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Light Emission Phenomena in Superconducting Niobium Cavities*

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Abstract

During the investigation of field emission limitations of superconducting niobium cavities, a CCD camera [1] was inserted at the end of the beam pipe on a single-cell 1500 MHz cavity. When operating the cavity in field emission, glowing filaments of light were observed trapped by RF fields in closed-orbit trajectories. These filaments were traveling at frequencies much lower than the oscillating RF fields and formed various patterns of light for up to several seconds. This experiment was then repeated on a production CEBAF five-cell cavity with similar results. Events from both experiments were captured on video tape and are presented in this paper along with a discussion of the possible origin of these types of light patterns and the plans to further investigate the phenomena.

1 BACKGROUND

During the investigation into sources of field emission on single-cell cavities, a CCD camera assembly was added below the cavity, which was being tested as part of a series of single-cell tests. The camera assembly [2] consisted of an inexpensive, miniature CCD camera, in a copper tube filled with epoxy. This assembly was mounted in a stainless outer tube sealed at each end with stainless blanks. The cavity end of the tube contained a sapphire view port to isolate the camera assembly from the inner cavity surfaces and the other end contained ceramic feedthrus for instrumentation.

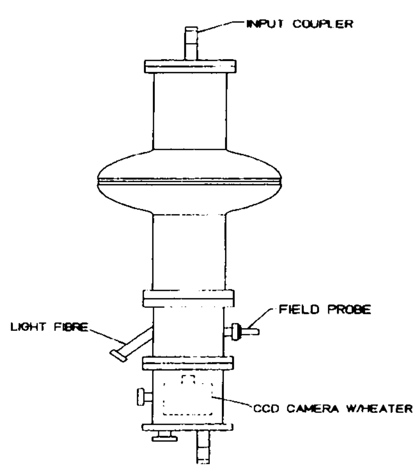

Figure 1. Experimental Setup for Single-Cell Cavity.

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A vacuum was maintained around the camera to reduce the overall heat leak of the system and an additional heater and temperature diode were used to keep the camera operational during the cryogenic testing of the cavity. The heater was adjusted to keep the camera at 295K throughout the testing. The placement of the camera allowed for the complete viewing of input coupler, beam tubes and cell irises (Figure 1).

2 SINGLE-CELL TEST RESULTS

During the testing of the cavity #HP, three classes of glowing filaments were observed: 1) regular-shaped closed (Figure 2a), 2) irregular-shaped closed (Figure 2b) and 3) open (Figure 2c). These filaments were located mostly in the center of the beam axis, between the irises. The closed and open filaments were repeatedly observed during the 1-2 hours of testing and some of the patterns lasted for several seconds. The closed filaments changed plane of rotation frequently during the few seconds and varied in size from 3 cm in diameter to larger then 7 cm in diameter (the diameter of the cavity beamtube). During both closed and open observations, filaments generated reflections on the beamtube and irises (Figure 2c) From the video tape, consecutive frames were analyzed to determine the frequency of oscillation and the velocity for the closed and open patterns of light. The closed filaments' frequency of oscillation was about a few tens of hertz; the open filaments had a velocity of a few meters per second.

Figure 2a. Single-Cell Closed Filaments.

Figure 2b. Single-Cell Irregular-Shaped Closed Filaments.

Figure 2c. Single-Cell Open Filaments with Reflection on Beamtube Wall.

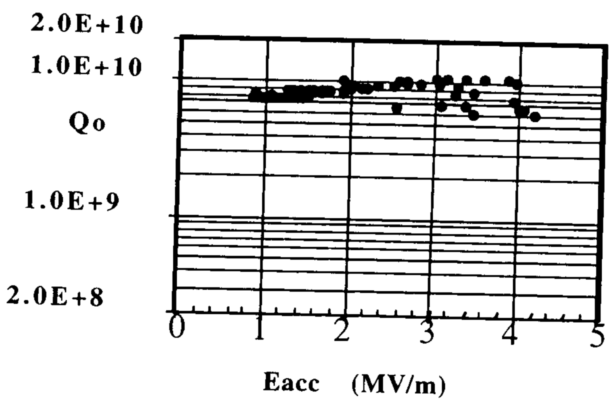

Figure 3. Single-Cell Vertical Test Results.

