PROGRESS OF 2-CELL CAVITY FABRICATION FOR CORNELL ERL INJECTOR*

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Abstract

Five 1300 MHz superconducting niobium cavities are to be used for the injector of Cornell ERL prototype. The beam power requirement (100 kW each cavity CW) and the need to minimize emittance dilution due to the cavity structure have important impacts to the design and fabrication of these cavities. We plan to use Conflat stainless-steel flanges brazed to niobium tubes. Two copper prototype cavities have been built and measured. Parts for the first niobium cavity have been manufactured. In this report, we will present the progress of the prototyping copper as well as niobium cavities.

INTRODUCTION

A 5 GeV, 100 mA (CW) ERL light source for X-ray sciences is being explored at Cornell University [1]. Both the main linac and the injector RF system are based on the superconducting RF (SRF) technology. The first stage of the Cornell ERL project is a 100 MeV, 100 mA (CW) prototype machine to study energy recovery with high current, low emittance beams [2]. NSF has funded the construction of the prototype injector, which consists of a 500 keV DC gun, a normal conducting copper buncher cavity, and five superconducting 2-cell cavities.

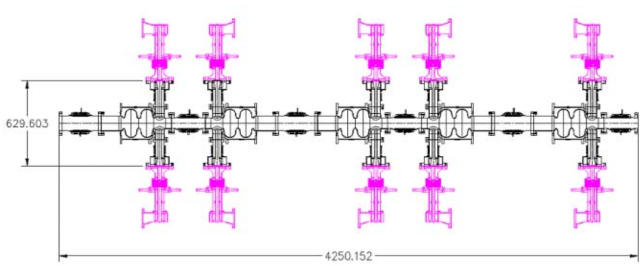

Figure 1: Cavity layout for Cornell ERL prototype injector.

The injector SRF cavities accelerate bunches from 500 keV to 5 MeV with minimal emittance growth. Five 2-cell niobium cavities are fitted into one cryomodule [3]. Each cavity provides 1 MV voltage, corresponding to an accelerating gradient of 5 MV/m in CW operation. Injector cavities will also be operated at 15 MV/m at a reduced beam current of 30 mA. Each cavity has two symmetric RF input couplers to cancel kicks due to coupler fields. Each coupler delivers 50 kW power to the beam. Beam-line HOM absorbers are fitted between cavities to damp HOM's. A sketch layout of the five injector cavities, symmetric twin input couplers, and HOM absorbers is shown in Fig. 1.

RF PARAMETERS

The 2-cell cavity is optimized to allow HOM's caused by beam-cavity interaction to propagate into ferrite-lined beam tubes [4]. Table 1 lists the cavity parameters and Fig. 2 shows the cavity geometry.

Table 1: RF parameters of 2-cell niobium cavity.

Parameter	Value	Unit
Frequency	1300	MHz
R/Q	218	Ω
Epk/Eacc	1.94	-
Hpk/Eacc	42.8	Oe/(MV/m)
Cell-cell coupling	0.7%	-
Input coupler Q_{ext}	$4.6 - 41$	$\times 10^4$
Accelerating voltage	1(3)	MV
Accelerating gradient	5(15)	MV/m
Unloaded Q at 2 K	1×10^{10}	-

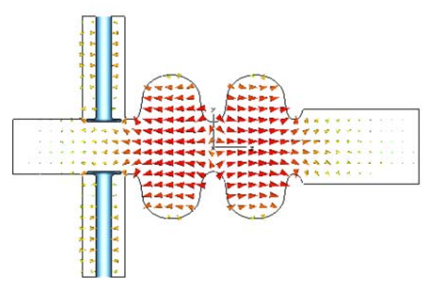

Figure 2: 2-cell cavity with twin RF input couplers.

CONSTRUCTION CONSIDERATIONS

Niobium

As shown in Table 1, the required gradient is modest, corresponding to a peak surface magnetic field of < 650 Oe. Premature thermal quench is unlikely to be a problem as a result of the reduced surface RF current. High purity niobium of RRR 250-300 (1/8 inch thickness sheets) is used to build the cells of the cavity. Post-purification

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by 1400 °C annealing will not be applied. Annealing at 600-800 °C remains an option for the purpose of reducing hydrogen content in niobium and avoidance of Q-disease.

