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CAPACITOR ANALYSIS FOR RF ANTENNAS*

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Abstract

Commercially available vacuum capacitors have been used in radio frequency (rf) antenna designs. The dimensional envelope of the capacitors has adapted favorably to antenna concepts. However, capacitors that are commercially available have not demonstrated acceptable performance characteristics for maximum design currents of 800 A rms at 80 MHz and 1300 A rms at 30 MHz or for voltages of 50 kV peak. The reason for capacitor failure was investigated. The investigation consisted of (1) establishing existing mechanical design features, (2) defining desired operating criteria of key capacitor components, (3) determining component design limitations, and (4) developing a modified concept for testing. The design criteria included a variable capacitance range of 50 to 450 pF at the maximum current conditions. Effects of capacitor cooling by means of radiative transfer and forced convective transfer were considered. The resulting modified capacitor design concept uses as many components of the commercially available capacitors as possible. An apparatus for testing and evaluation was designed for the proposed capacitor concepts. Tests have demonstrated reliable operation at 750 A and 80 MHz cw on a similar design.

Introduction

Designs developed at Oak Ridge National Laboratory (ORNL)[1] for rf antennas for plasma heating have used commercially available capacitors as tuning devices. Capacitors used thus far have dimensional characteristics that adapt favorably to the required compact antenna geometry. The capacitance range of 20–450 pF is acceptable and is commercially available. The maximum current required is approximately 1500 A rms at 30 MHz, decreasing to 800 A rms at 80 MHz.

The variable capacitors currently available are manufactured by Jennings and Comet for the communications industry. They have a self-contained vacuum and are intended to be actively cooled by convective heat transfer. Demineralized water is used as coolant for the application under consideration. When used in communications applications, the capacitors are designed to be oriented with the axis aligned in a vertical direction.

Increasing the capacitor's current rating by modifying the design of the Jennings capacitor was investigated. An analytical approach was used initially. To evaluate the design modifications, a capacitor test stand was designed and operated at ORNL.

Analysis of the Vaccum Capacitor Design

An independent investigation of the available vacuum capacitors at ORNL established the design shown in Fig. 1 (Jennings model CWV2-450). Capacitor failure is believed to be a result of vacuum leakage. Three features were initially considered to have possible design deficiencies:

1. the bellows geometry,
2. the capacitor plate geometry coupled with the effective cooling, and
3. the outer case at the ceramic insulator interface.

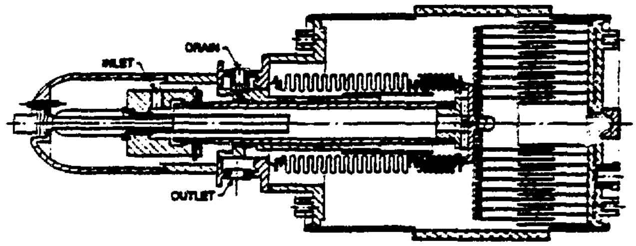

Fig. 1. Jennings model CWV2-450 capacitor cross section.

An investigation was conducted to determine the possible cause of overheating of these three components of the capacitor and the resulting capacitor vacuum loss.

Bellows Heating

Excessive heating of the bellows was considered in the capacitor design because some failed capacitors at ORNL were observed to have pinhole leaks in the bellows. The predicted heat flux of the bellows was 15 W/cm^2. This heat flux should not be excessive if coolant circulation on the inner bellows surface is adequate. However, because of the horizontal alignment of the bellows axis in the rf antenna, coolant circulation could be impaired. Fluid stagnation in the convolutions could result in excessive bellows operating temperatures.[2] The following bellows design modifications were made to the Jennings capacitor.

1. The bellows outer diameter was increased, thus cutting losses by the inverse ratio of the diameters. Furthermore, the absorbed heat flux was also reduced by the square of this ratio.
2. The number of bellows convolutions was reduced, as was the convolution height [(outside diameter - inside diameter)/2]. These modifications lessened the likelihood of coolant stagnation in the convolutions by reducing the stagnant coolant volume.
3. A liner on the inside of the bellows was lengthened in the modified design. This design modification increased fluid velocities along the length of the bellows.