The single cell cavity started at a Q-value of 7×10^9 and processed to 10^{10} with no radiation present at the dewar top plate. Cavity gradients during these filament events were between 2-4 MV/m. Figure 3 shows the vertical test results for the single-cell cavity. The RF testing was stopped at 4 MV/m to protect the camera from over exposure to radiation (local to the camera) and to prevent arcing and glowing of the sapphire window. To investigate this phenomena further, a five-cell cavity was assembled with the same camera and slightly different hardware (Figure 4).

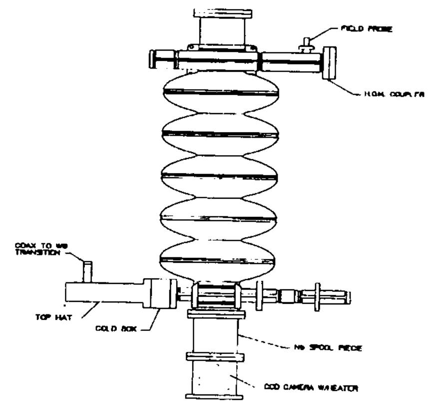

Figure 4. Five-Cell Experimental Test Setup.

3 FIVE-CELL TEST RESULTS

A standard CEBAF five-cell cavity including cold RF window, coax to waveguide transition and field sampling probe were used for the test. The goal was to look for similar types of events that were seen in the single cell and capture them on video tape to make comparisons. The cavity was powered up to low field (2 MV/m) and was increased slowly by an automated RF testing program while data was being taken. At fields around 3 MV/m glowing point sources showed at several iris locations but with no radiation present at the camera.

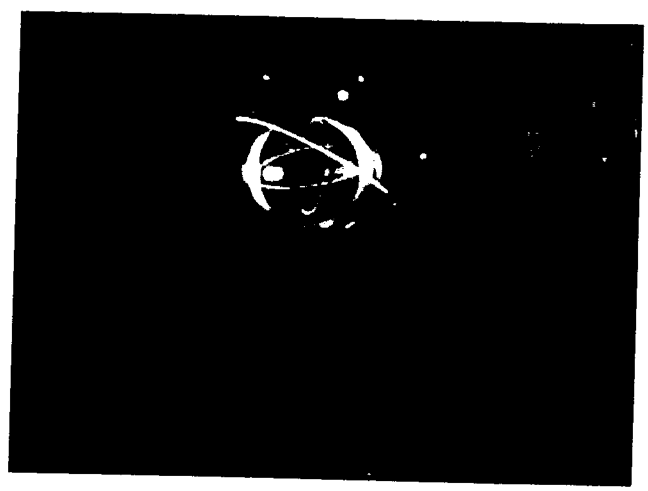

Figure 5a. Closed Filaments in the Five-Cell Cavity.

At approximately 4.4 MV/m several closed filaments occurred at the center cell of the cavity, at the same time and lasted for several seconds. The glowing point sources at the irises and the multiple closed filaments are present in Figure 5. As with the single-cell cavity test the five-cell generated closed filaments following a flash of light.

These filaments, however, only appeared one time during the five cell cavity test, just at the start of field emission as represented with "A" in Figure 6. Following this event the cavity Q-value decreased with increasing gradient until point "1". Then with a flash of light the Q-value went up to point "2". At this time the gradient was lowered to 2.5 MV/m and a new run was started. This second run showed no events and the Q value at the higher level. A review of the video tape showed that a single glowing point source was removed in conjunction with the increasing Q-value.

