EVALUATION OF RF SEALS FOR RESONANT CAVITY APPLICATIONS*

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Abstract

In radio-frequency quadrupoles (RFQ) and drift-tube linacs (DTL), electrical seals are required at mechanical interfaces to preserve the cavity quality factor (Q). Studies determined the response of copper-plated C-seals to continuous wave (cw), high-field operating conditions. In addition, low-power evaluations of machined-surface, knife-edge, indium wire, C-type, and multilam seals were done at room temperature and cryogenic (25 K) temperatures. For the high-field tests, the Q as well as seal temperature, was measured with power. For the low-power test, the Q was measured as a function of temperature.

Introduction

Resonant-cavity acceleration structures that require mechanical assembly often have physical separations in electrical current paths. Two structures of this type are the drift-tube linac (DTL) and the radio-frequency quadrupole (RFQ). Physical separations have a deleterious effect on the operational characteristics of the cavity. Specifically, interruptions in the current path cause structural power loss, which results in a low cavity quality factor (Q), poor efficiency, and high heating in the area of the joint.

Various forms of rf seals can prevent power loss by to providing a good current path, as well as mechanical detachability. Some common types are the C-seal for spring-loaded compression in the joint, and the indium wire seal and the knife-edge seal for deformation flow to fill the joint. In either of these approaches, the effectiveness of the joint is a function of the physical properties of the mating surfaces, the degree of real compression, and the electrical characteristics of the seal.

The effectiveness of a seal as a function of numerous variables, prompted a study of certain seals in selected applications. The goal of the study was to establish that the seals would perform as expected in their respective applications. Specifically, two types of tests were done. The first was a test of a copper-plated C-seal at cw field levels at and above that of present day RFQ applications. This test provided information about several topics: the effect on Q of putting a seal in a cavity, the heating of the seal up to 7500 A/m, and the electrical properties of the seal as a function of power.

The second test was a low-power evaluation of a number of different seals as a function of temperature (20 K to 298 K). Because it was done at low power in a coaxial test cavity, this test was a more "generic" study of power loss in the seal than the first test.

Experimental Configuration

The high-power C-seal test was done in a rectangular cavity (Fig. 1), resonant in a TE-011 mode at 502 MHz. The approach was to make a fully brazed structure first and measure its parameters at power. Next, the bottom was cut off and modified to accept the rf and vacuum seals. Finally, the cavity was run again and measured. Taking advantage of the rectangular geometry of the cavity allowed the modifications of the cavity to be accounted for in the Q_0 analytically and direct comparisons to be made. The cavity was driven to 110 kW cw with an unloaded Q (Q_0) of approximately 28 000.

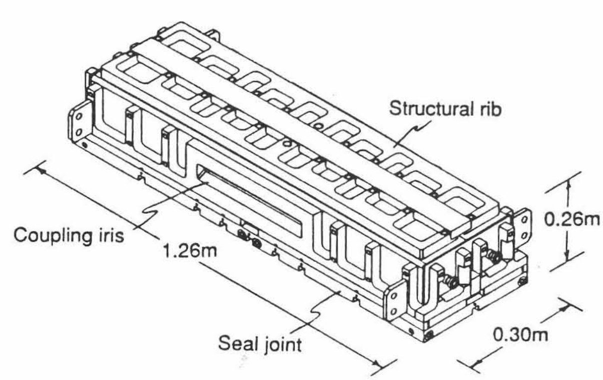

Fig. 1. Sketch of the high-power seal test cavity.

The low-power cryogenic seal test was done in a coaxial cavity, resonant at 425 MHz for the f-001

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mode. This mode has the currents crossing the midplane of the center conductor, where the seal was located. Measurements were done with a network analyzer, and the system was cooled with a modified cryopump cold head. The test seals were the machined-surface, knife-edge, indium wire, C-type, and multilam seals (Fig. 2).

