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TITLE: DESIGN OF AN ACCELERATING CAVITY FOR THE SUPERCONDUCTING SUPER COLLIDER LOW-ENERGY BOOSTER

AUTHOR(S): C. C. Friedrichs and L. Walling

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Los Alamos National Laboratory
Los Alamos, New Mexico 87545

Design of an Accelerating Cavity for the Superconducting Super Collider Low-Energy Booster

C. C. Friedrichs and L. Walling
Los Alamos National Laboratory

B. M. Campbell
Superconducting Super Collider Laboratory

Abstract

This paper presents the history and current status of the design of the accelerator cavity to be incorporated into the Low-Energy Booster (LEB) of the Superconducting Super Collider (SSC). The LEB is a proton synchrotron, 540 meters in circumference, and having 108 buckets around the ring. Acceleration programs, each 50 msec long, take place at a rate of 10 per second. The beta change of the particles from injection to extraction is from 0.8 to 0.997. Since the rf excitation frequency must track beta, the rf frequency must shift from 47.5 to 60 MHz over the 50-msec acceleration program. The cavity will use ferrite in a perpendicular control bias mode to effect the required tuning.

I. INTRODUCTION

Development of perpendicularly biased, ferrite-tuned cavities for use in proton synchrotrons was ongoing at Los Alamos from 1984 through October 1990, when the project moved to SSC. During the tenure at Los Alamos, two different cavities using perpendicular control bias were designed, fabricated, and tested. The first cavity was designed to achieve a 20% tuning range; after testing was completed at Los Alamos, it was delivered to the Tri Universities Meson Facility (TRIUMF) at Vancouver, B. C., for further evaluation. The second cavity was designed for use in a higher-energy synchrotron, and could be tuned over a 4% frequency range. After completion of the test program at Los Alamos, this cavity was delivered to SSC for incorporation into their ferrite-tuned cavity test stand. High-power operation of these cavities demonstrated that ferrite permeability changes of 1.4 to 3.5 are easily obtainable, and very high magnetic and electric Qs can be realized even under high-power conditions. Both cavity designs were successful, but both demonstrated a strong need for improvement in the ferrite-cooling technique. This paper presents a basic cavity design similar to that of the first Los Alamos cavity, but incorporating a substantially improved ferrite-cooling concept. The cavity and amplifier are tunable over the required range 47.5 to 60 MHz. The circuit Q will be approximately 5000, and the average shunt impedance over the band will be approximately 160 kΩ. The cavity has an overall length is approximately 1.1 meters. It is designed for reliable operation with a gap voltage of 120 kV.

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II. Booster Cavity Design

A. Design Concept

The major design issues for a ferrite-tuned cavity are as follows: How is the cavity excited ? How is the ferrite biased ? How is the ferrite cooled ? The correct answer to all three for a high-reliability design is believed to be "As simply as possible". With that dictum in mind, the present design has evolved. A simplified drawing of the proposed cavity is shown in Fig. 1.

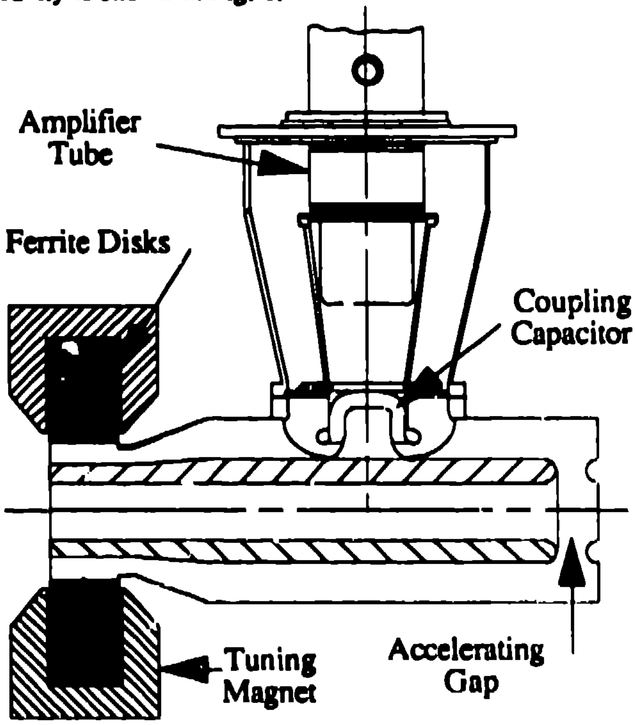

Fig. 1. The Proposed LEB Cavity

The proposed design uses a quarter-wave coaxial resonator with the accelerating gap at the high-voltage end and the ferrite at the high-current end. The excitation amplifier, which uses a 4CW150,000E tetrode, is incorporated directly into the cavity structure, with the cavity serving as its output network. A coupling capacitor is used to match the amplifier to the cavity impedance at the coupling point.

