BREAKDOWN IN HIGH GRADIENT LINEAR ACCELERATOR CAVITIES

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ABSTRACT

A multiple-use cavity test system was developed to establish the criteria for breakdown in high gradient linear accelerator cavities, in terms of accelerating gradient, cavity geometry, surface finish, materials, vacuum level, RF pulse shape and repetition rate, frequency, temperature and external magnetic field. The experimental set-up and test procedure as well as experimental results, are presented.

INTRODUCTION

Voltage breakdown is one of the major limiting factors in the design of a high accelerating gradient linear accelerator structure. Kilpatrick empirically derived the relationship between frequency and maximum electric field as shown in Figurel.[1] Several recent studies show that this Kilpatrick's Breakdown Criterion gives a relatively conservative Emax value.[2,3,4] It is of interest to determine the ultimate limitation of accelerating gradient in terms of geometry (shunt impedance), surface finish and material, vacuum level, frequency, RF pulse shape and repetition rate, temperature, and external magnetic field.

EXPERIMENTAL SET-UP AND PROCEDURE

Figure 2 shows a cross sectional view of the accelerator cavity breakdown test system. In order to test various cavities using the same system, the test cavity was clamped between two plates. Indium gaskets were used to maintain vacuum as well as to provide a RF seal. After careful cleaning (vapor degrease, alkali soak, cyanide bath and water and methanol rinse) of the test cavity, and assembling the system in the clean room, it was pumped down to the pressure level of 10^{-7} mmHg. Then the test cavity was wrapped with a heating blanket and kept at 200°C for 8 hours. Figure 3 shows a schematic diagram of the high power experimental set-up. The peak output power of the tunable magnetron was varied from 0.2 to 2.6 MW by varying the external magnetic field and the anode voltage. The RF pulse repetition rate could be varied between 70 and 300 pps, yielding an average output power from 0.06 to 3.1 KW. The test cavity was immersed in the circulating water bath to thermally stabilize it. The thermocouple was placed inside the test cavity body to monitor the temperature rise during the high power test. The cavity pressure level was estimated by measuring the vacuum ion pump current. Due to the finite conductance of the vacuum system, a factor of 2.8 was used for this estimation. The test cavity was initially excited by low peak power at high repetition rate for one hour to condition the cavity surface (RF processing).

EXPERIMENTAL RESULTS

Table I summarizes the high power results for three different cavity geometries. The results clearly show that one can operate an accelerator cavity at power levels far exceeding the level of Kilpatrick's Breakdown Criterion for the pulsed operation case. Figure 4 shows the reflected and the transmitted RF power pulse for both the normal operating condition and for operation at the breakdown level. In order to study the effect of surface finish, several ca·ities were made and processed differently. The test results showed that both mechanical (diamond polish) and electrical polishing had minor effect on the breakdown threshold. Also there was no noticeable dependence of the breakdown level on the repetion rate (from 70 to 300 pps) and temperature (-180°C to 40°C).

Table I

	Cavity I	Cavity II	Cavity III
Frequency (MHz)	2997	2997	2997
ZT^2/L (MΩ/m)	104.0	117.1	130.2
E_p/E_o	3.61	6.04	8.08
Qtheor	18520	18411	16835
l (m)	0.025	0.025	0.025
Qexp (half cavity)	7780	7310	6670
Zeff (half cavity)	43.7	46.5	51.6
P_t (MW)	2.52	1.02	0.45
E_o (MV/m)	66.3	43.6	30.5
Emax (MV/m)	239.4	263.1	246.4

Operating Condition
Pulse Width = 4.4 μsec
Repetition Rate = 200
Cavity Starting Pressure = 2×10^{-7} mmHg
Cavity Surface Finish = 8 microinch

CONCLUSION

A multiple-use cavity test system was developed and successfully employed to study the voltage breakdown phenomena in S-band linear accelerator cavities. The high power test results indicate that the maximum surface electric field of well prepared OFHC cavities can be as high as 240 MV/m at S-band frequencies for pulsed operation. This is five times higher than the maximum field given by Kilpatrick's Breakdown Criterion. The surface processing experiments show that neither diamond-polishing nor electro-polishing enhanced the breakdown threshold level. It was also found that the breakdown level did not depend on pulse repetition rate between 70 and 300 pps and temperature between - 180°C to 40°C. Further experimental studies of breakdown level dependence on materials, vacuum level, pulse shape, frequency and external magnetic field are currently underway.