Together, these design modifications caused coolant flow rates to increase, thus reducing the coolant ΔT. Figure 2 is a cross section of the modified design.

The drawbacks of these bellows modifications include an increased bellows spring constant and a limited standard bellows material that has questionable performance characteristics. Also, mechanical stresses exerted on the bellows because of internal coolant pressure become a more significant factor in bellows design requirements.

Capacitor Electrode Heating

The capacitor electrodes consist of several nested cylinders (cans). Cans on opposite electrodes have diameters that allow the two electrodes to mesh together, making possible a large range of capacitance. Although no indication of can overheating has been observed with the commercially available capacitors, can temperature profiles were predicted for the high-current limits. Figure 3 shows maximum can temperature vs electrical current for 30-MHz and 80-MHz operating

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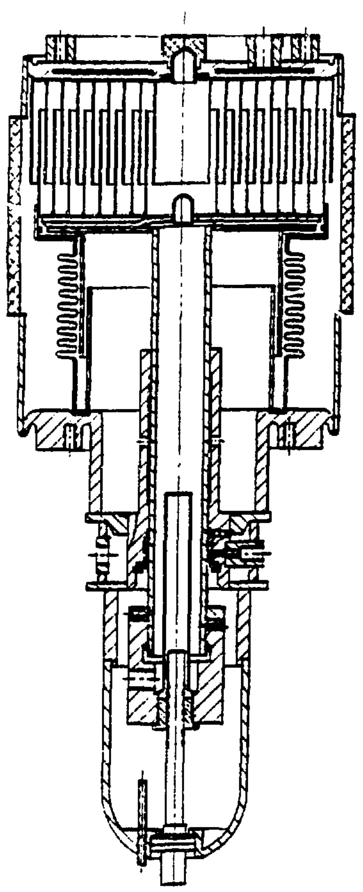

Fig. 2. Modified capacitor design cross section.

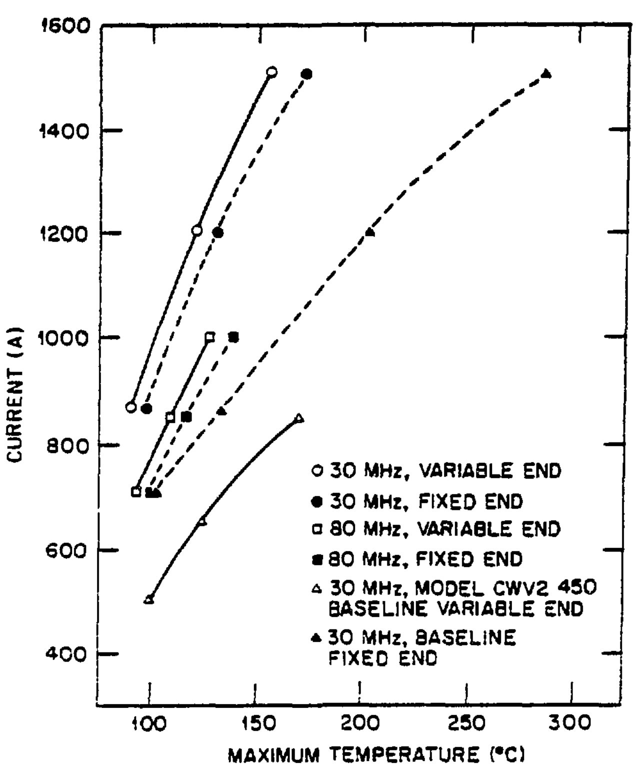

Fig. 3. Maximum can temperature vs capacitor electrical current.

conditions. A finite-difference, analytical solution technique was used to obtain the results.