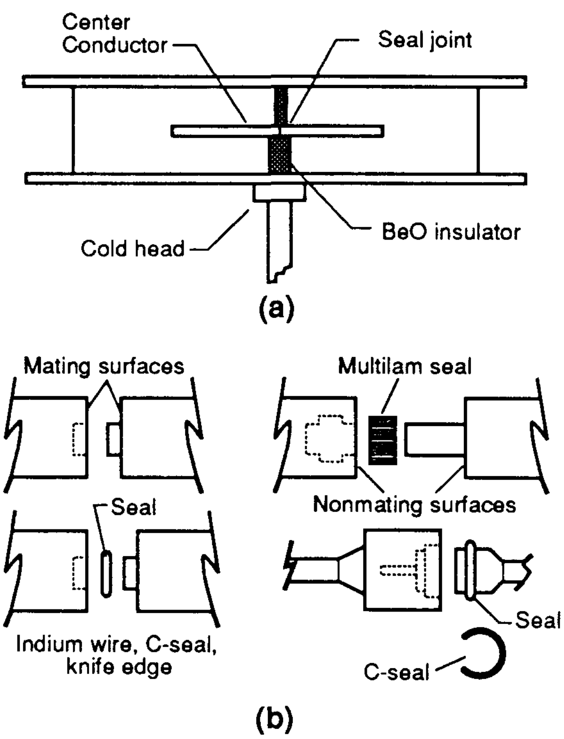

Fig. 2. a) Coaxial cavity configuration. b) Various seal set-ups.

Results

In the high-power seal test, it was necessary first to determine how the seal affected the cavity Q_0 at low power. The Q_0 of the brazed structure was measured and compared the theoretical value. Then a coupling iris was machined into the cavity, and a loss term for the iris was unfolded from the unloaded Qs for the cavity before and after the coupling iris was in place. Combining the loss term with the new theoretical Q_0, calculated from the changed dimensions, gave an overall theoretical Q_0 for the modified cavity. The overall value presumably represented the cavity Q_0 with no seals present. Comparing this value with the measured value for the unloaded Q gave a difference of 1.1%, which indicated that the seals at low power did not introduce a greater loss in the cavity than the wall itself.

Running the cavity at power then determined the response of the seal to higher wall currents. Measurements were made of the loaded Q, the coupling coefficient, and the temperature of the wall and the seal at the cavity midplane. These data were used to calculate the unloaded Q related to power in the cavity (Fig. 3) and to calculate the wall and seal temperatures related to the magnetic field at the wall (Fig. 4).

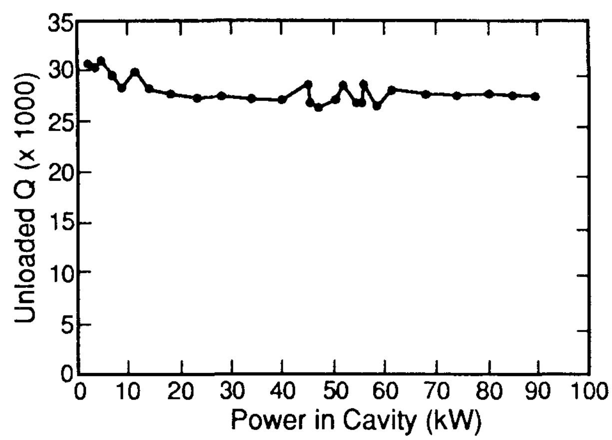

Fig. 3. Average unloaded Q as a function of power in the cavity.

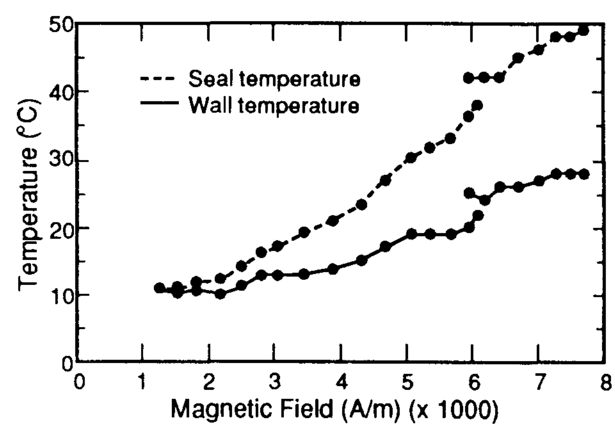

Fig. 4. Seal and wall temperature related to magnetic field at the wall.

