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HIGH-POWER OPERATION OF ACCELERATOR STRUCTURES AT LIQUID NITROGEN TEMPERATURE

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Abstract

The microwave properties of two S-band resonant structures were measured under pulsed high-power operation at liquid nitrogen temperature. One was a simple cylindrical pillbox cavity operating in the TM_{010} mode, and the other was a high surface gradient side-coupled standing-wave structure. Both were machined from OFHC copper. At low power levels, the Q of both structures measured at liquid nitrogen temperature (-197°C) increased by the same factor over that at 20°C. When measured at high power levels, the enhancement factor was much lower. The low-temperature Q was found to be a function of the peak power of the RF pulse, rather than the average power level. The test method is described, and results of the tests and theoretical studies are presented.

Introduction

Background

The obvious advantages of the use of superconducting materials in particle accelerators have been explored extensively over the past 25 years[1,2]. However, the cost of constructing and operating the refrigeration systems necessary to maintain the low temperatures required[3,4] limits consideration of this approach to large, well-funded research projects.

An alternative worthy of investigation is accelerators constructed of conventional materials, operating at temperatures attainable with more conventional refrigeration systems of moderate cost. The conductivity of the metals suitable for use in accelerators increases at low temperatures. Therefore the efficiency of a guide structure constructed of copper, for instance, can be increased by reducing its operating temperature.

The microwave surface resistivity of OFHC copper decreases by a factor of 2.6 at the temperature of liquid nitrogen (-197°C)[5]. Considering the availability of this refrigerant and the modest cost of packaged cryogenic systems capable of maintaining this temperature, one might expect that an accelerator system operating under these conditions would prove advantageous for some applications. In particular, in situations where the space available for the accelerator structure is limited, or where there is a limitation on the RF power available, this might be considered.

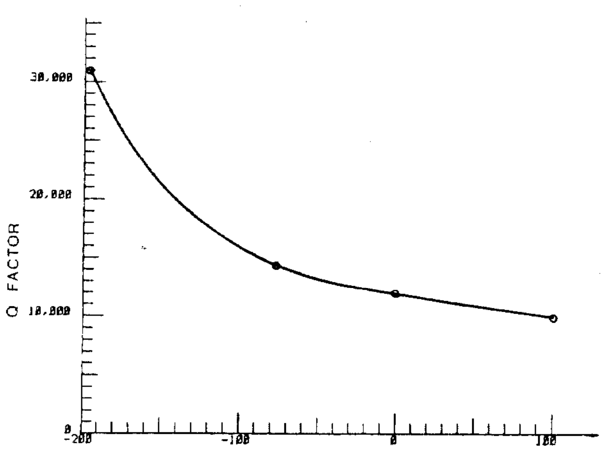

Fig. 1 Variation of Q-factor with temperature for a cylindrical cavity of OFHC copper.

Objectives

In order to evaluate the advantages and problems associated with a system operating at liquid nitrogen temperature, a limited investigation was undertaken at Varian with the following two objectives: first, to establish the feasibility of operating an accelerator structure at -197°C, and second, to determine what advantages might be realized with respect to size or power input requirements.

Experimental Work

Low Power Tests

Preliminary tests with a simple cylindrical TM_{010} cavity of OFHC copper at several temperatures verified the Q-factor improvement predicted by Benard et al[5], as shown in Figure 1. Similarly, a two-cavity side-coupled accelerator structure demonstrated a Q factor enhancement of 2.7 at liquid nitrogen temperature. The resonant frequency increased from 2987 MHz at room temperature to 2997 MHz at liquid nitrogen temperature.

High Power Tests

A three-cavity side-coupled structure was constructed for high-power tests (Figure 2). It was fitted with a WR-284 rectangular waveguide input, which includes a section of silver-plated stainless steel to minimize heat conduction through the copper waveguide to the cooled accelerator structure. Measurements on this structure at low power indicated a Q factor of 14,500 at room temperature, which increased to 40,500 at liquid nitrogen temperature - an enhancement factor greater than 2.7.

