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SUPERCONDUCTING CAVITIES FOR SYNCHROTRON USE*

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Summary

For two months, as of this writing, a 60 cm length of niobium S-band standing wave accelerator has been installed in the Cornell Electron Synchrotron. The Q_0 has remained at its initial value of 1.1 X 10^9, and the accelerating field at breakdown has remained at 4 MeV/m. The cavity has been used to accelerate the synchrotron beam to 4 GeV by itself and to accelerate the beam to 12 GeV in concert with the normal RF system.

The Structure

Properties of the "muffin-tin" type of structure employed are detailed in ref. 1. Table 1 is a summary of the important parameters.

Table 1

Mode	Pi
ZT^2/Q	3.1 X 10^3 ohms/m
Geometry factor	233 ohms
B_{pk}/E_{eff}	44 gauss/MeV/m
E_{pk}/E_{eff}	2.6(1.6 for single cell)
Bandwidth	4.7%

Fig. 1 shows an artist's cut-away view of the structure with its coupling probe. Fig. 2 is a cross-section through one of the

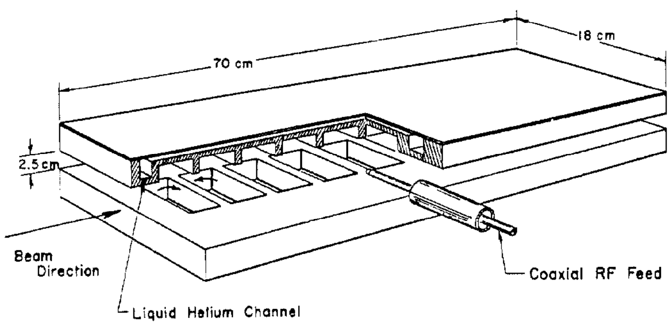
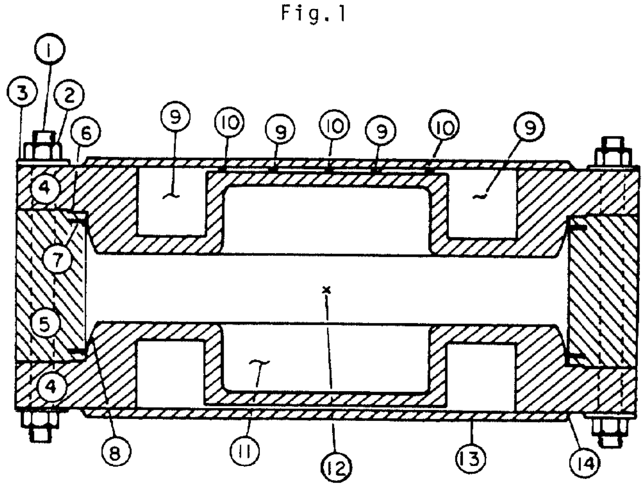


Fig. 1



1. Ta bolt
2. Al nut
3. Spring washer
4. Nb cavity half
5. Spacer ring
6. In wire seal
7. Spring slot
8. Exponential slot
9. He channel
10. Spacer pad
11. Cavity cell
12. Beam line
13. Nb back plate
14. Electron beam weld

Fig. 2

cells showing the manner in which the cavity halves are supported, joined, and gasketed. The cavity halves are bolted to the spacer ring using tantalum bolts with spring washers under the nuts. A vacuum seal is provided by indium wire placed between each half and the spacer ring. A crack between each half and the spacer ring is necessary in order to have the indium seal lie in a plane and to make vacuum seals to the beam holes without having two seals intersect. The slots in the spacer ring are necessary to provide spring loading of the indium seal while maintaining direct contact between the halves and the spacer ring; this direct contact is necessary to avoid frequency shifts caused by cold flowing of the indium.

As originally constructed, there was a uniform 0.46 mm crack between the halves and the spacer ring. It was discovered that this crack, combined with the slots in the spacer ring, was resonant at our operating frequency. This caused appreciable power losses because slight asymmetries between the halves drive currents across these cracks. The crack was modified to have an exponential taper, which made its electrical length shorter and eliminated the resonance.

In this version of the structure, the liquid helium is contained in channels cut in the cavity halves as shown.

Fig. 3 is a photograph of a finished half of the muffin tin structure.

