P.3: Development of the β=0.47 Single Spoke Resonator (SSR-2) Superconducting RF cavity

The development of the 325 MHz Single Spoke Resonator-2 (SSR-2) bare cavity represents an important milestone in superconducting RF engineering. Successfully produced at RRCAT in collaboration with CDM, BARC, this component is intended for Fermilab under the Indian Institutions and Fermilab Collaboration (IIFC) for the PIP-II project. The SSR-2 cavity is optimized to accelerate medium-velocity protons via superconducting technology, offering superior performance for accelerator systems. Its development process utilized precision fabrication of high-purity niobium parts and sophisticated electron beam (EB) welding to achieve structural integrity and electromagnetic excellence within rigorous and highly demanding technical specifications.

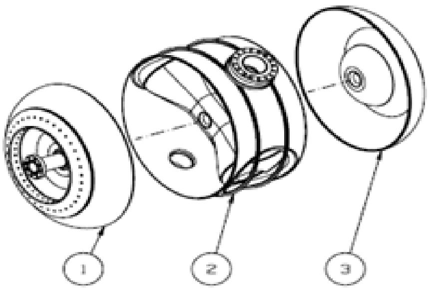

Fig. P.3.1: SSR-2 Cavity sub-assemblies: 1) End wall left, 2) Shell-spoke assembly, 3) End wall right

Material Specifications

The SSR-2 cavity operates at 325 MHz with a geometric beta (β) of 0.47, designed specifically for medium-velocity proton acceleration. The cavity structure comprises two end walls along with a shell containing spoke, which creates accelerating gap (figure P.3.1). The fabrication utilized high-residual-resistivity-ratio (RRR ⩾ 300) niobium sheets, critical for maintaining superconducting properties. The main beam tube and side port flanges were manufactured from Titanium Grade-5, while transition regions employed Titanium Grade-2, optimizing both structural strength and thermal conductivity at cryogenic temperatures.

Fig.P.3.2: Various components of SSR-2 cavity

Manufacturing Process

The manufacturing sequence employed high-precision machining followed by BCP to remove 20 µm of surface material, ensuring a contaminant-free weld edge. The cavity was assembled using EBW across multiple joints, including Nb-Nb full-penetration welds of varying thicknesses (4.75 mm, 4.0 mm, and 3.2 mm) and dissimilar metal joints (13 mm and 6 mm) as shown in figure P.3.2 and P.3.3. After completing the conical stiffening ring and spoke EBW, the assembly underwent rigorous MSLD to verify vacuum integrity and joint reliability.

Fig. P.3.3: SSR-2 Cavity assembly after final EB welding

Qualification and Performance

The completed SSR-2 cavity underwent comprehensive post-fabrication qualification testing. MSLD confirmed vacuum integrity with a measured leak rate of $\leqslant 5\times10^{-11}$ mbar·l/s, well below the FNAL requirement of $\leqslant 1\times10^{-10}$ mbar·l/s. RF characterization measurements performed at room temperature (300K) demonstrated a resonant frequency of 324.71 MHz with a quality factor exceeding 8200, confirming dimensional accuracy post-fabrication. Field flatness evaluation via bead-pull technique revealed >98% uniformity, indicating excellent electromagnetic field distribution within the accelerating region. These results validate the manufacturing methodology and confirm the cavity's readiness for subsequent surface treatment and superconducting operation.

Summary

The integration of precision engineering, rigorous quality assurance, and innovative repair strategies demonstrates a comprehensive approach to complex superconducting cavity manufacturing. Future production units will benefit from lessons learned regarding shell circularity control and pre-weld machining allowances, further optimizing manufacturing consistency and reducing dimensional deviations.

The machining support for finalizing joints carried out by DMTD team and RF measurement by RFSD team.

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