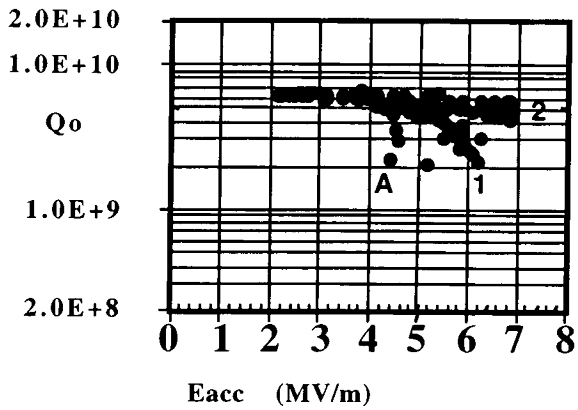

Figure 6. Five-Cell Vertical Test Results.

4 DISCUSSION

Filaments of three types were observed and captured on video tape during the 2K testing of both a single-cell and five-cell 1500 MHz cavity. Filament types identified were closed regular, closed irregular and open. The nature, sources and conditions for such events to occur are currently being investigated. One possible explanation for such events is that the light filaments are plasma in nature. In experiments done in 1958, P. L. Kapitza found that rings of thin filaments (plasma) could be generated in spherical resonators of H_{01} and E_{01} type [3,4]. The resonators were filled with helium and other gases such as argon, carbon dioxide, and air; and resonated around 1.5 GHz. Kapitza found that, in helium, the filaments were generated in the region of maximum electric field at pressures from several cm of Hg to several atmospheres. Discharges in Kapitza's apparatus lasted a few seconds, had a high degree of stability and floated in the resonator without altering the filament discharge. Filaments generated in helium were bright, easily "ignited" and were thinner with higher purity helium. Kapitza also discovered that the impurities in the helium gas such as hydrogen at the 1% level played an important role in generating the filaments at lower pressures. Besides these similarities, our experiment is fundamentally different from Kapitza's in that the residual pressure in our resonator is much lower than his. The filaments we observed also were thin and very well defined, apparently in contradiction to those described by Kapitza, which were thicker and more diffuse.

It is also conceivable that these filaments are due to charged particles generated by field emission and trapped in the RF fields. The particles could be heated on the cavity surface and projected toward its center, where, in the case of the closed orbits, they are trapped by the RF fields. The glow could be due to light emission generated from the interaction with field emission, or by ionization of the residual helium gas. It is not apparent, however, how the fields of a TM_{01} mode can produce the closed trajectories that were observed.

5 FURTHER INVESTIGATION PLANS

The plans to investigate this phenomena will be aimed at determining what is the nature of the filaments and central force to generate such light patterns. The testing will continue with single-cell cavities under typical vertical test conditions to gain additional information aimed at deeper investigation of these phenomena. The following is a list of some of the types of data that will be collected in additional tests and the test setup modifications necessary to generate them:

1. Light spectrum from closed and open filament events by piping light out of the dewar.
2. The relationship to input power changes and the shape of the closed filament. This requires no changes to the test setup.
3. Increasing the image resolution by increasing the shutter speed of the camera. This can be accomplished by removing the camera from the dewar through the use of mirrors and upgrading the camera.
4. Obtain a second view point by adding a second camera in the test setup.
5. Collect vacuum data from a Residual Gas Analyzer during testing.

6 REFERENCES

[1] Edmund Scientific Co., Industrial Optics Division, Catalog: 609-573-6250, pp. 177., Model #H53004.

[2] P. Kneisel, "Understanding and Improvements of Limitations through Application of Cryogenic Instrumentation", Proceedings from the CEC/ICMC-97, (1997).

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[4] P. L. Kapitza and S. I. Filimonov, "Apparatus for Production of a Free Plasma Filament. Determination of the Current and Resistance of the Filament", Soviet Physics JEPT, Vol. 34, No. 3, pp. 542-553, (1971).