Status of the SSC LEB RF Cavity

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Abstract

A tunable, high-accelerating-gradient cavity prototype has been designed and built for use in the rf system for the Low Energy Booster (LEB) at the Superconducting Super Collider (SSC). Testing of the cavity using one tuner cooling variant has been completed. This paper reports on results of low level, high level and tuning tests performed on the cavity. The tuner was damaged during high power testing. Discussion of the fault is included.

I. INTRODUCTION

The LEB will accelerate a 100 mAdc proton beam from 1.2 GeV/c momentum up to 12 GeV/c. The resultant change in proton velocity requires the rf frequency to vary from 47.5 MHz to 59.8 MHz over the 50 ms accelerating ramp. The rf is also required to deliver a peak ring voltage of 765 kV. Lattice space, higher order mode impedance, and cost considerations all push toward achieving this voltage with the minimum number of cavities.

The cavity is a $\lambda/4$ coaxial design with the inductive portion of the cavity being a ferrite loaded tuner. The design goal is to be able to run with as few as 6 cavities (127.5 kV per cavity). This high voltage operation, along with the wide tuning requirement, results in high stored energy and the potential for increased rf losses in the ferrite. Perpendicular magnetic biasing of the ferrite is used to help minimize these losses [1]. Three different ferrite cooling options (beryllium oxide (BeO) disks, water, and dielectric fluid) have been considered. This paper reports in detail on tests done on the BeO conduction cooled tuner.

Figure 1 shows a diagram of the cavity. The tetrode amplifier (150 kW) is capacitively coupled into the cavity. The applied magnetic field, provided by the magnet yoke, biases the ferrite to different permeabilities (μ) and hence tunes the cavity. The conduction cooled tuner was built at the Budker Institute of Nuclear Physics (BINP) and has been tested at SSCL. It uses BeO sandwiched between ferrite rings to help conduct dissipated heat out to the water cooled copper jacket. The ferrite is potted into the tuner housing using thin layers of a flexible glue known as Elastoseal.

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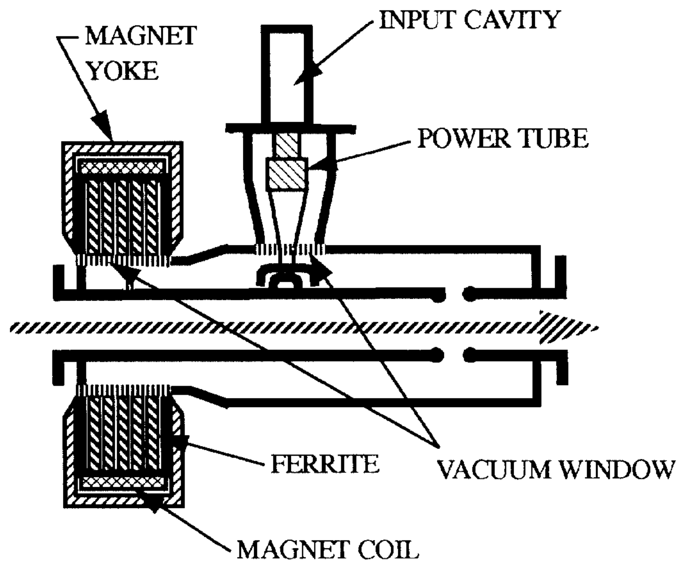

Figure 1. LEB prototype cavity.

II. LOW LEVEL TESTS

A. Tuning range

Figure 2 shows the cavity's resonant frequency as a function of the applied bias current. As the bias field is increased, the ferrite's μ decreases resulting in a higher resonant frequency. The figure shows the cavity is capable of tuning over the required frequency range.

B. Cavity Q

The cavity Q was also monitored at different resonant frequencies (see Figure 3). As the bias field is increased (higher resonant frequency), the ferrite has lower magnetic losses, and the Q rises. However, the calculated Q was approximately two times higher than observed. Calorimetry measurements indicated the unexpected losses were located in the tuner.

C. Temperature effects on tuning

As the ferrite temperature rises, its saturation magnetization M_s falls. This causes a decrease in μ and hence an increase in the cavity's resonant frequency [2]. This effect was characterized by raising the tuner housing temperature by externally heating the tuner's cooling water. The change in resonant frequency was monitored as the tuner, and hence the ferrite's,

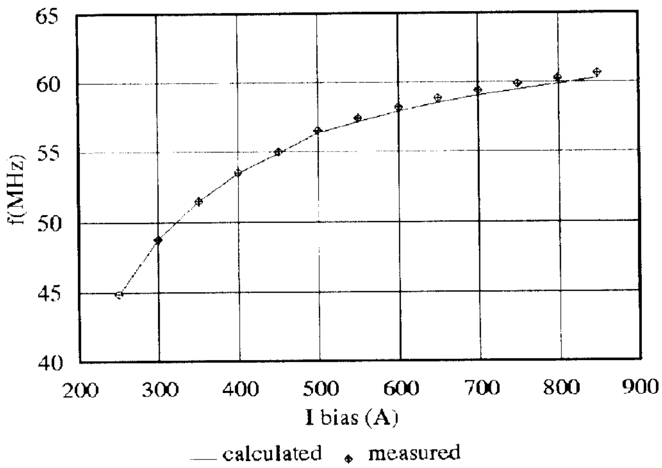

Figure 2. Cavity tuning with bias current.

