DEVELOPMENT OF SPOKE CAVITIES FOR RIA *

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Abstract

This paper reports the development status of 345 MHz, 4 cm beam aperture, three-spoke-loaded, TEM-class superconducting cavities for particle velocities 0.4 < v/c < 0.8. Two prototype cavities have been operated cw at 4.2 K at accelerating gradients above 10 MV/m. Results of cold tests, including mechanical properties and microphonic behavior, are presented.

INTRODUCTION

Superconducting, TEM-class, 345 MHz spoke-loaded cavities are being developed for the high-energy section of the driver linac for the proposed U. S. rare-isotope accelerator facility (RIA) and other ion-linac applications [1,2]. Spoke-loaded cavities enable operation at lower frequency than is practical with elliptical-cell cavities and, in the case of the multi-beam RIA driver linac, offer an attractive alternative to 805 MHz reduced-beta elliptical-cell cavities.

As discussed in a previous paper [3], the lower operating frequency possible with spoke cavities leads to several operational advantages, namely:

1. Longer cell length, providing more voltage per cavity and/or broader velocity acceptance.
2. Increased longitudinal acceptance, reducing beam loss and increasing control tolerances.
3. Lower surface resistance, enabling operation at 4.2 K

The aim of the work presented here is to demonstrate the feasibility of using spoke cavities for the high energy section of the RIA driver linac by cold-testing prototype niobium cavities.

DESIGN AND CONSTRUCTION

Figure 1 shows a sectioned view of one of the three-spoke-loaded cavities [4,5]. The niobium cavity shell is contained in an integral stainless-steel (SS) helium jacket. Two 2-inch diameter coupling ports and a helium port can be seen at the top of the cavity. Also visible are several of the niobium ribs welded to the exterior of the niobium shell for mechanical stiffening. The SS jacket is joined to the niobium shell at the beam ports and at the coupling ports using a copper braze joint.

Cavity Design

The design priorities were to minimize the peak surface electric and magnetic field and to provide good mechanical stability. The three lowest frequency rf eigenmodes of the cavity are TEM-like modes with each spoke excited as a half-wave line. The accelerating rf eigenmode is the lowest frequency mode, in which adjacent spokes differ in phase by π radians.

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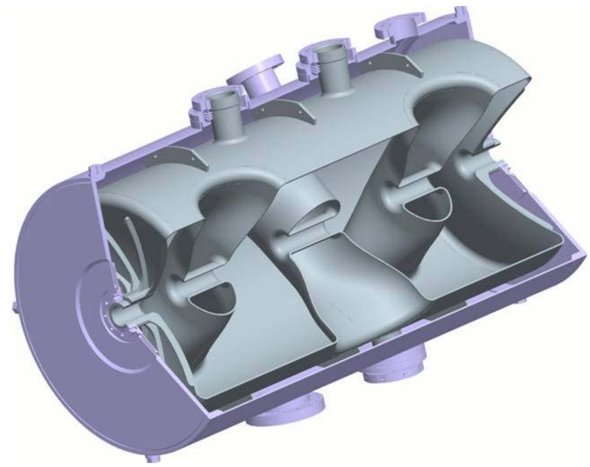

Figure 1: Cut-away view of the niobium cavity shell nested in an integral stainless-steel helium vessel 83 cm in length. Some of the mechanical support ribs welded to the exterior niobium shell are visible.

The spoke elements are elliptical in cross section in order to minimize the peak surface fields while accommodating a 4 cm beam aperture. The major axis of the ellipse is normal to the beam axis in the center of each spoke to minimize the surface electric field and maximize the beam aperture. The major axis is parallel to the beam axis in the region of the spokes near the outer cylindrical diameter of the cavity in order to minimize the peak surface magnetic field.

Table 1 details the electromagnetic properties for the accelerating rf eigenmode. The accelerating gradient E_{ACC} in Table 1 is referenced to an effective length $l_{eff} = n \cdot \beta_{PEAK} \cdot \lambda/2$, where n is the number of spokes, λ the free-space wavelength at the frequency of the accelerating mode, and β_{PEAK} the reduced velocity at the peak of the transit-time function.

β_{PEAK}	**0.5**	**0.63**
Frequency	**345 MHz**	**345 MHz**
L(3βλ/2)	**65.2 cm**	**82 cm**
QRs (G)	**88.5 Ω**	**93 Ω**
R/Q	**492 Ω**	**549 Ω**
below for E_{ACC} = 1.0 MV/m		
RF Energy	**0.398 J**	**0.565 J**
B_{PEAK}	**86 G**	**90 G**
E_{PEAK}	**2.79 MV/m**	**2.93 MV/m**

Table 1: Properties of the two triple-spoke cavities.