The analyses indicate that effective cooling on the variable end has been improved to allow can temperature at the same level as the existing fixed-end cooling. Also, with the new design concept, can temperatures at the desired current levels are very near the peak temperature range of the baseline capacitor at 850 A and 30 MHz. The improved can thermal conditions are a result of the increased coolant flow rates achieved with a larger bellows.

Outer Case Heating

Electrical heating of the outer case was investigated for various currents and frequencies. Manufacturer's information indicated that 135°C was the maximum allowable temperature for the copper case–insulator interface.

The analysis of case heating is presented in Fig. 4. This graph indicates that the 135°C temperature limits for the ceramic insulator interface are reached well before maximum currents are obtained. A water flow rate of 2 gpm was assumed in the analysis.

The thermal analysis of the case investigated only the modified capacitor geometry (with improved cooling effects on the outer case). With the addition of case cooling passages, the 135°C temperature limit should be within reason. An additional modification, either trace cooling tubes or a water jacket, should adapt to the design concept.

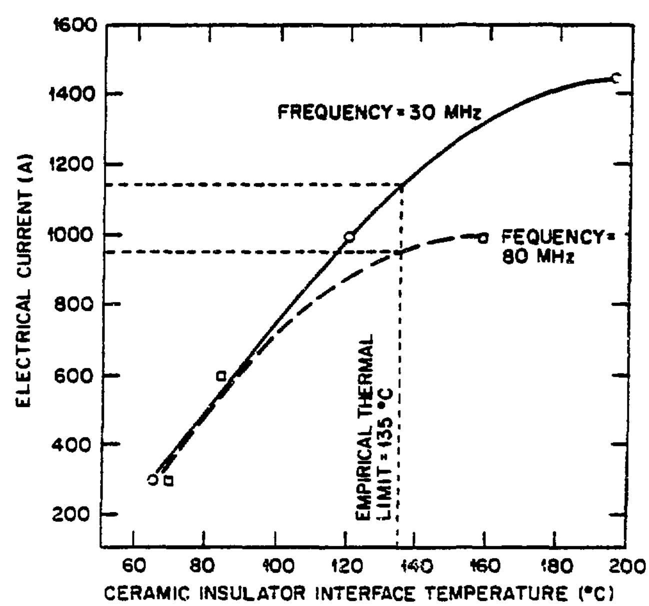

Fig. 4 Capacitor electrical current vs predicted ceramic insulator temperature for modified capacitor design.

Design of the Capacitor Test Stand

Actual performance evaluations were planned for the upgraded capacitor designs, and a capacitor test stand was designed and fabricated at ORNL for the evaluations. Figure 5 shows a cross section of the test stand assembly. The structure is capacitively coupled and resonates at 80 MHz. Approximately 40 kW is needed to induce currents of approximately 800 A rms.

The test stand was designed to be adapted to a variety of capacitor geometries. These include the Comet and Jennings capacitors, as well as a capacitor designed at ORNL for the antenna to be supplied to the Tokamak Fusion Test Reactor (TFTR).

