DESIGN FEATURES OF A SEVEN-CELL HIGH-GRADIENT SUPERCONDUCTING CAVITY

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Abstract

A cavity development program is in place at Los Alamos National Laboratory to evaluate structures that could be used to accelerate pions. The work is being guided by the conceptual design of PILAC, a high-gradient superconducting linac for raising the energy of rapidly decaying intense pion beams generated by Los Alamos Meson Physics Facility (LAMPF) to 1 GeV. The specification requires a cavity gradient of 12.5 MV/m at 805 MHz. The design of a seven-cell prototype cavity to achieve these high gradients has been completed by the Accelerator Technology division. The cavity is presently under procurement for high power testing at 2.0 K in 1993.

Introduction

The R & D effort in rf superconductivity at Los Alamos has succeeded in making some significant contributions to the world community in this field. Among these are high accelerating gradients of Ep = 40 MV/m and 80 MV/m achieved in single-cell 805-MHz and 3-GHz cavities. A relatively small group at Los Alamos is now engaged in the development of a multicell 805-MHz cavity with the intent of performing rf tests to field levels of 12.5-15 MV/m. While this work is intended to demonstrate surface treatment and rf capabilities that will achieve such performance, the design parameters for the cavity are appropriate for a system which could accelerate energetic pions at 805 MHz. The seven-cell cavity design discussed in this paper is patterned after the modular system proposed for accelerating pions to 1 GeV in PILAC. This system depends on boosting the pions to high energy before they decay and thus requires high accelerating gradients, at least 12.5 MV/m average, with a cavity $Q_0 = 5 \times 10^9$. The frequency of the cells is selected for the highest survival fraction while being a multiple of LAMPF's fundamental frequency, 201.25 MHz. The best frequency is 805 MHz, which results in a relatively large cell. To achieve such high gradients in a seven-cell assemblage will be a major achievement. The seven-cell cavity is presently under procurement with delivery and testing scheduled for 1993.

Mechanical Design of the Seven-cell

The Seven-cell cavity is shown in Fig. 1. It consists of three major subassemblies:

(a) The weldment of seven cells including coupling ports and end flanges.

(b) The stiffening cagement, which consists of six tubular titanium rods and attachment bulkheads.

(c) A pin-free adjuster assembly, which permits fine tuning of the cavity by elastic deformation of the end half-cells.

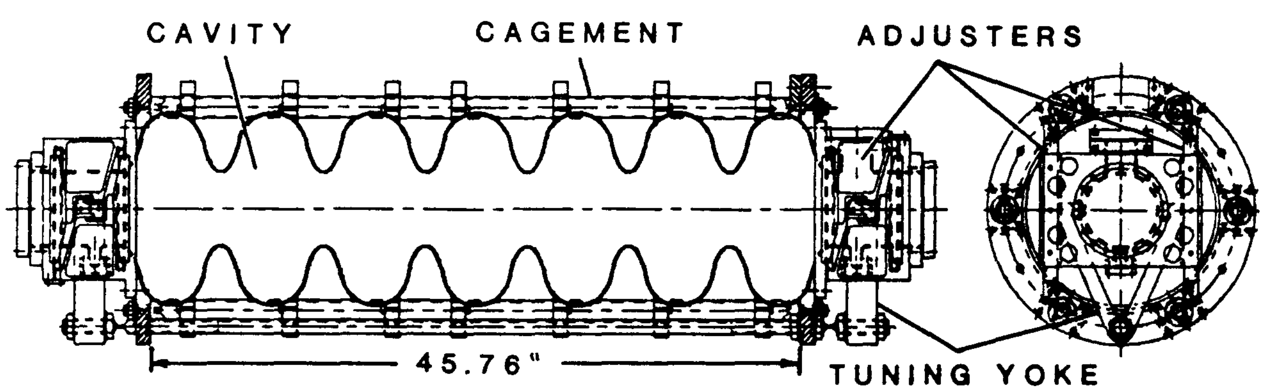

Fig. 1. Seven-cell 805-MHz cavity assembly.