Figure 2: Major niobium subassemblies of the β=0.62 triple-spoke resonator after final electropolishing

Construction

Except for the beam ports, which were machined from bar stock, all niobium elements were formed from 1/8 inch sheet. All niobium, except for the support ribs, was characterized by a residual resistivity ratio RRR > 250. The cavity spherical end-walls and the spoke elements were hydro-formed. The spokes were formed in halves and seam welded together. Transition rings were formed and welded to the ends of the spokes to provide a transition to the cylindrical housing with a blend radius of ½ inch.

All welds were electron beam (EB) welds performed at pressures below 10^{-5} torr, and the joined parts were cooled in vacuum below 50C before venting the welding chamber.

Tuning and Electropolishing

Tuning and preliminary surface processing were performed when the three major sub-assemblies of the cavities were complete. The sub-assemblies are the two spherical end-walls, complete with beam ports and support ribs, and the cylindrical body of the cavity with coupling ports and all three spokes.

Prior to welding the three sections together, each was heavily electropolished (Fig 2), removing 150 – 200 microns of material to eliminate any damage caused by forming and machining. After EB welding the three niobium sections together, the SS helium jacket was clam-shelled into place and welded together. The niobium-SS braze transitions were then EB welded to the niobium shell to complete the assembly.

PROCESSING AND COLD TESTS

The completed cavities were given a light (4-7 micron) buffered chemical polish (BCP). BCP was performed through the 2 inch ID coupling ports with the cavity in a horizontal position. It was found that a bubble could cling to an area roughly 10 cm in diameter at top of the housing, possibly preventing full chemical polishing of this portion of the surface. To ensure a complete BCP, following the first BCP the cavities were rotated 180 degrees and given a second 4-7 micron BCP.

The total thickness removed from the surface of the spokes and the spherical end wall sections was measured with an ultrasonic thickness gauge, and ranged from 150 to 200 microns. A somewhat lesser amount, about 115 microns, was removed from the cylindrical outer walls.

After electron beam welding of the cavity end walls to the housing the niobium cavity was filled with standard 1:1:2 BCP for a total of 7 minutes at 12°C to remove any residue or oxide buildup from electron-beam welding.

High-pressure rinsing

Following BCP, the cavity was rinsed with filtered 18 MΩ-cm, high-pressure water at a rate of 20 liters per minute for roughly one hour through each of the beam ports. Rinsing was performed with the beam axis oriented horizontally, and the water drained out though the 2 inch diameter radial coupling ports.

The cavity was rotated 180° about the beam axis several times during rinsing to minimize pooling of particulates in the housing. Drying was performed in a curtained clean room area for 24 hours before the cavity ports were sealed with standard stainless-steel vacuum flanges sealed with copper gaskets.

Clean room assembly

Assembly of the rinsed cavity together with high-pressure-water-rinsed variable power coupler and cavity vacuum system hardware was performed in a clean assembly area. The clean assembly was performed with cavity installed inside the cylindrical test-cryostat vacuum shell. The rf coupler and cavity-vacuum pumping line were inserted though an access flange on the bottom wall of the cryostat and attached to the cavity using standard copper-gasket vacuum flanging. Particulate levels were monitored throughout the assembly procedure using a hand-held laser particle counter, and were consistent with class 100 to class 1000 conditions.

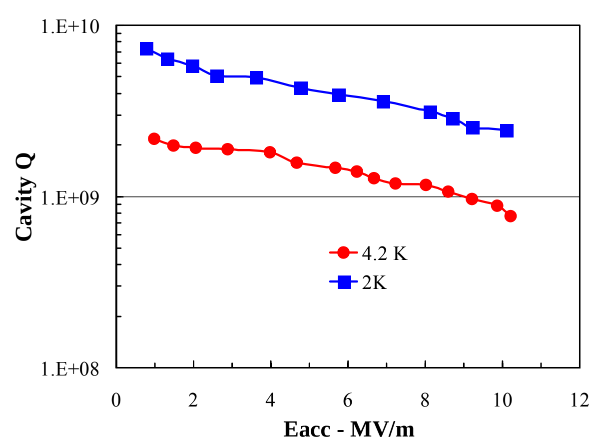

Figure 3: Cavity Q as a function of accelerating gradient for the β = 0.5 triple-spoke cavity.