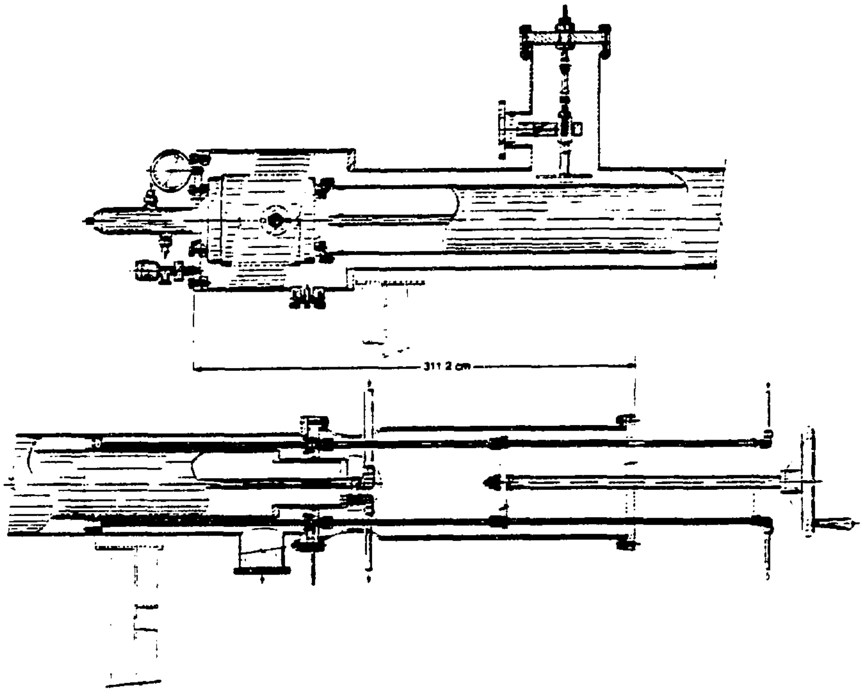

Fig. 5. Capacitor testing apparatus cross section.

Figure 6 illustrates the setup. The capacitor tests were planned to be conducted with the test stand chamber evacuated (3×10^{-7} torr) or filled with either SF_6 or N_2 gas (2 atm). In practice, however, the low-voltage regions of the test stand were filled with SF_6 to preclude multipactor. Thus, the tests primarily evaluated the high-current capabilities and internal voltage limits of the capacitor.

Test results for the Comet capacitor (similar to the upgraded design previously described) showed that it had low capabilities at greater than 700 A rms and 80 MHz. This corresponds to a peak voltage of 25 kV across the capacitive elements. At this current, 8 kW was absorbed in the variable end of the capacitor and 3 kW was absorbed in the fixed end. This shows reasonable agreement with the ORNL model. One capacitor was tested to destruction; after 15 min of operation at 800 A rms followed by 30 min at 750 A rms, the capacitor failed. An "autopsy" revealed that the bellows developed a pinhole leak. Because of the unavailability of large-diameter bellows, Comet had used the conventional smaller size.

Other tests on the test stand included a lower-capacitance capacitor designed specifically for the ORNL resonant double loop antenna for the TFTR tokamak at Princeton Plasma Physics Laboratory (PPPL). It met the design limits at 80 MHz of 62 kV for 0.1-s pulses and 46 kV for 2-s pulses. The voltages were limited by the test stand, with breakdown occurring at the coupling capacitor.

References

[1] D. J. Taylor, F. W. Baity, D. Hoffman, and J. Ray, "ORNL compact loop antenna design for TFTR and Tore Supra," to be published in the proceedings of this conference.

[2] R. C. Hawthorne and H. C. von Helms, "Flow in corrugated hose," in *Product Engineering*, pp. 98–100, June 10, 1963.

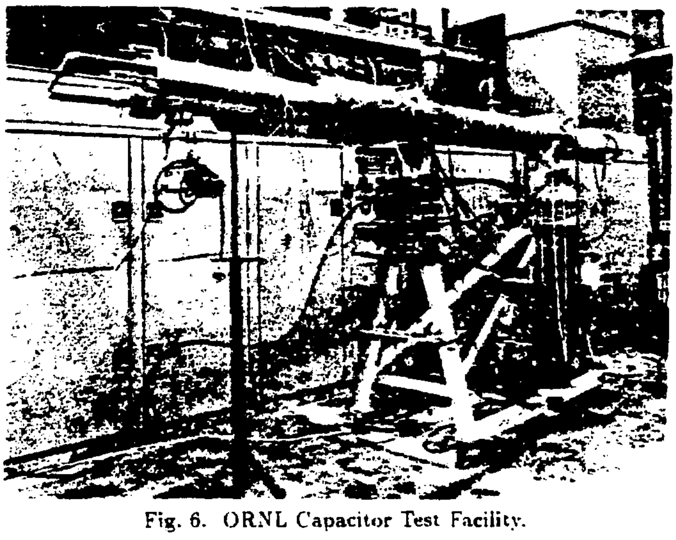

Fig. 6. ORNL Capacitor Test Facility.