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(a) Seven-cell Weldment:

Individual half cells are formed of 3-mm-thick high-relative resistivity ratio (RRR) (RRR ≥ 250) niobium to dimensions determined by SUPERFISH with ±0.13 mm precision. The shape of the cells consists of a segment of a spherical toroid joined by a short conical section to a segment of another two-radius spherical toroid. There are therefore no parallel faces. The aperture is 13 cm, and the cell-to-cell coupling is about 2.6% with a peak to accelerating field ratio of 2.03. The half cells are indexed to each other by weld-prep shoulders developed using the E-beam welding facility at Los Alamos. The weld preps are thinned to 2 mm, and 0.13 mm weld shrinkage, experimentally determined, has been allowed. The finished dimensions provide for 80 µm of acid etching and it is calculated that a thermal shrinkage factor of 0.144% applies, i.e., the room-temperature resonant frequency will be 803.84 MHz average.

Various frequency-shift and stress conditions that apply to the seven-cell prototype are given in Table 1. These are discussed in detail in references [1] and [2].

b) Stiffening Cagement:

The cells are equipped with welded rings or optional tabs for the attachment of spherical bearings to hold the stiffening rods. These rods are provided to raise the microphonic frequency of the cavity assembly from a first transverse-mode frequency of only 44.6 Hz to more than 200 Hz. In fact, by using six 38-mm OD x 33-mm ID titanium rods clamped to the cavities with the spherical bearings, the first and second transverse modes were raised to 241 Hz and 470 Hz, respectively, for an overall cavity weight of 86 kg. By loosening the spherical bearing clamps, the center cells of the system can be compressed or expanded to tune the average frequency. The bearing clamps are then tightened to lock the system. The rod ends are attached to bulkhead rings which interface with the adjuster linkages. Because the exact length of the seven-cell cavity is not determined until after final tuning, the rods are equipped with shim stacks, which allow the bulkhead rings to be set to the nominal relaxed position of the adjusters. Under this condition, only the end half cells are free to be adjusted by the tuners.

(c) Fine Frequency Adjusters:

Table 1 shows that if both iris ends of a full end cell are deflected by 0.25 mm each, the resulting frequency shift of that cell is 567.6 kHz. Alternatively, this can be accomplished by tuning only the two end half cells by 0.25 mm each, leaving the remaining five full cells and two half cells rigidly clamped to the titanium cagement. Thus, for the complete seven-cell assembly, the tuning sensitivity for end half-cell tuning is:

Table 1
Frequency Excursions and Material Stresses Resulting from Various Loading Conditions

Loading Condition	Δf [kHz] End Cell	Δf [kHz] Mid Cell	Max Stress [psi] clearance End Cell	Max Stress [psi] clearance Mid Cell
Atmospheric pressure (free iris w/bellows)	-119.9	-129.5	2677	2654
Atmospheric pressure (free iris w/o bellows)	-189.4	-212.3	3535	3647
Atmospheric pressure (constrained iris)	13.80	0.096	1557	1550
25 Torr exterior pressure (constrained iris)	0.4589	0.00318	51.78	51.5
Radiation pressure (free iris w/ bellows)	-1.067	-1.750	15.07	22.58
Radiation pressure (constrained iris)	-0.137	-0.111	7.39	6.70
Iris deflection (0.01 in)	-567.6	-585.6	8906	8265
Iris force (100 lb)	-22.98	-27.39	361	387

$$\frac{\Delta f}{\Delta \ell} = \frac{567.6}{(10)(7)} = 8.11 \text{ kHz / mil.}$$

In order to work well within the room-temperature yield strength for Nb (6 ksi) and also not to exceed 5% field nonuniformity caused by end-cell deformations, the allowable range of the end half-cell deflection is ±0.13 mm. The adjuster designed to provide this tuning is shown in Fig. 2. There are four such units, symmetrically placed, two at each end of the cavity. They actuate against the ring bulkheads which are attached to the stiffener tubes and the beam tube flanges at opposite ends of the cavity chain. Once the cavity is tuned, the shim packs are installed to position the ring bulkheads against the adjusters so that the drive yokes are perpendicular to the axis of the cavity, i.e., the nominal zero-set position. The actuator, presently under design, forces the adjusters to expand or compress the end half cells over their ±0.13 mm range to give a tuning range of ±41 kHz.