Stainless-Steel Conflat Flange

Waiving 1400 °C treatment opens up the possibility of using stainless-steel Conflat flanges for beam tubes and RF ports. 316 LN stainless-steel is brazed to niobium in a vacuum furnace by using the pure copper wire as the filler material [5]. The 316 LN stainless-steel disk material (Western Forge & Flange Co.) has a 0.12% nitrogen content. The material hardness is in the range of 160-180 on the Brinell scale and remains > 140 after the furnace braze process, which is adequate for sealing copper gaskets. The reliability of SS-Nb flange has been shown by LEP 350 MHz SRF cavities at CERN with no single problem reported during life-time accelerator service. ANL SS-Nb flanges in low-beta SRF cavities also show excellent reliability. Several brazed flanges with a maximum 4 inch diameter have been fabricated, all leak tight after repeated thermal cycling between LN temperature and room temperature. An alternative method under evaluation for making SS-Nb flange is to machine explosion-bonded SS-Nb composite material.

Fig. 3 shows a brazed SS-Nb flange and a flange fabricated from explosion-bonded SS-Nb. Both flanges have a 4 inch diameter.

Figure 3: Conflat flanges for 2-cell niobium cavity. Left: vacuum furnace braze; Right: explosion bonding.

Gap Between Beam Tube Flange Surfaces

The regular Conflat joint has small gaps of extended depth between mating flanges. Short bunches can excite dangerous wake-fields in the gap space of beam-line flange joints. Over-heating and arcing are concerns. The traditional RF finger contact is effective in shielding the gap from the wake-fields. Unfortunately, particle measurements show that it is not suitable for use in conjunction with high gradient niobium cavities. Contact fingers when under compression generate excessive amount of copper particles as shown in Fig. 4. Particulate contamination in niobium cavity is a known source of field emission and should be avoided.

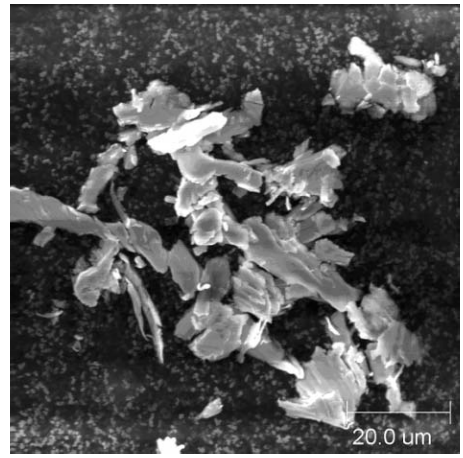

Figure 4: Copper particles generated from RF fingers.

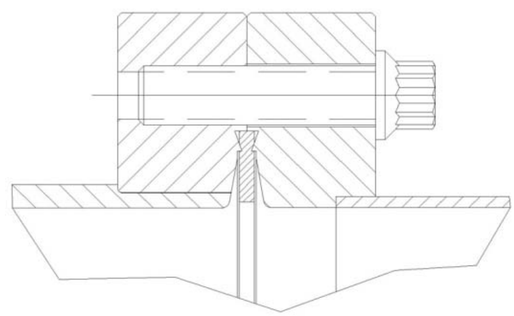

Figure 5: New design of the Conflat flange for the 2-cell injector cavity.

A modified Conflat flange design (Fig. 5) has a reduced diameter and a tapered flange surface. The space between the flange and gasket surfaces has a reduced depth and an increased width. A lower loss factor and surface electric field are achieved due to this modification. RF finger contact is eliminated. A joint by a pair of new Conflat flanges is tested to be leak tight after repeated thermal cycles from room temperature to super-fluid liquid helium.

Input Coupler Block

The strong coupling (Q_{ext} 4×10^4) of the RF input coupler with the 2-cell cavity entails a small clearance between the coupler ports and the adjacent cell. Precision manufacturing is necessary to achieve the tight tolerance needed for minimizing bunch disturbance due to coupler fields. We choose to machine the coupler block from 4 inch thick solid niobium with a high purity (RRR 200). RF field in the coupler block region is still relatively high. A high niobium purity provides the best guard against possible thermal quench due to coupler fields. Mechanical analyses show a maximum stress of 3.4 MPa when it is subjected to the load of one atmospheric pressure. The RRR 200 niobium has a yield strength of 40 MPa.

