PROTOTYPE RF CAVITY FOR THE HISTRAP ACCELERATOR

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ABSTRACT

HISTRAP, a proposed synchrotron-cooling-storage ring designed to both accelerate and decelerate very highly charged very heavy ions for atomic physics research, requires an rf accelerating system to provide ±2.5 kV of peak accelerating voltage per turn while tuning through a 13.5:1 frequency range in a fraction of a second. A prototype half-wave, single gap rf cavity with biased ferrite tuning was built and tested over a continuous tuning range of 200 kHz through 2.7 MHz. Initial test results establish the feasibility of using ferrite tuning at the required rf power levels. The resonant system is located entirely outside of the accelerator's 15cm ID beam line vacuum enclosure except for a single rf window which serves as an accelerating gap. Physical separation of the cavity and the beam line permits in situ vacuum baking of the beam line at 300°C.

INTRODUCTION

HISTRAP[1] is a proposed 46.8 m synchrotron-cooler-storage ring optimized for advanced atomic physics research. It is injected with heavy ions from either the HHIRF 25 MV Tandem Accelerator or a dedicated 14.5GHz ECR source via an 0.25 MeV/nucleon RFQ linac. A design program is underway in which prototypes of major HISTRAP components including an rf cavity, a dipole magnet[2], and a beam line section[3] have been fabricated, assembled, and tested.

In the standard high current operating mode, heavy ions from the tandem are injected into HISTRAP with a magnetic rigidity of about 1.0 Tm and with circulation frequencies between 1.0 MHz for $^{12}C^{6+}$ and 0.38 MHz for $^{238}U^{43+}$. These ions are either accelerated to a maximum magnetic rigidity of 2.67 Tm with circulation frequencies between 2.7 MHz and 1.0 MHz, or decelerated to a minimum magnetic rigidity of 0.10 Tm with circulation frequencies between 0.10 MHz and 0.038 MHz. Other beam species are injected with a variety of charge-to-mass ratios and kinetic energies per nucleon. The longitudinal phase-space area of the injected beam depends upon its mass and kinetic energy per nucleon. This is particularly true for post-stripped tandem beams where the stripper foil thickness and resultant induced energy spread depend on the isotope. In fact, most of the rf cavity voltage is needed to provide phase space area for injected beams.

RF REQUIREMENTS

For all ion species of interest, the maximum required accelerating voltage is 2.5 kV peak per turn. A tuning range between 0.2 MHz and 2.7 MHz is adequate using harmonic numbers between one and six. For operation with typical ions in the accelerating mode, the rf tunes over most of the available range within a period of about 0.5 s. The tuning program must track with the dipole magnetic field of the synchrotron, in order to maintain constant beam radius during acceleration.

Given the required accelerating potential, the rf system requirements appear to be quite modest. However, the required frequency swing is very large, and the relatively compact accelerator configuration and large aperture (15 cm) provide little space (1.3 m axially) for an accelerating system. Vacuum requirements for HISTRAP are such that all beam line vacuum components must withstand baking at 300°C. Consequently, rf system components which are not compatible with the baking process must be thermally isolated from the beam lines.

PROTOTYPE CAVITY

The selected rf cavity configuration has a ferrite loaded half wave coaxial resonator with a single accelerating gap as shown in figure 1. The center conductor is concentric with, but completely separate from, the beam line and accelerating gap except for retractable contact rings that establish electrical contact between the cavity and the accelerating gap, figure 2. When vacuum bake-out of the beam line is required, the contact rings are retracted so that the cavity components are thermally isolated from the beam line. Water cooling on the center conductor is provided for removal of both normal rf heating and heat radiated from the beam line during bake-out. A second set of contacts on the ends of the cavity are used to suppress rf resonant modes on the beam line. Characteristics of the cavity are listed in table 1.

The unusually wide tuning range for a single cavity accelerating system, cavity size limitations, and relatively low frequency result in rather stringent requirements for

Table 1

RF CAVITY CHARACTERISTICS

Peak rf voltage	2500 volts
Tuning range	0.2 to 2.7 MHz
Overall length	1.2 meters
Beam tube diameter	0.15 meters
Center conductor OD	0.254 meters
Outer conductor ID	0.648 meters
Ferrite rings	
Material	TDK SY7 (NiZn)
ID	0.3 meters
OD	0.5 meters
Thickness	0.025 meters
Rings per cavity	28
Ferrite cooling	water cooled Cu separators
Peak power density in ferrite	200 mW/cc
Ferrite permeability range	8 to 1400
Peak ferrite bias current	3000 ampere turns
Shunt capacitance required	6000 pF
Total peak cavity rf drive power	20 kW