REFERENCES

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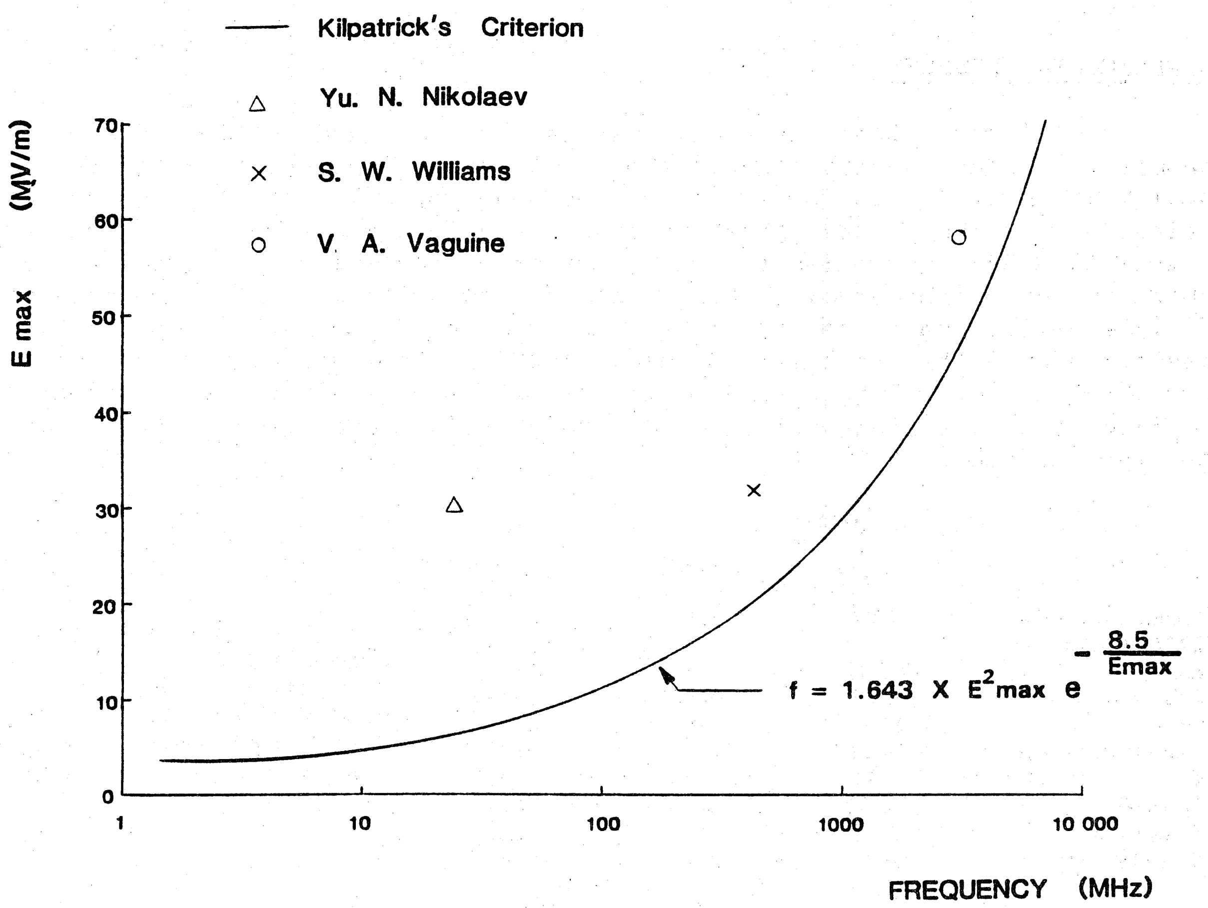

Fig. 1 Kilpatrick Breakdown Criterion and some experimental results.

