BREAKDOWN IN HIGH-GRADIENT ACCELERATOR CAVITIES

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SUMMARY

In the development of high-gradient accelerator structures, voltage breakdown is always a major constraint. Recent experimental study of this process indicates that the Kilpatrick's Breakdown Criterion gives conservative breakdown threshold values.

A new microwave high power cavity tester has been developed to establish the criteria for voltage breakdown in terms of the accelerating gradient, surface finish and processing techniques, materials, RF pulse length and repetition rate, and temperature. The experimental set-up and procedure, as well as the results, are described.

INTRODUCTION

High gradient, high efficiency accelerator structures are increasingly popular topics of discussion among particle accelerator physicists. The attainment of a 100 MV/m averaged axial accelerating gradient is the milestone currently required for high-energy physics machines such as the linear collider. The major constraint upon the development of high gradient structures is voltage breakdown. The phenomenon of RF breakdown was studied early by W. D. Kilpatrick, who semi-empirically derived a relationship between the maximum surface electric field and the operating frequency, widely known as the "Kilpatrick Breakdown Criterion".[1] Recent experimental studies show that this criterion yields a relatively conservative Emax value, as shown in Fig. 1.[2,3,4] Our most recent experimental results suggest that the Emax value may be as high as 5 times the Kilpatrick level for well-prepared OFHC surfaces in a clean environment.[5]

It is of interest to investigate what improvements could be realized in the Emax value by using various materials, different surface finishes, and other processing techniques, since some investigators have reported that the breakdown threshold level varies by large factors with these variables.[6,7] In this paper, a new breakdown test cavity is described which has been developed in order to study systematically the RF breakdown of various materials and finishes. The experimental results from this cavity tests are presented as well.

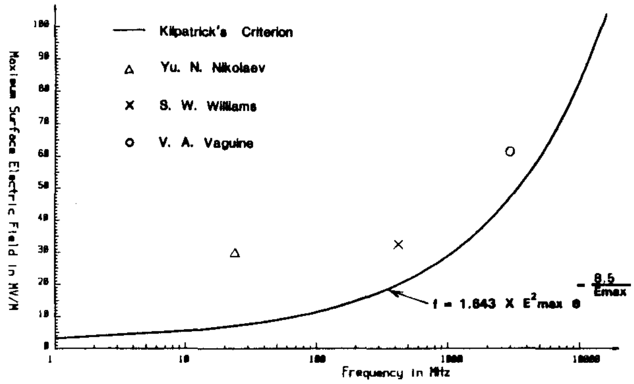

Fig. 1 Kilpatrick Breakdown Criterion and some experimental results.

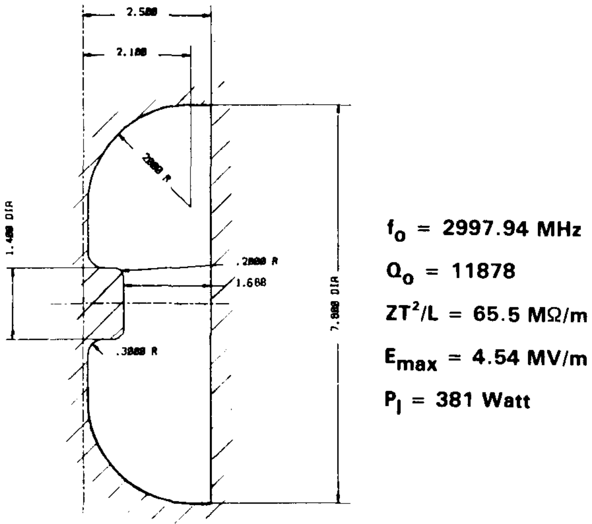

Fig. 2 Cross-sectional dimensions of breakdown test cavity and its theoretical parameters.

EXPERIMENTAL SET-UP AND PROCEDURE

Fig. 2 shows the cross sectional dimensions of the terminated LAMPF type cavity without a beam hole used for these experiments, and its LALA computed parameters. Fig. 3 shows the details of the demountable nose button and the position of Emax. As seen in this figure, an inlay of the material under test is brazed onto one half of the top surface of the OFHC nose button. Since the cavity design is azimuthally symmetric, as is the E field distribution for a quasi-TM_{010} mode resonance, both halves of the nose button experience the same maximum surface electric field. This provides a direct comparison of the two different materials. The nose button is screwed to the cavity, using a thin gold wafer (3 mil thickness) to provide good RF and thermal contact. The cavity is mechanically clamped to the copper-plated stainless steel end plate. An annealed OFHC O-ring has been successfully employed to provide a good RF contact as well as a good vacuum seal between the cavity and the end plate. The test

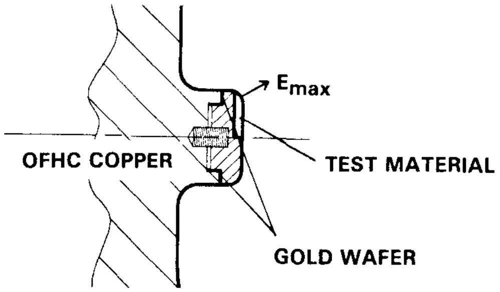

Fig. 3 Design of demountable nose button and position of Emax.