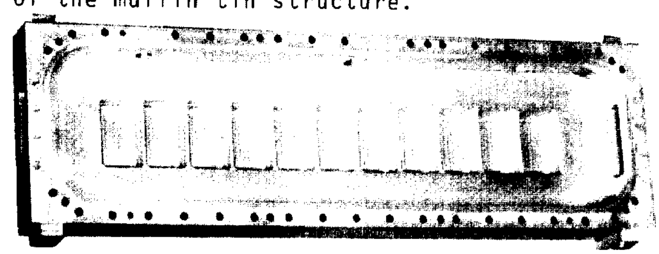


Fig. 3

Accelerator Mounting and Environment

The accelerator section itself is suspended inside the cryostat by stainless steel wires and connected to the synchrotron beam pipes through niobium cut-off tubes and stainless steel bellows which are held at 80°K at their midpoints. A vacuum much better than that in the synchrotron is maintained at the cavity by differential pumping. There are three sputter-ion pumps between the cavity and the nearest synchrotron magnet in each direction, each pump being separated from the next by a 2.5 cm X 5.1 cm stainless steel tube of 60 cm length. 0.025 mm thick titaium alloy sleeves[2] are placed in the gaps of adjacent synchrotron magnets to provide further isolation. The pressure in the pumps nearest the cavity is typically 4 X 10^{-9} torr. Short electrostatic precipitators (10 cm long, 1.7 kV/cm) are located in the synchrotron beam pipes adjacent to the cavity on each end in an effort to prevent the entry of dust.[1] Fig. 4 is a photograph of the cryostat in place in one of the straight sections of the synchrotron. The vessels on top are helium reservoirs.

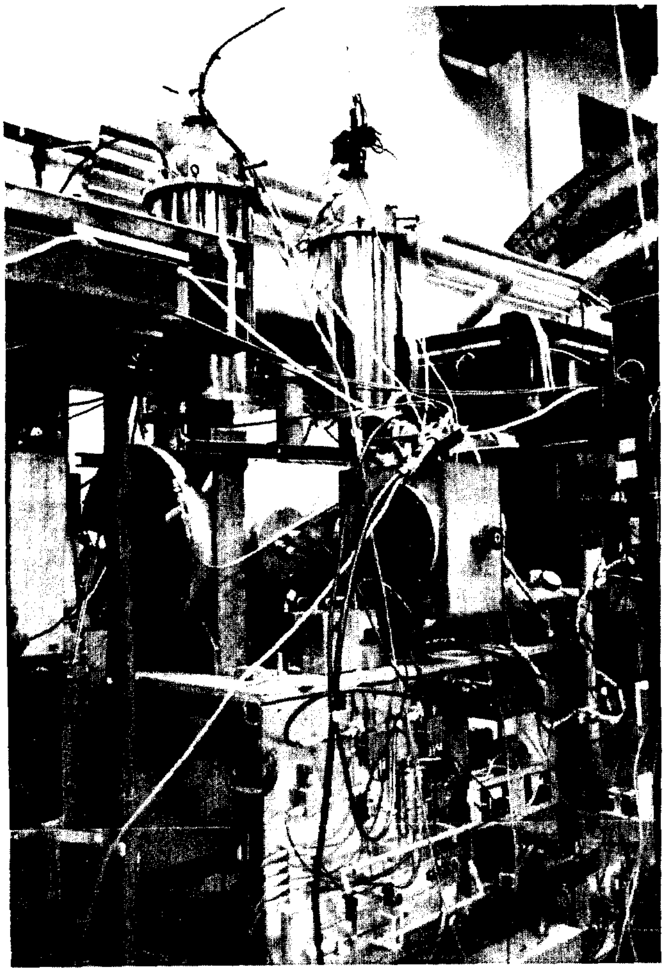


Fig. 4

Laboratory Tests

Subsequent to electropolishing[1], oxipolishing[3], and anodizing to 20 volts, the cavity was tested in the laboratory. A Q_0 of 1.1×10^9 was measured by calorimetry. An additional loss to room or nitrogen temperature due to the finite length of the cut-off tubes was measured to be $Q_0^{-1} = 3.1 \times 10^{-10}$. The accelerating field at breakdown was measured to be 4 MeV/m, this breakdown being associated with electron emission internal to the cavity. An electric probe in the cavity, biased to collect electrons, detected a current which was proportional to E^2 exp $(-a/E)$, where a =31.9 MeV/m and E is the effective accelerating field in MeV/meter. A barrier existed at 3.31 MeV/m; this could be processed away in a few minutes. Another barrier existed at 4.19 MeV/m, and could not be processed through. Application of more power to this barrier led to a thermal breakdown characterized by a loss of the cavity's stored energy in 1 msec. Near breakdown, heat pulses were observed by means of therometers mounted on the botton of each cup. One cup showed much larged pulses than any of the others.

Simultaneous excitation of the pi and 5 pi/11 modes was tried as a means of disrupting the barrier at 4.19 MeV/m. No significant alteration of the barrier was observed.

During high field operation of the cavity, visual observation through the beam port revealed the presence of several (perhaps 20) glowing points on the irises. These points appeared on both upper and lower halves. The light quality varied from dim, dull red at medium power to bright white near breakdown, the spectrum of the light being continuous as far as could be discerned with a simple grating spectroscope. We conclude that the light has its origins in the incandescence of dust particles or spots of lossy, loosely connected oxide or carbide.[4] While it is not yet proven, it is likely that these incandescent spots significantly enhance field emission of electrons and at least participate in the initiation of breakdown. Investigation of this phenomenon is continuing through the use of smaller cavities furnished with a window. We hope thereby to identify the nature of these glowing points.

Beam Tests

The superconducting cavity, with all other RF cavities turned off, accelerated an electron beam to 4.0 GeV. This required a minimum gradient of 3.44 MeV/m. The tolerable peak voltage at injection ranged from 0.78 MeV/turn to 1.22 MeV/turn the optimum value being 0.90 MeV/turn.

