of this line, the second order aberration has been suppressed with the help of sextupole magnets. The sextupoles also have a detrimental effect on the emittance due to their nonlinear magnetic field. In the whole tuning range, the emittance dilution due to sextupoles magnets has been kept successfully below 10%.

The designed transfer line (shown in Fig.A.2.1) is 44.5 m long and has 37 magnets : 7 dipole magnets, 26 quadrupole magnets and 4 sextupole magnets. The line can be broken in the three modules. The first module is an achromatic arc from the extraction point of the CR to the first dipole magnet of the line. The second module acts as a matching section