The cavity Q_0 dropped by 9.2% from low to high power, a loss accounted for by the corresponding rise in the cavity temperature. This finding indicates that up to 7600 A/m (89-kW cw) at the wall, the seal's electrical performance deteriorated only in the form of ohmic heating a condition increased resistivity. There was no indication of mating surfaces changing and contributing to the electrical loss.

The temperature of the seal rose steadily with increased power, as did the wall temperature. Applying linear regression to the data obtains the following relation:

$$T_{seal} = 0.00662\, H_x - 1.749°\mathrm{C}. \quad (1)$$

TABLE I
Unloaded Q Data for Seals and Ratios[a]

Test[b]	Q_o (298 K)	Q_o (25 K)	$\frac{Q_o\ @\ 298K}{Q_o\ SF}$	$\frac{Q_o\ @\ 25K}{Q_o\ SF}$	$\frac{P_{seal}\ @\ 25K}{P_{bar\ +\ seal}\ @\ 25K}$ (%)
Plain Bar					
Solid	7452	27170	0.949	3.46	–
Machined	7418	25030	0.944	3.19	7.9
Knife edge	7512	25330	0.956	3.22	6.8
Indium	7655	27325	0.974	3.48	−0.6
C-seal	7346	24802	0.935	3.16	8.7
Multilam	6212	20791	0.791	2.65	23.5
Stepped bar					
Solid	7268	24875	0.987	3.38	–
C-seal	6691	23189	0.909	3.15	6.8

[a] f_0 = 424 MHz (fundamental mode); plain-bar SUPERFISH Q_0 SF = 7857; plain-bar SUPERFISH Q_0 cf SF = 7857; stepped-bar SUPERFISH Q_0 (SF) = 7362; cold-temperature values taken at T = 25 K.

[b] $$\frac{P_{seal}\ @\ 25K}{P_{bar\ +\ seal}\ @25K} = \frac{(Q_0)_{seal}}{Q_{seal}} = 1 - \frac{(Q_0)_{seal}}{(Q_0)_{bar}} \; ; \qquad Q_{seal} = \left[\frac{1}{(Q_0)_{seal}} - \frac{1}{(Q_0)_{bar}}\right]^{-1}$$

The tests run at power indicated no degradation of the seal physically to the field levels indicated at cw power levels on the time scale of hours.

In the cryogenic seal test, various seals were installed at the midplane of a coaxial resonator, and the Q was measured as a function of temperature.

Various ratios were used to determine the performance of the seal under test. Specifically, to establish the effectiveness of the seal, the room temperature Q_0 was compared with the value obtained from SUPERFISH with no seal. Determining the characteristics of the seal at cryogenic temperatures (25 K) required the following comparisons: comparing the cold Q_0 with the SUPERFISH value gave a Q_0 enhancement factor. Comparing enhancement factor with the value for the solid bar gave a measure of how well the seal maintained electrical contact down to low temperature. Finally, a value was obtained of what percent of loss in the bar assembly is due to the seal. Table I shows the Q data and ratios for the test seal.

Conclusion

For the copper-plated C-seal at cw power to 7500 A/m, the only observed degradation of the electrical performance of the seal from its low power value could be accounted for by normal ohmic heating of the seal. Further, there was only a small (less than 2%) difference in the wall loss of the cavity caused by the presence of the seal, compared to a solid wall.

For the cryogenic, low-power seal test, the machined-face, knife-edge, indium wire and C-type seals all had seal loss values of less than 9%. The multilam seal, likely resulting from a poor configuration geometry, gave a loss of 23.5%.

The indium wire seal gave exceptionally good results, equaling the solid bar within experimental error. This could be accounted for by slight surface differences between the copper bars. Generally, all the seals tested, except the multilam, maintained good electrical properties down to cryogenic temperatures at low power (less than 1 mW).

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