This structure was then operated at liquid nitrogen temperature with an EEV type M5193 S-band magnetron as an RF source. The peak rf pulse power from the magnetron was variable from 0.2 to 2.8 MW by changing the anode voltage and magnetic field. The average power was altered by varying the pulse repetition rate between 35 and 300 pps and the rf pulse width between 2.4 and 4.5 us. Results of the tests are shown in Figure 3, in which the input VSWR is plotted as a function of peak and average power

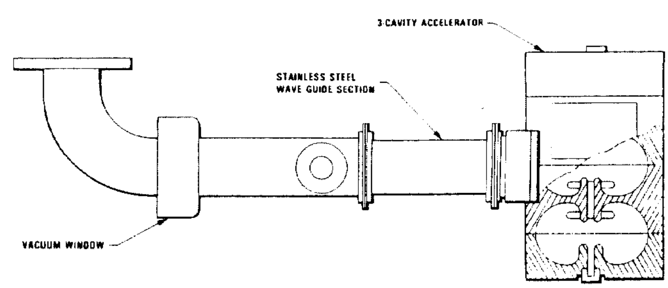

Fig. 2 LT-3 3-cavity LASL type high power test fixture.

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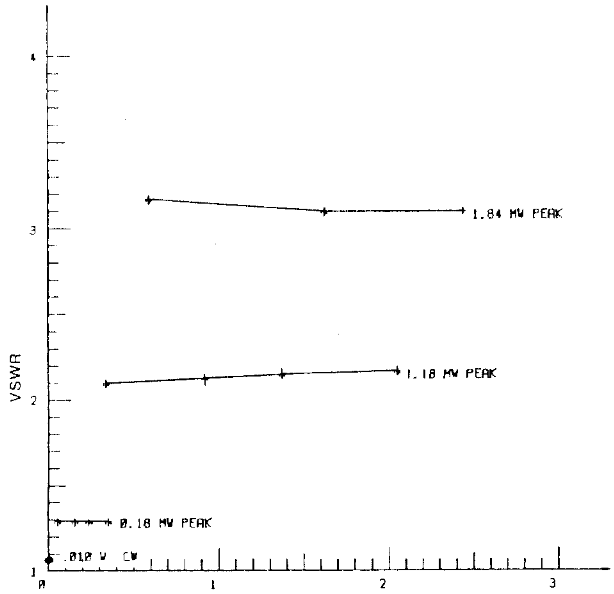

Fig. 3 Input VSWR vs average power for various peak power levels; LT-3 guide at -197°C.

delivered to the structure. (The VSWR is a function of the Q factor; the coupling iris was designed to match the input waveguide for a resonator Q of 40,500.)

As indicated in Figure 3, the Q factor decreases with peak RF power, but at a particular peak power it is not a function of the average power. A cylindrical pillbox resonator operating in the TM_{010} mode was constructed for high-power operation to determine whether this behaviour is due to an electric or magnetic high-field effect. The characteristics of this resonator are compared with those of the side-coupled accelerating structure in Table 1. As seen here, the value of E_p/E_o for the pillbox is 1.6, compared to 7.8 for the accelerating structure. On the other hand, the ratio Hp/Eo is about 70% of that for the accelerating structure.

As with the accelerating structure of Figure 2, the Q factor of the pillbox resonator decreases with

Table 1. TEST RESONATOR PARAMETERS

PHYSICAL	LT-3 Guide	Pillbox
Structure	3-Cavity LASL Structure	Single Cylindrical Cavity
Cavity diameter	7.64 cm	7.67 cm
CALCULATED AT 20°C (LALA)		
Power Loss per Cavity for E_o = 1MV/m	377W	715W
Stored Energy per Cavity for E_o = 1MV/m	3.4×10^{-4} J	5.9×10^{-4} J
Maximum Magnetic Field for E_o = 1MV/m	49.6 G	34.2 G
Q-Factor	16800	15600
ZT^2/QL (temperature independent)	7870 Ω/m	4470 Ω/m
Ep/Eo (temperature independent)	7.8	1.6
EXPERIMENTAL RESULTS AT 20°C		
Resonant Frequency	2987.5 MHz	2990.2 MHz
Low-power Q-Factor	14500	14800
Q External (temperature independent)	45000	31200
EXPERIMENTAL RESULTS AT − 197°C		
Resonant Frequency	2997.6 MHz	2999.6 MHz
Low-power Q-Factor	40500	40200
Coupling Factor	0.90	1.29