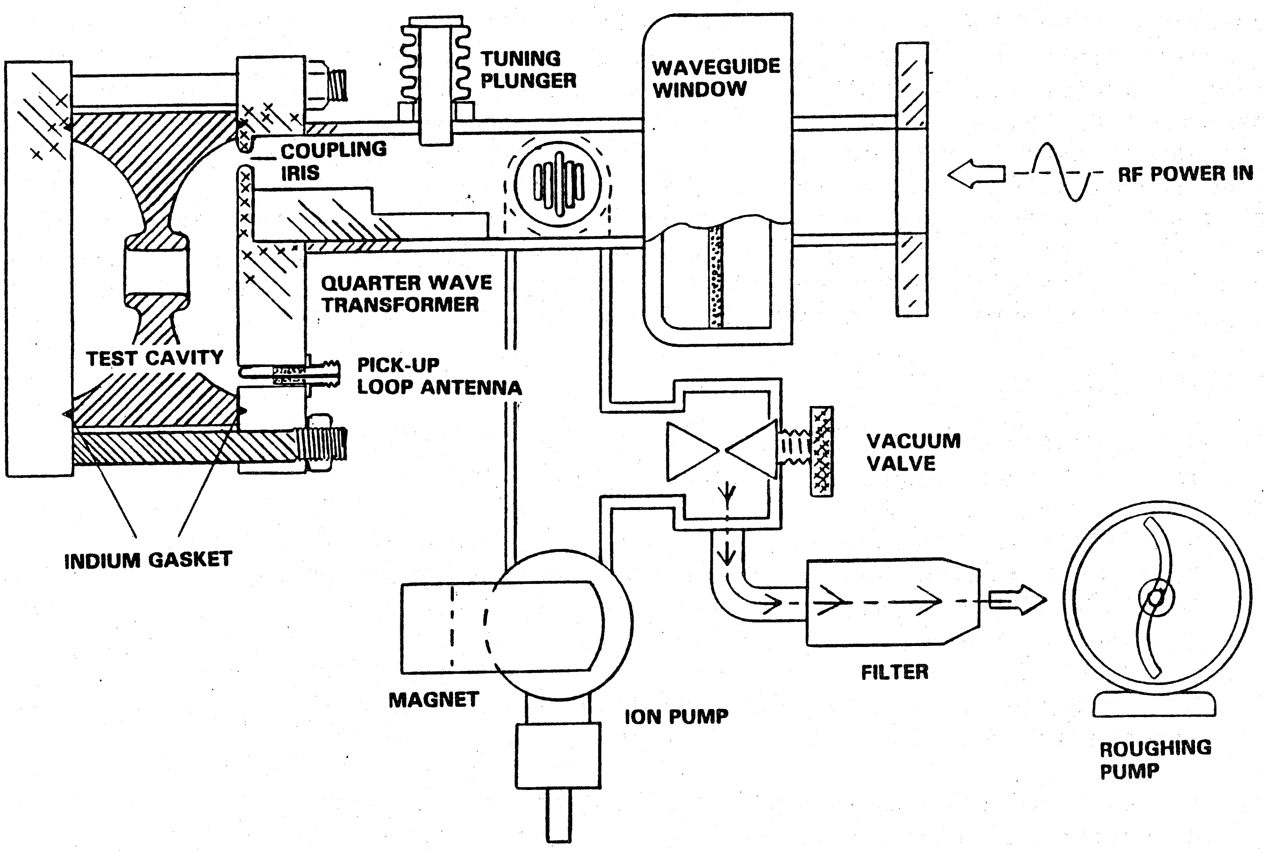

Fig. 2 A cross sectional view of the cavity test system.