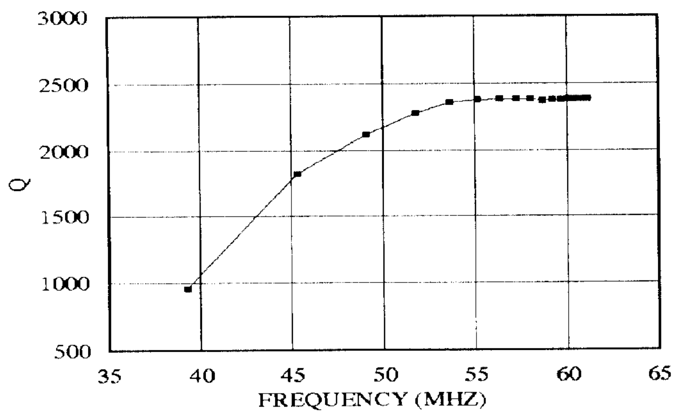

Figure 3. Cavity Q vs. frequency.

temperature changed. An ~ 100 kHz/degC temperature dependence was observed.

III. HIGH POWER TESTS

A variety of tests were performed to thermally characterize the cavity. These were done at relatively low voltages to avoid any electrical stress problems. The average power dissipated in the tuner was measured with calorimetry. This measured power includes not only ferrite losses, but also losses in the cavity walls, BeO and Elastoseal.

A. Power scaling with frequency

The dependence of the dissipated tuner power has been characterized as a function of voltage and frequency. As expected, the power scales as the square of the gap voltage. It was also found that, for a given gap voltage, ~ 1.8 times more power was dissipated at 47 MHz than at 60 MHz. This is a result of a higher percentage of the total cavity energy being stored in the tuner at low frequencies, and the ferrite being more lossy at low bias.

B. Ferrite temperature

The LEB cycles at a 10 Hz rate. For continuous 10 Hz operation, heating of the tuner's ferrite is considered to be a critical consideration. One must be careful not to approach the ferrite's Curie temperature (120° C for this ferrite). Also, a large temperature difference between the ferrite and water cooled wall would lead to thermal stress which might crack the ferrite.

The ferrite temperature was measured under various conditions. The cavity was run at a given voltage and duty factor until it reached thermal equilibrium (~ 30 min). The rf was then turned off, and a thermistor was quickly inserted between the ferrite and vacuum window and touched to the inner radius of the center ferrite.

Figure 4 shows the temperature difference between the ferrite and the water cooled wall normalized by the tuner power (the difference temperature was observed to scale linearly with power dissipated in the tuner). The plot shows that the ferrite temperature depends not only on the dissipated power but also on the frequency. This phenomenon can be explained by the fact that at low frequencies the ferrite is more lossy. Hence, more of the total tuner power is deposited in the ferrite as opposed to the walls, BeO, or Elastoseal.

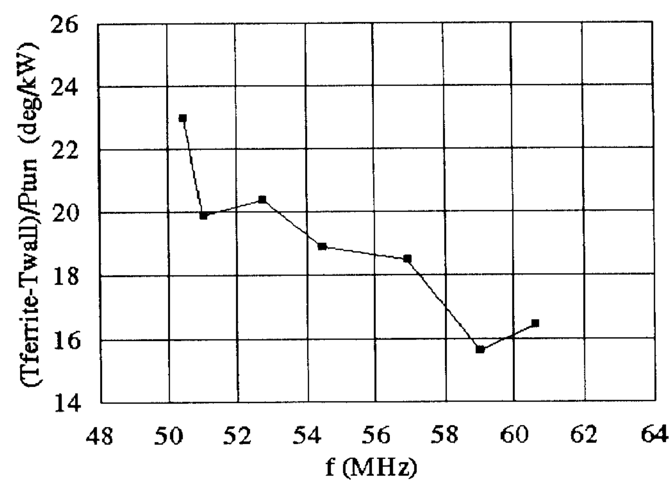

Figure 4. Ferrite temperature scaling.

IV. TUNING PERFORMANCE

The tuner is required to sweep the cavity through the appropriate frequency program over the 50 ms LEB ramp. To help determine the tuner's capabilities in this respect, the frequency response of the tuner has been measured. The amount of shift in the cavity's resonant frequency (df) for a given change in bias current (dI) can be used as a measure of the responsiveness of the tuner. For very slow changes in the bias current (static tuning), a given change in resonant frequency is measured, and df/dI is easily calculated. As the time rate of change in the bias current increases, however, eddy current effects in the magnet yoke and tuner housing will limit the change in resonant frequency.