Mechanical Axis and Electrical Axis

The beam emittance is vulnerable in the injector as the beam energy is still relatively low. Deviation of the cavity electrical axis from its mechanical axis must be under control. This is insured by precision manufacture of trimmed half-cells and tight control of weld shrinkage uniformity. The goal tolerance is 0.1 mm for the stamped cell contour. The goal tolerance is 0.25 mm for the cup axis offset and 0.25 mrad the cup axis tilt. The goal tolerance for weld shrinkage variation is 0.1 mm. Initial measurements with copper cavity parts show that the achieved tolerances are close to the goal values. A CMM has been purchased and will be used for further precision measurements.

COPPER PROTOTYPE CAVITY

Two copper prototype cavities have been fabricated. The end half-cell is different from the center half-cell by design. Three sets of forming dies are built for deep drawing cavity cups and the beam tube transition. Stainless-steel flanges are joined to copper tubes by vacuum furnace brazing. Cavity parts are joined by electron beam welding to exercise the jigging fixtures which are to be used for niobium cavity fabrication. Fig. 6 shows a completed copper cavity.

RF measurements of the first copper cavity shows a good field flatness of 90% as built. A 5 MHz error above the goal frequency is revealed. The major contributor is a mistake in the trim dimension at the equator weld prep. The second copper cavity with the corrected trim dimension has a frequency error of 1 MHz, well within the manufacture statistics.

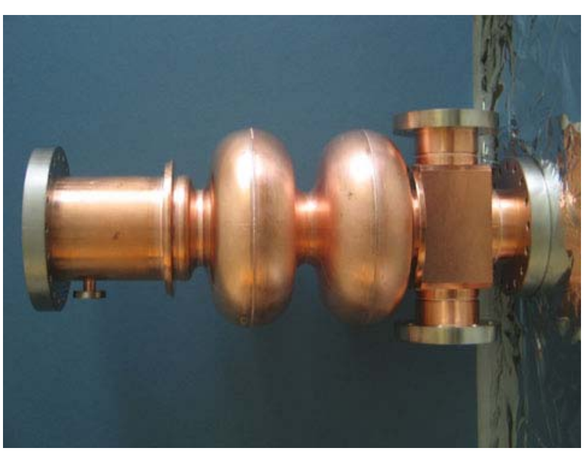

Figure 6: 2-cell injector prototype copper cavity.

Selective HOM's are also measured with the second copper cavity in the absence of RF input couplers. The lowest dipole mode (TE11) has a frequency of 1677.08 MHz, 20 MHz above the TE11 mode cut-off frequency of the 106 mm diameter beam pipe. The achieved safety margin for propagating the dangerous transverse mode into the beam pipe agrees well with the calculation results.

An existing set-up has been adapted for tuning the 2-cell cavity. Further post-tuning measurements of the field flatness, frequencies of the fundamental mode as well as HOM's are reported in [6].

NIOBIUM CAVITY

Cups for the first niobium 2-cell cavity have been stamped. The niobium coupler block has been cut by wire EDM. Beam tubes with brazed stainless-steel Conflat flanges are being fabricated. A new weld preparation is being studied for producing a flat surface on the RF side by full penetration from out-side weld. Test welds with sample niobium pieces as well as mockup niobium dumb-bells are on-going to determine the weld shrinkage and its variation tolerance.

CONCLUSION

Prototyping of 2-cell cavities for Cornell ERL injector is progressing. Two copper cavities have been fabricated. We gained confidence in achieving the goal fabrication tolerance. The goal fundamental mode frequency is achieved. A 20 MHz safety margin in the frequency of the lowest dipole-mode is achieved to insure the propagation of the dangerous HOM's into the beam tube. 4 inch diameter niobium beam tubes are successfully brazed to stainless-steel flanges. The RF finger contact is found to be a massive source of copper particles. Its use in 2-cell niobium cavity is eliminated. A modified Conflat flange design is conceived and tested. The first niobium cavity is under fabrication and its cold test in an existing dewar is being planned. Five 2-cell niobium cavities with integrated helium vessels will be fabricated.

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