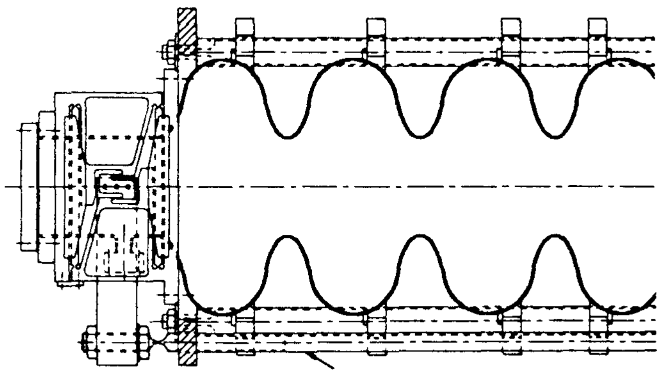

Fig. 2. Adjuster mechanism for end half-cell tuning.

The adjusters are four-rod linkages that function like pantographs to translate rotational motion of the yoke into linear expansion or compression of the end half-cells. A mechanical advantage of 7.5 on one end and 6.5 on the other reduces the load and increases the stroke of the actuator drive rod. The adjusters are stiffened with welded "bridges" and are cut from solid 2.5-cm-thick plates of Ti:5Al:2.5Sn alloy. Note that there are no pivot pins. All actuation is achieved by metallic blade flexures for zero backlash. The maximum stresses in the blades are well within the working stress of the alloy chosen, especially at LHe temperatures. Even though the nominal operational range of the adjusters is only ±0.13 mm, they can actually provide up to ±1.5 mm actuation without exceeding the yield strength of the titanium alloy.

The design goal for the actuator, which will control the fine tuning, is 1 Hz/motor step, or 31Å on the deflection of the end half cells. With the mechanical stroke of the yoke taken into account, this translates into about 220Å/Hz, a very ambitious objective indeed.

For the present procurement, the seven-cell cavity has been ordered with a static solid titanium adjuster rod with fine thread nuts for coarse frequency control. The fine-adjust actuator will be retrofitted later, after it has been developed.

Material Selection and Seal Tests

One of the objectives of the seven-cell design is to avoid indium seals, which create reliability problems. There is evidence that indium seals flake and deposit small particles on the high-field rf surfaces. Consequently, all flanges were designed to use the Helicoflex delta seal with either copper or silver liners. These liners require flanges with hardnesses of VHN 125 and 100, respectively. Consequently a hard flange material was chosen, WC-103, which is a Nb:10 Hf:1 Ti alloy. This material welds readily to RRR grade Nb and also retains its strength and hardness after 1450° C heat treatment. However, it should be shielded from the interior of the cavity during heat treatment because tests have shown that some Hf is transported out of the alloy with Ti and could contaminate the rf surfaces.

Seal tests are presently being conducted in a special fixture which clamps the Helicoflex delta seal between stainless steel and a plate of WC-103 alloy. The fixture is sensitive to quick immersion because of the differential cooldown rates of the different materials. The WC-103 plate is being tested before and after heat treatment. One test has been successful in superfluid helium. Two other tests were questionable because of quick immersion and lack of adequate tolerance control on seal compression. The tests are being repeated. We are confident the combination of the WC-103 alloy and the Helicoflex delta seal will function satisfactorily when conditions are controlled more precisely.

Conclusions

The seven-cell prototype cavity for testing high gradient fields at 805 MHz has been designed and is presently under procurement. The design incorporates a combination of high RRR niobium for the cells and a hard niobium alloy for the sealing flanges. The seals will be Helicoflex delta seals. The structure is stiffened using tubular titanium longerons so that the first transverse bending mode frequency is above 240 Hz. The cavity tuning is achieved by deforming the end half cells using titanium metal web flexures in a unique four-rod linkage. Testing of the cavity will take place at Los Alamos in 1993. The design goal is to achieve an average gradient of 12.5 Mv/m in seven 805 MHz cells.

References

[1] G. Spalek, "Summary of Tuning Stresses and Loads for the 7-cell Developmental Superconducting Cavity," Los Alamos National Laboratory, AT Division Technical Note AT-1:92-11, January 13, 1992.

[2] S. Black et al., "Calculation of Mechanical Vibration Frequencies of Stiffened Superconducting Cavities," to be published in the 16th International LINAC Conference Proceedings, Ottawa, Ontario, August 23-28, 1992.