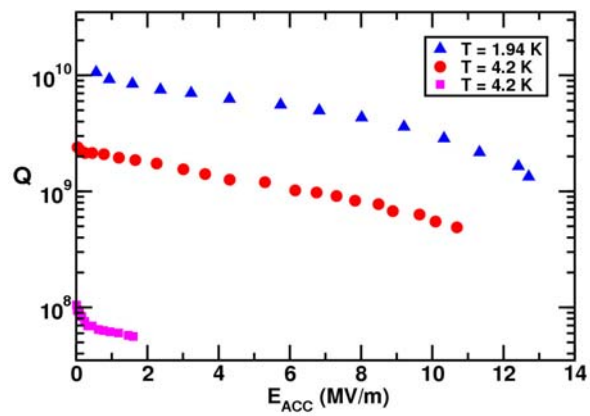

Figure 4: Cavity Q *vs.* E_{ACC} for the β = 0.63 triple-spoke cavity. The lowest (squares) Q-curve followed a slow cool-down and indicates hydrogen contamination.

Cold Test Procedures and Results

The cavity and associated helium reservoir were cooled rapidly by using liquid helium from an external 500 liter He storage dewar. The cooling rate through the temperature range 75 K - 150 K, generally accepted as the hydride formation region for high RRR niobium, was typically 40 K/hr.

At 4.5 K, CW conditioning of low- and medium-field multipacting required typically three hours with up to 200 Watts of rf. This was followed by roughly 1 hour of short-pulse conditioning with the maximum rf power available, 1 - 1.5 kW

Figures 3 and 4 show the performance obtained with the two triple-spoke cavities. We note several results:

- Accelerating gradients of 10 MV/m were achieved at 4K with both cavities.
- The rf losses at 2K were about a factor of four lower than at 4K, so that factoring in refrigerator efficiency, cw operation at 4K seems entirely feasible
- Although some x-ray emission was observed at accelerating field levels of 8 MV/m and above, the test results indicate that field emission was not a major source of rf loss in operation at 4 K. Gradients were limited by thermal quenching.

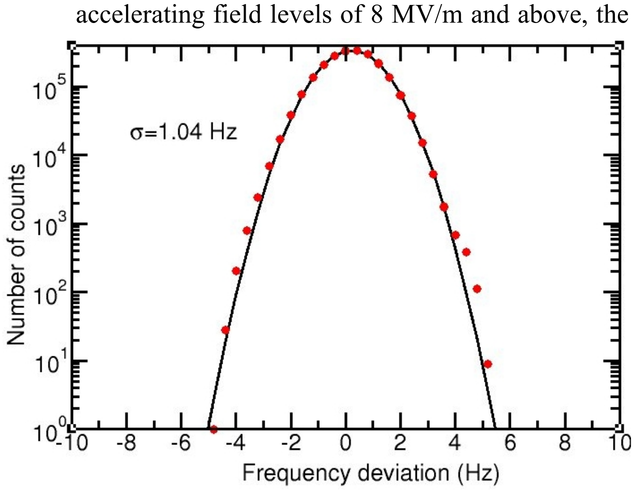

Figure 5: Distribution of frequency errors measured at E_{ACC}=9.7 MV/m. The distribution is Gaussian over 5 orders of magnitude, with an RMS fluctuation of 1.04 Hz.

Figure 4 includes performance data taken at 4K after a slow cooldown (traversing 150 to 100K over 24 hours). The low Q is characteristic of 'Q-disease', caused by hydride formation. This being the case, baking the cavity at 600-800 C, which is known to remove hydrogen from high RRR niobium, is likely to further reduce rf losses and improve performance Mechanical Stability

Mechanical Properties of the β = 0.5 Cavity

Extensive measurements of mechanical properties have so far been done only for the β = 0.5 triple-spoke cavity.

Lorenz detuning was 7.3 Hz per $(MV/m)^2$. The shift of rf frequency caused by changing the pressure of helium in the cooling jacket was found to be -9.6 kHz/atm

Microphonic frequency fluctuations were measured at 4.2K with the cavity operating at E_{ACC}=9.7 MV/m. The results, shown in Figure 5, indicate that the mechanical stability of the triple-spoke cavity is excellent. The magnitude of the microphonics is sufficiently small, 1 Hz RMS, that a tuning window of a few tens of Hertz would be adequate for phase control.

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