cavity is carefully assembled in the clean room after a chemical cleaning process (vapor degrease, alkali soak, cyanide bath followed by water and methanol rinse). The cavity is excited through the end plate coupling iris located near the outer radius of the cavity. Fig. 4 shows a cross-sectional view of the test cavity system. A vacuum system which includes a vacuum valve, a rotary oil roughing pump, a filter, and an 8 l/s vacuum ion pump is attached to the waveguide narrow wall. The pressure level of the test cavity is estimated by measuring the vacuum ion pump current taking into account the conductance of the vacuum system (pressure factor of 2.8). The cavity is always pumped down to the pressure level of 2×10^{-7} mm Hg before RF power is applied. A tunable magnetron (EEV M-5193) is used as the RF source. The transmitted RF power into the test cavity is monitored through the small loop antenna placed at the end plate. The test cavity is immersed in a circulating water (40°C) bath or in a liquid nitrogen (-180°C) dewar. Several thermocouples are placed close to the button to monitor the temperature during the experiments. The test cavity is initially excited at a low peak power level (0.4 MW) at a high repetition rate (300 pps) for one hour. By keeping the cavity pressure level below 10^{-6} mmHg, RF processing is carried out by successively increasing the peak power level and repetition rate in small increments. The breakdown power level is determined by monitoring both transmitted power and vacuum ion pump current levels. The Emax value in MV/m is estimated by using $E_{max} = 4.54 \times 10^3 \times \sqrt{(P_{max} \times Q_{exp})/(381 \times Q_o)}$ where Pmax is the breakdown power level in MW and Qexp is the experimentally obtained Q factor of the test cavity.

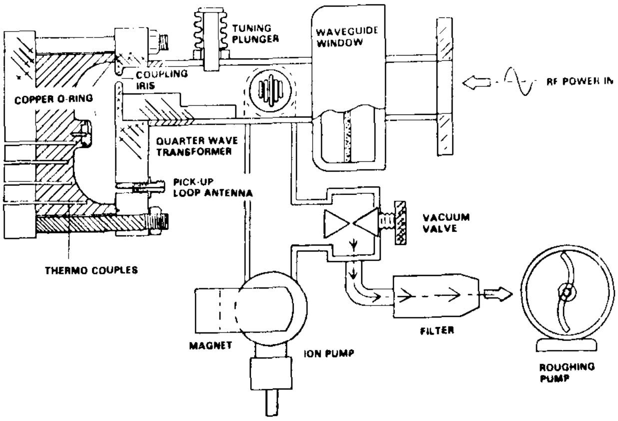

Fig. 4 Cross-sectional view of test cavity system.

EXPERIMENTAL RESULTS

Following is a summary of the results of a series of experiments conducted with the test cavity, including the results previously reported.[5]

A) OFHC Copper (8 microinch finish) results:

1. The maximum surface electric field can be as high as 240 MV/m for a well prepared surface with clean environment (starting pressure level 2×10^{-7} mm Hg), for pulsed operation (pulse width 4.4 microsecond) at S-band frequencies.

2. Neither diamond polishing nor electro-polishing enhanced the breakdown threshold level.

3. The breakdown threshold level does not depend on the pulse repetition rate between 70 and 300 pps, or cooling temperature between -180°C and 40°C.

B) Other materials, coating, plating and finish results:

1. No significant differences are observed between stainless steel, aluminum, titanium and OFHC copper as the cavity nose.

2. Ti coating does not enhance the breakdown level.

3. Ni plating makes the breakdown worse.

4. Cu plated surface has the same breakdown characteristics as solid OFHC copper.

5. Craters such as those produced on the copper surface (diameter 50-200 μm) are not observed on the tungsten surface, but a multiplicity of micro-pittings (diameter 10 μm) is observed when the surface is examined under magnification.

CONCLUSION

A new cavity breakdown test system was developed and successfully employed to study the RF breakdown characteristics of various materials such as stainless steel, nickel, tungsten, titanium and aluminum, as compared with OFHC Cu. Various finishes (plating, coatings and polishing) and processing techniques were studied as well. The experimental results are summarized in the text. The results indicate that no significant improvement of RF breakdown over that obtained with OFHC Cu is obtained for the materials and finishes employed to date. Further studies on other materials and finishes using SEM and RGA are planned.

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REFERENCES

1. W. D. Kilpatrick, "Criterion for Vacuum Sparking Designed to Include Both RF and DC", UCRL-2321, Sept. 1953.

2. Yu. N. Nikolaev, "Investigation of a High-Voltage Vacuum Discharge at 25 Mc", Sov. Phys. Vol. 8, No. 4, Oct. 1963.

3. S. W. Williams et al, "Voltage Breakdown Testing for the Radio-Frequency Quadrupole Accelerator", Proceedings of 1979 Linear Accelerator Conference.

4. V. A. Vaguine, "Standing Wave High Gradient Accelerator Structure", Rev. Sci. Inst., Vol. 48, No. 11, Nov. 1977.

5. E. Tanabe, "Voltage Breakdown in S-Band Linear Accelerator Cavities", IEEE Trans. Nucl. Sci., NS-30, p. 3351, 1983.

6. P. Kranjec et al, "Test of the Critical Field Theory of Electrical Breakdown in Vacuum," J. Vac. Sci. Technol. 4, 1966.

7. J. J. Maley, "Effect of Particles on High Voltage Vacuum Breakdown and Interelectrode Current", J. Vac. Sci. Technol. 11, 1974.