THE APPLICATION OF HEAVILY DAMPED SUPERCONDUCTING CAVITIES TO THE ACCELERATION OF HIGH CURRENT ELECTRON BEAMS*

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Abstract

In order to achieve the high luminosities required for a B-factory,[1] the average currents required in the two rings are 1 ampere for the high energy ring and 2 amperes for the low energy ring. With such high currents the impedances of the rings must be very low. The reasons will be given for choosing superconducting RF cavities for this purpose and the methods used to obtain the required damping of the higher order modes will also be described. Prototype 1/3 scale and full scale superconducting cavities have been built and tested and the results of these tests will be given.

Introduction

In the design of a B-factory,[2] electron positron collider, or any high current storage ring, the following arguments may be made. The use of superconducting RF cavities has the obvious advantage of saving the ohmic heating power required to maintain the RF fields in the cavities. This, however, is not the compelling argument for the use of superconducting cavities. This ohmic heating power is generally far less than the power required by the beam to make up for the synchrotron radiation losses. The compelling argument is that when superconducting cavities are used, the accelerating field (5-10 MV/m), can be increased well above the CW field possible in copper cavities (1-2 MV/m). Because higher gradients can be used, the number of accelerating cavities can be decreased as long as the beam required RF power per cavity does not exceed the capabilities of the input couplers and windows. The main contribution to the beam impedance usually comes from the cavities and is proportional to the number of cavities. Moreover superconducting cavities can have larger beam holes further reducing the impedance. Therefore, because there are fewer cavities of lower impedance, the threshold current for beam instabilities is increased. Thus the higher order mode damping requirement on the cavities is decreased and the feedback requirement on the beam is decreased, if not eliminated.

Comparison of Impedances

In a normal copper accelerating cavity it is desirable to have the R/Q as high as possible in order to maximize the accelerating voltage for a given power dissipation. In a superconducting cavity this requirement no longer exists and the impedance of the cell can be made much lower. A comparison in the shapes of the normal cells used in CESR and the superconducting cells proposed for the B-factory is shown (see Fig. 1).

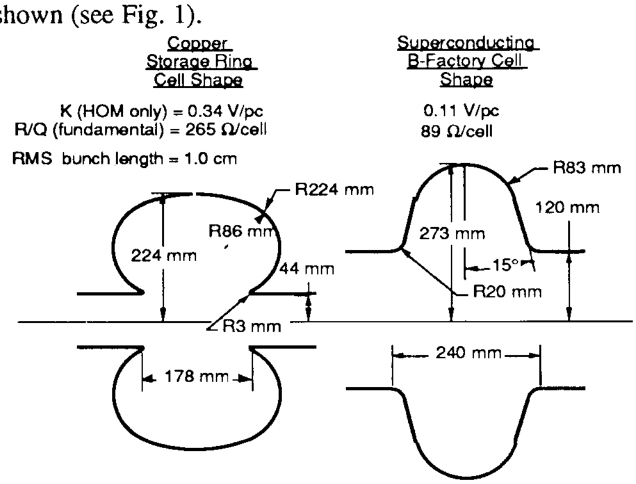

Fig. 1 Comparison of Cell Shapes

As can be seen the overall parasitic mode loss factor as determined by TBCI[3] has been reduced by a factor of 3 over the CESR shape. Another major advantage provided by the new shape is that the impedance of the most dangerous HOMs have been reduced by large factors as compared to the typical shape of a NC cavity. The following graph compares the R/Q of the NC shape with the CESR-B SC cell shape for the most dangerous monopole and dipole modes (see Fig. 2).

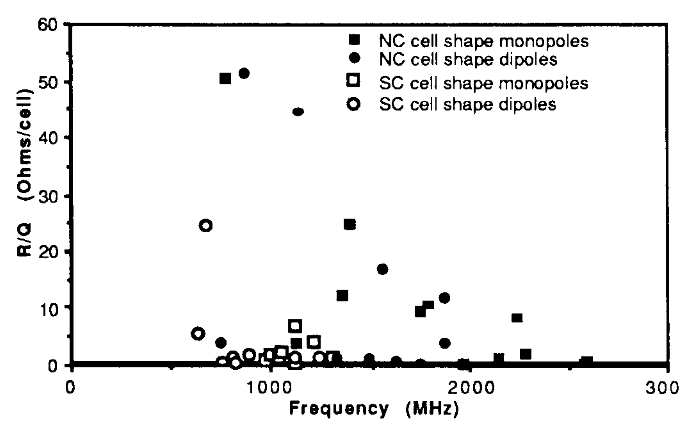

Fig. 2 R/Q vs. Frequency for both Cavity Shapes

Proposed Accelerating Cavity

A sketch of the accelerating cavity system is shown below (see Fig. 3).[4] Because of the very large input power per cell, a waveguide input coupler has been chosen. The beam pipe on both sides of the cavity are very large (240 mm diameter) with the result that all longitudinal HOMs will propagate in the beam pipe. This allows us to absorb HOM power and damp HOM modes at room temperature outside the cavity. The "fluted" beam tube shape is to take care of the propagation of the TM_{110} and the TE_{111} modes which are cut off in the round beam tube. This scheme proposed by Kageyama at KEK, reduces the cutoff frequency of the transverse modes without changing the cutoff of the longitudinal modes.