The ferrite tuner is configured such that rf wave propagation in the ferrite-filled region is in the radial rather than the azimuthal direction. This radial-mode tuner permits the design of a simple bias magnet with uniform bias fields throughout the ferrite. This design does give rise to appreciable tuning fields on the beam axis; however, if the cavities are positioned in back-to-back pairs with opposite polarity tuning fields, field variations of up to 15 % between the pairs can be tolerated without upsetting the properties of the beam.

The ferrite is constructed from toroid disks approximately 2.5 cm thick. The disks will be about 14 cm inside radius by 30 cm outside radius and the disk separation will be between 0.3 and 0.5 cm. The separations provide channels for the cooling fluid. These channels are vertical, which allows the cooling fluid to flow in the direction of natural convection .

B. Ferrite Loss Characteristics

If one operates the ferrites in a mode such that the control bias H field is parallel to the rf H field[1] , then the permeability seen by the rf wave is the slope of the B-H curve at the operating point. If, however, one operates the ferrites in a mode such that the control bias H field is perpendicular to the rf H field , then the permeability seen by the rf wave is the ratio of B to H, where both are total values of the control fields. The significance of this is that in the perpendicular bias mode, substantial changes in rf permeability may be effected with the material in total saturation. T rf magnetic loss is related to the area within their hysteresis loops, and this area is essentially zero when the material is in saturation. Magnetic Qs substantially greater than 10^4 have been realized in the test cavities under high-power conditions.

The nickel-doped yttrium-iron-garnet ferrites that have been tested also exhibit very low dielectric loss. The electric Qs of these materials seem to be between 1000 and 5000 in the 50-MHz region.

C. Analysis Methods

It is impossible or at least extremely difficult, to construct a complete model from which all aspects of performance may be predicted. The design engineering goal is of course to create approximate models good enough to provide valid predictions over the realm for which the model was created. The LEB cavity is a fairly complex system, and numerous types of models have been created in an attempt to predict its operational behavior. The performance of the amplifier tube is analyzed by assuming sinusoidal input and output voltages, ignoring transit time, and Fourier-analyzing the current wave forms. The 2D code "Superfish" is valid for examining the cavity structure without its amplifier arm, but its most important contribution is in checking the transmission line model[2]. The transmission line model of the complete rf structure yields excellent predictions of voltages, currents, impedances, resonance, Q, and losses associated with the fundamental frequency, but its usefulness does not extend to higher frequencies. The 2D code "Poisson" accurately predicts the static conditions of the biasing circuit, and it is very useful for the basic design of the tuning magnet; but it does not treat the eddy current problem associated with the actual cycling bias conditions. A good 3D code for this problem has not yet been located. The 3D code "MAFIA"[3] has been used effectively for examining both higher order modes (HOMs) and field asymmetries in the gap induced by the amplifier arm of the cavity.

The ferrite cooling is analyzed using a 3D finite element model of a 45° ferrite segment. Boundary conditions of both free and forced fluid convection were analyzed. The ferrite will fracture at a tensile stress of 39 MPa., and its curie temperature is 200°C. The analysis predicts that tensile stress failure would occur well before the curie temperature was reached. This method of analysis will be used to determine the required velocity of forced convection after remaining tests are completed and a cooling fluid selection has been made.

D. Higher Order Mode Dampers

All rf cavities have an infinite number of HOMs, each of which present to the beam a complex impedance near the mode frequency. These modes interact with the beam, resulting in instabilities that produce either longitudinal or transverse defocussing and beam loss. Two HOM dampers have been proposed for the LEB cavity. Prototypes of each have been built and tested at low power on the second Los Alamos cavity.

One damper[4] consists of an annular 250 MHz cavity located close to and in series with the acceleration gap. The damper cavity is loaded by four shunt resistors, resulting in a Q of about 1.3. The cavity is designed such that it damps the HOMs much more strongly than the fundamental. The test results for this damper on the second Los Alamos cavity indicate that a similar design tailored for the SSC LEB cavity will satisfactorily damp all longitudinal HOMs up to 1 GHz. The normal cavity losses (ferrite and wall losses) at frequencies above 1 GHz are sufficiently high that external mode damping is not required. This damper is simple and is easily adapted to any cavity which has the accelerating gap located on one end. A potential drawback to this damper is that the ratio of first HOM to fundamental mode damping is not inherently large, and excessive fundamental damping may be required in order to quench the first HOM.