The superconducting cavity was also operated in conjunction with the 29 meters of normal copper cavities, which produce a maximum of 23 MeV per revolution. The object of this was to look for problems in the presence of substantial synchrotron radiation, to confirm that the control systems function properly, and to add more than 10% to the RF voltage available. The superconducting cavity contributes to the available voltage in two ways: in addition to directly adding 10% more voltage at the peak demand point, its ability to operate CW permits the power available for the normal RF to be redistributed to produce more voltage at the peak demand point.

With the normal RF power set so that quantum excitation losses destroyed all of the beam by 0.5 msec after the peak of a 12.0 GeV cycle, the superconducting cavity was turned on and the same normal RF power was redistributed. Now 78% of the beam persisted to 0.5 msec after the peak of cylce. No operational problems were encountered.

The RF controls are essentially the same as previously described.[1] While regulating the magnitude but not the phase of the field in the cavity, the tuning angle was varied by ±30°. No synchrotron oscillation instabilities were encountered.

At the beam intensities achieved so far, no evidence of regenerative beam deflection modes has been seen. The highest intensity accelerated by the superconducting cavity alone has been 110 microamperes, and the highest intensity passed through the cavity while superconducting has been 380 microampheres.

No problem due to dust in the cavity has been observed. Either the precipitators are effective or dust in the cavity is not important at the present level of operation. This question will not be resolved until the cavity is withdrawn and inspected.

The cavity was last chemically processed nearly four months ago, and first tested 3½ months ago. Since the first test, it has been let up to dry nitrogen several times. It has been kept near liquid nitrogen temperature most of the time, but has been warmed up to room temperature three times for a total of 31 days. It has been cooled to 1.8°K 17 times, but not kept below 50°K for more than three days at a time. The radiation exposure recorded using an ionization chamber mounted near the downstream end of the cavity is 75,000R.

At critical coupling, no degradation in either the Q_0 or the breakdown field has been observed. However, after a period of 20 days near or below liquid nitrogem temperature, the field which could be reached at heavy coupling (β=300) fell to 2.6 MeV/m. The breakdown was characterized by a runaway of the electron loading current. The cavity was warmed up to room temperature, and the equivalent of a monolayer of gas was evolved. Upon cooling back down, the breakdown field, both at β = 1 and β = 300, was found to have recovered to its original 4 MeV/m. Peak powers up to 550 watts were incident on the cavity in this measurement.

Future Program

Our next goal is to incorporate a closed cryogenic system so that the cavity can be run continuously at 1.8°K. In addition, we are attempting to fabricate accelerator sections from 1.5mm thick niobium sheet. To date, several single cell cavities and two cell cavities made by welding together deep drawn cups have been tested. In the single cell models Q's of 6 X 10^9 and accelerating fields of 9 MeV/meter have been achieved, while for the two cell models the corresponding figures are 2.6 X 10^9 and 4.8 MeV/m. These results have been obtained without annealing after drawing and beam welding.

The niobium cut-off tubes employed on the 60 cm cavity can be used only because the cavity is installed in the synchrotron at a point 9 meters downstream of the last bending magnet, and it is therefore possible to shield these tubes from synchrotron radiation. In general, a wider aperture is required. For this purpose, a structure with a uniform 14.0 cm wide by 2.5 cm high aperture has been developed. At the operating frequency, only the TE_{10} and TE_{20} modes can propagate in this aperature. These modes are excited by slight asymmetries between the top and bottom halves.[1] Filters which are very effective in reflecting both of these modes without restricting the aperture have been developed. Transmissions of -70 db are typical. The narrow bandwidths of the filters has obvious advantages for loading deflection modes. Application of these filters to a cavity structure, one half of which is shown in Fig. 5, have shown some

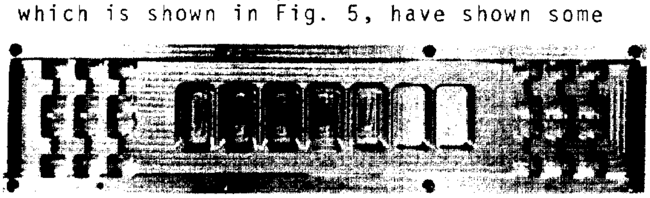


Fig. 5

success but require further development. There is evidence that more space is needed before and after the filter to permit attenuation of higher order cut-off modes.

This problem, the instrumentation of the 60 cm cavity, and the perfection of sheet metal techniques are actively being pursued at the present time.

We believe that our measurements to date demonstrate the basic feasibility of using this type of superconducting cavity in an electron synchrotron. The remaining problems which have been discussed above must be solved in order to demonstrate that the cavity is practical on a large scale.

It should be noted that the advantages of the "muffin-tin" geometry could be applied to cases where field uniformity is important but synchrotron radiation is not a problem by rotating consecutive sections of cavity by 90° about the beam axis.

Acknowledgments

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References

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