SUPERFISH, URMEL and URMEL-T calculations have been made of the cell for the fundamental mode as well as the higher order modes. MAFIA calculations have been made to verify the propagation of the TM_{110} and TE_{111} modes down the fluted beam tube, the wakefield losses in the fluted beam tube, and also to calculate the electric and magnetic fields present around the tongue of the "Sceszi" input coupler. The length of the tongue has been adjusted to give a Q_{ext} for the input waveguide of 2.0×10^5. At this value and at the planned excitation level the peak surface electric field in the vicinity of the coupler will be 6.5 MV/meter and the peak surface magnetic field will be 152 Oersteds.

We received one prototype niobium cavity and one copper cavity, complete with waveguide couplers from Dornier. Cornell manufactured the copper and niobium fluted beam tube. When the chemistry was completed at Dornier and the niobium cavity was delivered, the final assembly and tests took place at Cornell.

In addition to this effort we completed a 1/3 scale model of this cavity to operate at 1500 MHz. This model is complete in all details including the waveguide input coupler and the fluted beam tube.

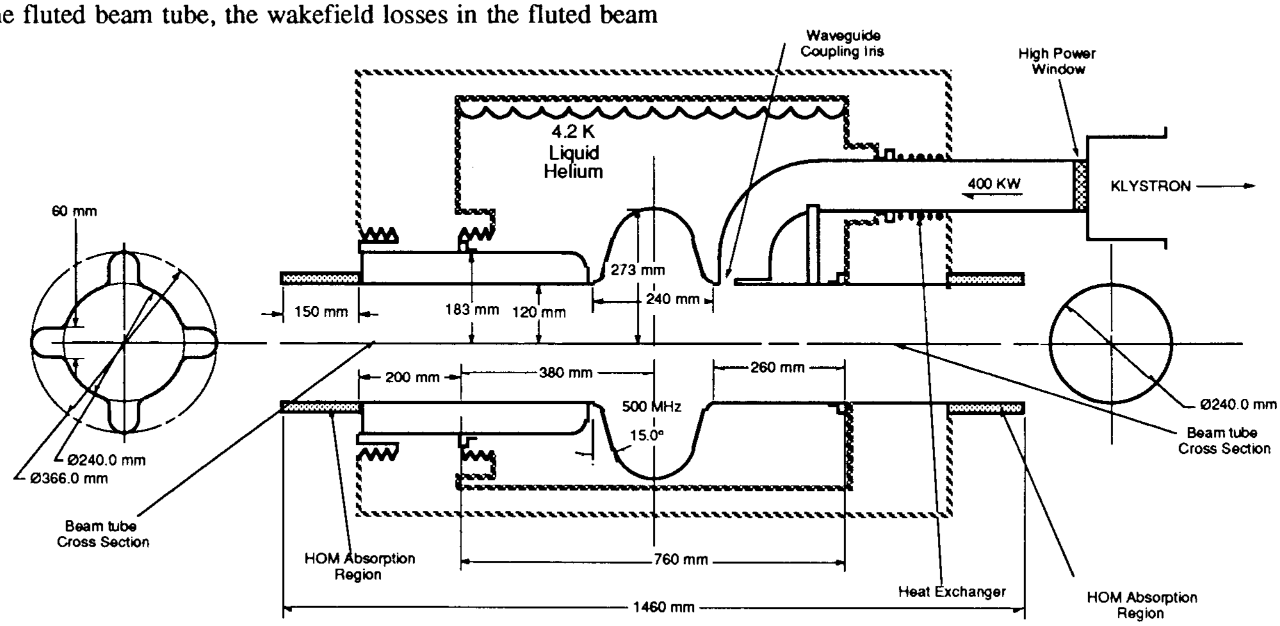

Fig. 3 Proposed Accelerating Cavity System

Cavity Test Results

The 1500 MHz model was tested at 2 K. The coupling was found to be very near the desired value of $Q_{ext}=2.0*10^5$. After sufficient chemical cleaning of the cavity the test results gave the desired 25 MV/m, peak surface fields at the desired Q_0 value of more than 10^9.

This year the 500 MHz cavity was tested at Cornell after rinsing with Methanol and final assembly. Again the coupling was measured and found to be very near the desired value of $Q_{ext}=2.0*10^5$. The results of the first test are shown (see Fig. 4). These results, which gave an accelerating field of more than 9 MV/meter and a Q_0 value of ~ 10^9 were extremely encouraging.

It is planned to do additional chemical cleaning at Cornell for further tests.