The other damper consists of an external transmission line. One end is attached to a capacitive ring enclosing the cavity center conductor near the gap, and the other end is connected to the cavity center conductor near the shorted end of the cavity. The transmission line is shunted by a 50-ohm resistor near the gap. The length of the transmission line is adjusted until the voltage across the resistor is zero. This mode damper works on the assumption that when this condition is met for one mode, namely the accelerating mode, it is not met for HOMs and their power is dissipated in the resistor. This coupler experiences very high circulating currents at the fundamental frequencies, and care must be taken to maintain the structure as a high Q (low loss) circuit. An effective damper of this type with adequate coupling capacitance should result in no more than 10% damping at the tuned frequency; however since the damper is a very high-Q circuit there would be large damping over parts of the 12.5 MHz LEB tuning range. Another problem with this type of coupler is that it can miss modes. Computer modeling predicted and measurements verified this possibility in the tests on the Los

Alamos cavity for a mode at 300 MHz. Preliminary computer modeling does not predict missed modes in the quarter-wave LEB cavity.

E. Cooling Fluids

Several cooling fluids are under consideration for use in the cavity tuner. The first is a Fluorinert TM [1] liquid, FC-77 TM. This liquid has a dielectric constant of 1.86, an electric $Q > 10^4$, a voltage breakdown of 223 kV/cm, and a boiling point of 97° C. It is the cooling fluid of choice pending SSC environmental and safety approval. The second fluid being considered is water. In spite of its high dielectric constant of 78 and $Q < 200$ it is possible to shape the cooling courses such that high fields are never present in the water. This consideration is necessary to keep its own heat dissipation from becoming objectionably high. The third fluid under consideration is air. Its cooling efficiency is much lower than the liquids, consequently very high air velocities would be required. The maximum expected voltage gradients in the air will be about 15 kV/cm, and the inception of corona or even arcing will occur at 25 kV/cm. Air operation would be at 60% of breakdown, while the liquids would both be operated below 10% of breakdown. If the ferrite losses prove to be on the low end of their expected range, forced air cooling could become an attractive choice.

III. Test Tuner

A new ferrite test tuner has been designed and is being fabricated to replace the tuner on the second Los Alamos cavity. This tuner is designed to operate with either water or Fluorinert TM as the cooling fluid. The purpose of the test tuner is to learn as much as possible about the use of both liquids in the presence of high level rf fields. Both the ferrites and the cooling courses in the test tuner will be instrumented with fiber optic temperature probes. Since calorimetric data accuracy with direct liquid cooling will be much greater than in previous tuners, it will be possible to substantially improve the ferrite loss calculations, in particular those calculations which predict the electric Q. The data will also be useful in verifying the finite element thermal calculations. After the tests are completed the metallic tuner parts will be microscopically examined for corrosion from the water.

IV. Conclusion

Since the proposed LEB Cavity is based on a design which incorporates many proven concepts, the probability of achieving a system which operates reliably at the full design voltage seems to be very high. Throughout the design process there has been a conscious attempt to cover the areas of uncertainty with workable contingencies. After the most recent test tuner has been fully evaluated, the LEB cavity design will be finalized, and a full working prototype will be fabricated and tested. The fall back position for this design is that if it doesn't work reliably at full design voltage, it will very probably work reliably at some reduced voltage, and additional cavities would be required to provide 700 kV per turn. There is enough room in the LEB design to accommodate twice the planned number of cavities.

V. Acknowledgments

The LEB Cavity design effort is the culmination of a seven year project, and over these years many people have made substantial contributions. Arch Thiessen, George Spalek, and Rod Smythe are recognized for their assistance, guidance and inspiration. The excellent technicians who all made creative contributions are Mark Doub, Dave Guenther, and Dave Keffeler. George Swain and Bob Kandarian are recognized for their excellent work in producing the design of the second Los Alamos Cavity. Finally Jimmy Rogers and various members of his RF Group are recognized for their assistance, guidance and motivation since the project moved to SSC.

VI. References

1. W.R. Smythe, T.G. Brophy, R.D. Carlini, C.C. Friedrichs, D.L. Grisham, G. Spalek, and L.C. Wilkerson, "RF Cavities with Transversely Biased Ferrite Tuning," *IEEE Trans. Nucl. Sci.* 32 (5), (1985), #2951.

2. C.C. Friedrichs, "Analytic Evaluation of the LAMPF II Booster Cavity Design," *IEEE Trans. Nucl. Sci.* 32 (5), (1985), #2843.

3. M.J. Browman, R.K. Cooper, C.C. Friedrichs, "Testing Urmel-3D by Modeling a Ferrite Tuned RF Cavity," Proceedings of the 1987 IEEE Particle Accelerator Conference, Washington, D.C., (March 1987), pp1898-1900.

4. W.R. Smythe, C.C. Friedrichs, and L.S. Walling, "Proton Synchrotron RF Cavity Mode Damper Tests," 1991 Particle Accelerator Conference, San Francisco, CA (May 1991).

[1] Product of 3M Company.