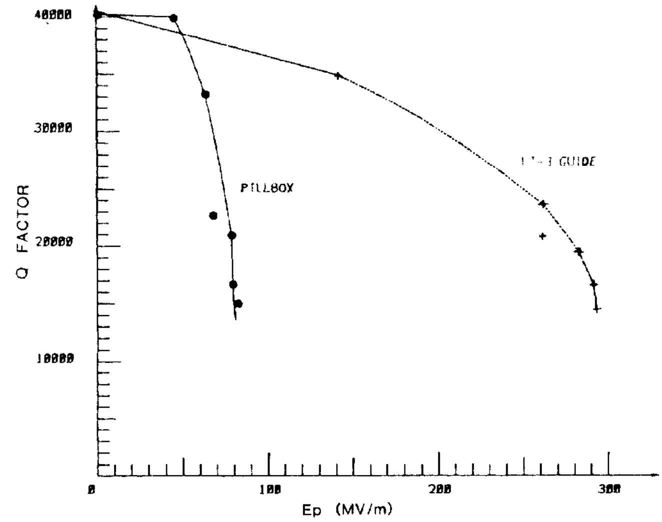

Fig. 4 Q-factor vs peak RF electric field at -197°C.

peak power, but is not affected by changes in average power. The behavior of the two resonators operating at -197°C is compared in Figures 4 and 5. It can be seen in Figure 4 that the deterioration in Q factor with peak rf electric field is considerably different for the two cases. Figure 5 shows, however, that the Q factor is the same function of peak rf magnetic field for both structures.

Discussion of Results

From the above results, the preliminary conclusion is that the phenomenon responsible for Q factor deterioration is caused by high RF magnetic fields. While this has not been investigated further, it seems likely that it is related to electron multipactor, which has been observed in superconducting resonators[6,7]. If this is the case, accelerator structures capable of operating at high power levels at liquid nitrogen temperature can be realized by proper design of the cavity contour, and possibly by surface treatment to inhibit electron emission.

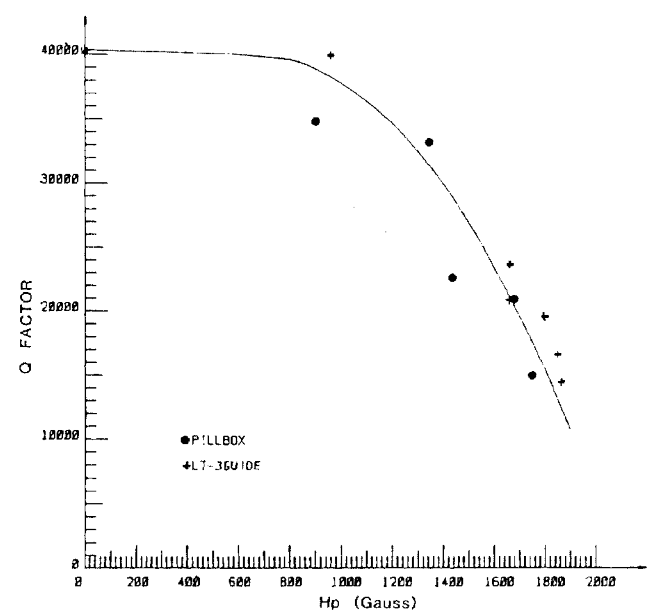

Fig. 5 Q-factor vs peak RF magnetic field at -197°C.

Conclusions

1. The Q factor of an OPHC copper 3-GHz resonator at -197°C (measured at low power) is 2.7 times greater than the value at 20°C.

2. Operating at a fixed peak power, the Q factor at -197°C does not vary with average power (within the range of the test).

3. The Q factor at -197°C decreases with peak RF power.

4. The decrease in Q factor at -197°C seems to be dependent on the peak RF magnetic field.

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