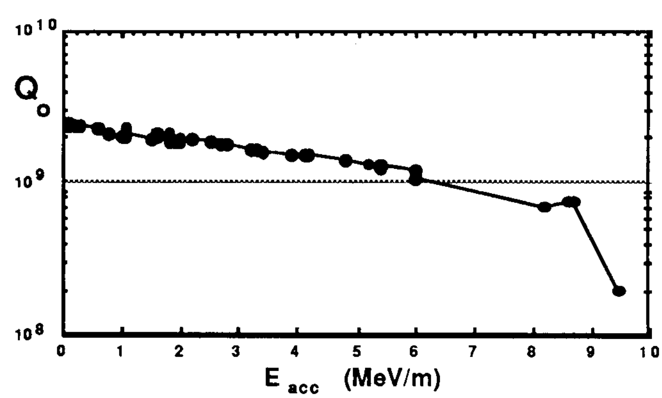

Fig. 4 Q vs. E_{acc} for B Cell Test

Ferrite HOM Loads

As mentioned above, all of the higher mode power is transmitted out the beam tubes of the cavity where it may be absorbed at room temperature. This will be done with specially designed Ferrite lined beam tubes at both ends of each accelerating cavity.[5] Because the modes are propagating, these modes can be damped in a 15 cm long beam tube section of TT2 Ferrite[6] such that the Q values of all the higher order modes are below 200, and most are below 100.[7] The microwave losses of Ferrite have been found to be $\geq 10^4$ times higher than copper at ~ 1 GHz, and to decrease by a factor of 10 at 10 GHz. The tolerance of a similar Ferrite to withstand high power RF has been tested up to 10 watts/cm^2 in sheets 1/8 " thick. Its vacuum properties appear promising. Bonding techniques are under development and RF measurements have been made on 1/6 scale models.

In order to calculate the mode damping in the final cavity, detailed measurements are being made of the material properties of the ferrite, μ', μ'', e' and e". These measured properties are then used in SEAFISH,[8] a complex version of SUPERFISH to calculate the Qs of the various HOMs as well as in AMOS[9] to calculate the impedance the ferrite presents directly to the beam.

Measurements have also been made on a full size prototype at low power using the 500 MHz copper cavity manufactured by Dornier. The results of these measurements are summarized in the graph of Q vs. frequency (see Fig 5). As can be seen, the Q of most of the modes is decreased below 100 and in almost all cases below 200. The few modes with larger Q values have R/Q < 1 Ω/cell.

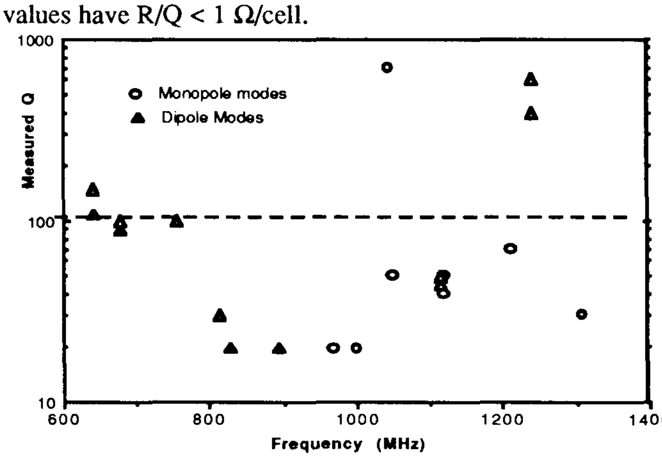

Fig. 5 Q vs. Frequency for Damped Cavity

Cryostat Development

In order to accomplish a beam test of the B-factory accelerating cavity in CESR, we are designing a horizontal test cryostat that will serve as a prototype of the final design[10]. The design is made challenging by the very large beam tube at each end of the cavity and by the very large waveguide delivering power to the cavity. The incorporation of heat exchangers on the waveguide between 4.2 K and 77 K is planned in order to minimize the heat leak to helium.

Preliminary estimates are that we can keep the static heat loss to the helium to less than 30 watts per cavity.

On the prototype cavity/cryostat the beam tube flanges and waveguides will be attached with indium seals. The design goal for overall cavity length including HOM dampers, a gate valve at each end and sliding joint between cavities is ≤ 2.1 m. In addition there will be tapers at each end to match to the rest of the machine. 24 cm diameter sliding joint and gate valves are under development.

Crab Cavity

In addition to the SC accelerating system required for a B-factory, there is also an RF system required to transversely kick the bunches in order to compensate for the finite crossing angle (12 mr) proposed for the two beams[11]. This crossing angle would cause harmful coupling between the synchrotron and betatron motion. By rotating the bunches before collision ("crabbing") so they collide head on, and then rotating them back, so they pass through the arcs normally, this dangerous coupling can be avoided.

Calculations show that a transverse kick of 2 MV is required. A design has been achieved the provides this transverse gradient in a single cell SC cavity operating in the TM_{110} mode at 500 MHz with a peak surface electric field of 25 MV/m, the same as in the accelerating cavities.

A 1/3 scale prototype of such a cavity has been tested to the required fields. Systems for damping all of the HOM's and LOM's (the crabbing mode is not the lowest frequency mode) have been devised and have been tested at room temperature. This work is more fully described elsewhere.[12] These damping schemes will be tested in a 1/3 scale SC cavity now under construction.

References

*Supported by the National Science Foundation, with supplementary support under the U.S. - Japan Agreement.

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