In order to characterize these effects, the bias power supply was adjusted to a given dc level with a small amplitude ripple imposed on top of that level. The resultant frequency swing was then measured as a function of ripple amplitude and frequency. Figure 5 shows measurements of df/dI as function of modulating frequency. The response is seen to roll off by 3 dB at ~30 Hz. However the drop in response is relatively slow (-4.5 dB/decade), which indicates that the tuner may have a significant amount of response even at a 1 kHz frequency. Improvements in the power supply will have to be made in order to obtain data at frequencies above 200 Hz.

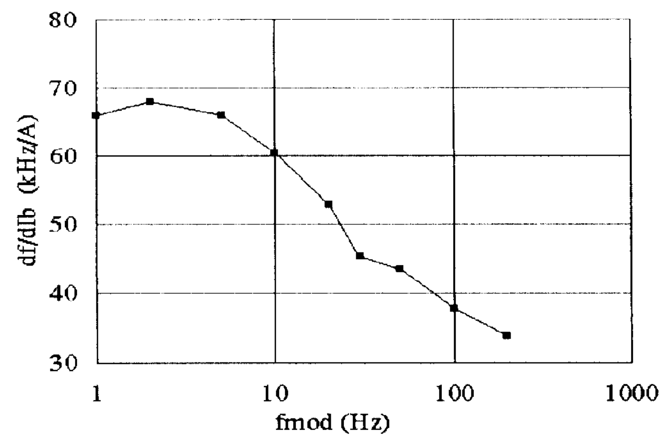

Figure 5. Tuner + cavity frequency response.

V. DISCUSSION OF TUNER DAMAGE

During the course of testing the cavity, it was operated over a wide range of voltages and powers. Figure 6 plots cavity operating points in terms of gap voltages ran at various tuner powers. The cavity was run at > 100 kV, but for only short times and at low duty factors, Most high voltage data was collected at 80 kV and moderate power(1.7 kW).

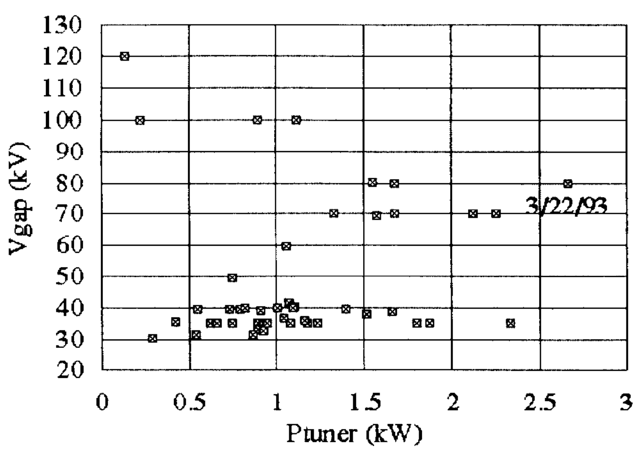

Figure 6. Cavity operating space.

At the time of the failure, the tuner was operating at 80 kV and pushed to higher powers (2.7 kW) than it had achieved before (data point labeled 3/22/93). Therefore, it was being asked to operate at high voltage and high thermal stress simultaneously. The 80 kV gap voltage corresponded to ~ 30 kV across the tuner at the 58 MHz operating frequency. The ferrite temperature was estimated to have reached 80° C (30° wall temperature). After ~10 min into the run, the voltage began collapsing ~ 10 ms into the pulse. Disassembly and inspection of the tuner revealed that the fault was located in a localized area in one of the outer ferrite rings. The deposition of power into this small volume had resulted in very high temperatures that melted some ferrite and caused significant cracking due to the high thermal stresses.

The inspection also revealed an area, away from the damage location, where a small air gap existed between the ferrite and copper wall at the inner radius of the ferrite. It is postulated that such an air gap existed at the location of the damage. At this operating voltage, the fields in such a gap are calculated to be 20 - 25 kV/cm. This could have resulted in the onset of corona and localized heating of ferrite. After some period of time the localized heating thermally induced a crack in the ferrite which then led to intense localized heating and catastrophic failure of the ferrite.

VI. SUMMARY

The prototype cavity has been assembled with a conduction cooled tuner and tested. The tuner fault limited some of the high voltage and power testing, however much valuable information was obtained. The tuning range achieved was more than adequate to cover the LEB requirements. The high frequency tuner response starts to roll off at ~ 30 Hz, however the roll off appears to be slow and extrapolates to a non negligeable response at 1 kHz.

The overall cavity Q was somewhat lower than expected with the extra losses being located in the tuner. The source of these losses is not yet clear, however it is obvious that they limit the high power operation of the tuner.

The cavity was successfully run at 80 kV and at moderate powers. However, the tuner was critically damaged when pushed to higher powers. Explanations of the fault are tied to breakdown of air pockets due to electric field stress and the high thermal stresses present in the tuner

Testing has now begun on a water cooled version of the tuner.

VII. ACKNOWLEDGMENTS

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VIII. REFERENCES

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