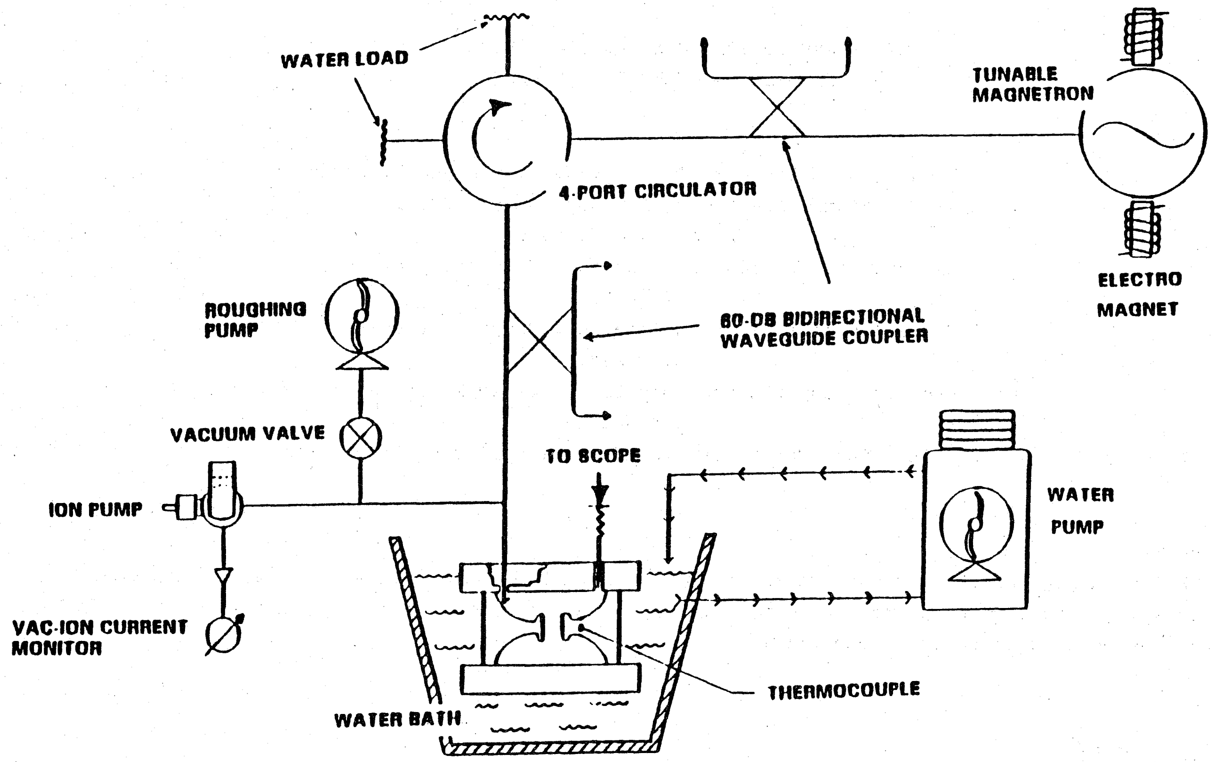

Fig. 3 A schematic diagram of the high power test set-up.

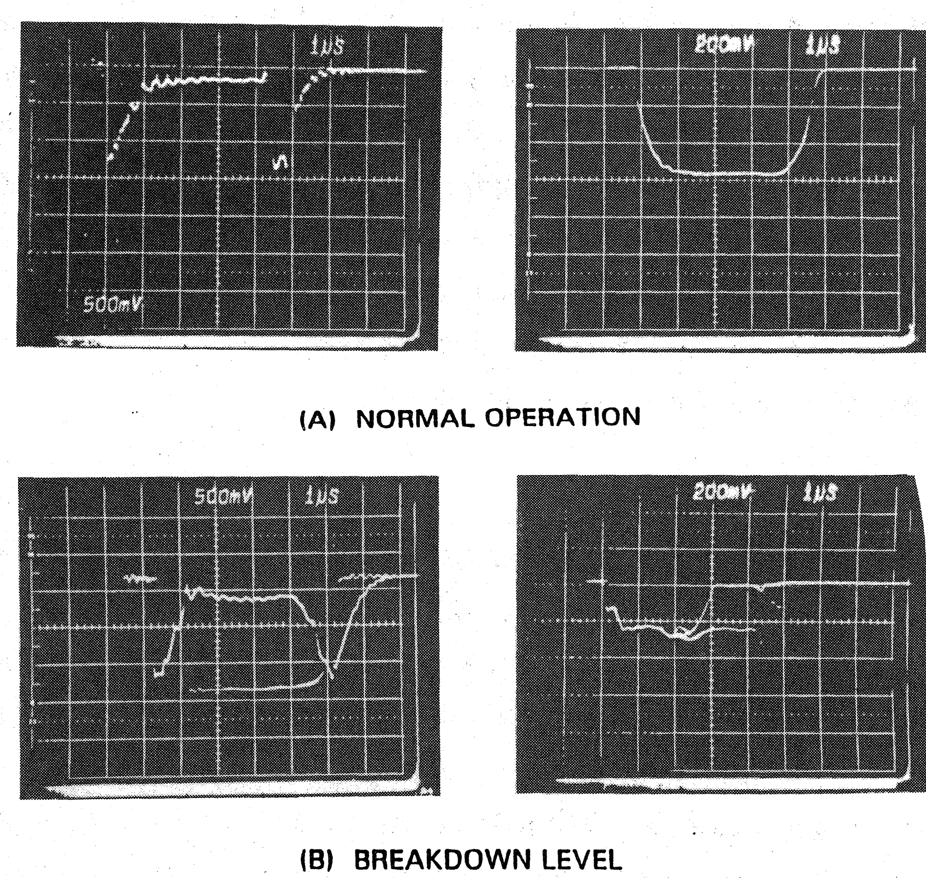

Fig. 4 Reflected and transmitted RF power