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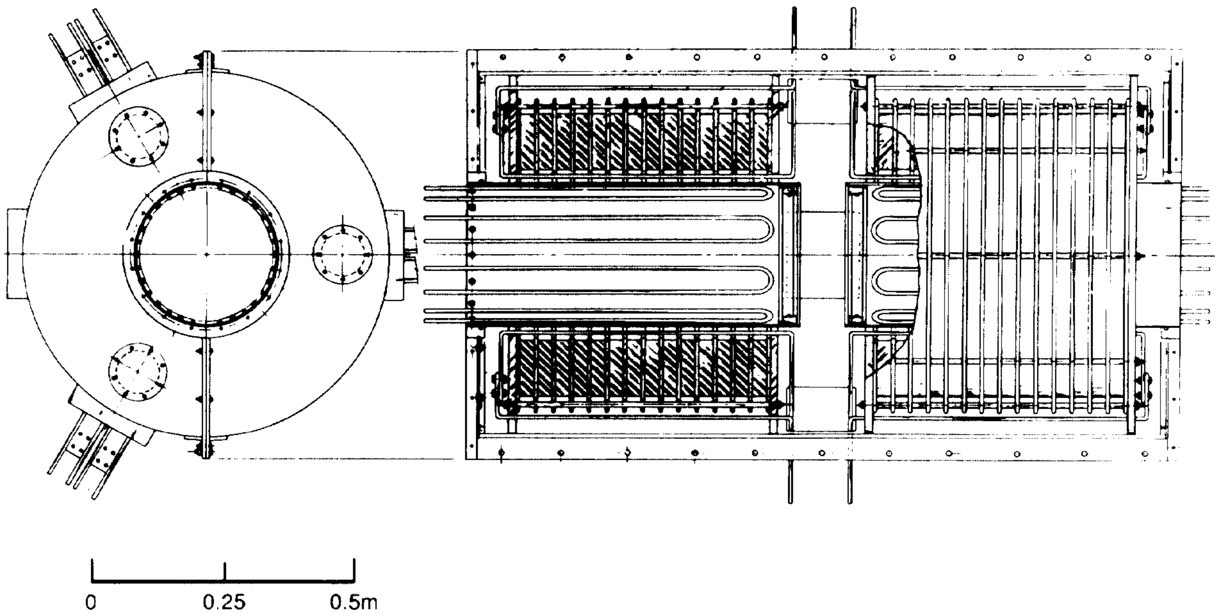

Fig. 1, A cut-a-way longitudinal view and an end view of the HISTRAP rf Cavity.

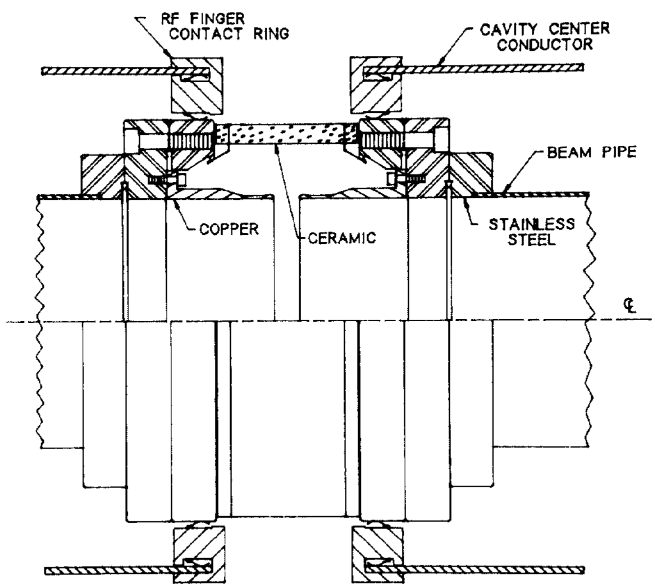

Fig. 2, A sectional view of the accelerating gap showing the gap insulator and the contact rings between the cavity and the beam line.

the ferrite load. Fortunately, the rf voltage requirement is quite low. Nevertheless, SY7 ferrite has a low Curie Temperature, 90°C, and a tendency to become unstable at moderate rf excitation levels. The cavity was designed to hold as much ferrite as possible in order to minimize the rf power dissipation per unit of ferrite volume. The ferrite rings are separated by 6.4 mm thick copper rings which are water cooled by peripherally attached copper water lines. The expected ferrite temperature rise under full rf excitation is about 5°C.

An array of 3 individual "figure 8" bias windings produces up to 3000 ampere turns of bias field in the ferrite in order to swing the permeability from 1400 to 8. Leads from each half winding are extended out of the cavity through the several ports in the cavity's outer conductor. External connections are used for closing each figure 8 and for placing the turns in series or parallel configurations. Space is available for up to 5 turns if more bias excitation is required.

PROTOTYPE TEST RESULTS

A prototype cavity was fabricated, assembled, and tested. The prototype has only 16 ferrite rings at this time which are sufficient to check most required characteristics. Figure 3 shows a photograph of the cavity partially assembled with the 16 rings in place. Ferrite specifications for the rings are listed in table 2. By operating the cavity with only 16 rings, the designed rf field intensity levels in the ferrite are reached with about half of the normal cavity rf voltage. The required rf excitation power level is similarly reduced.

Table 2

FERRITE SPECIFICATIONS

Initial permeability	2500
RF excitation loss at 0.2MHz and 275 gauss of rf field	<0.06 W/cc
RF excitation loss at 2.5MHz and 22 gauss of rf field	<0.06 W/cc

The ferrite rings were tested individually to determine respective permeability, magnetization, and rf loss characteristics. Typical values of initial permeability are between 2000 and 3000, and rf loss characteristics are safely within specification. Measurement of magnetization characteristics was not successful on individual rings due to intrinsic inductances in the test circuit. However, values of permeability calculated from cavity tuning data, shown in figure 4, indicate that 3000 ampere turns of bias is sufficient to drive the permeability down to less than 8.

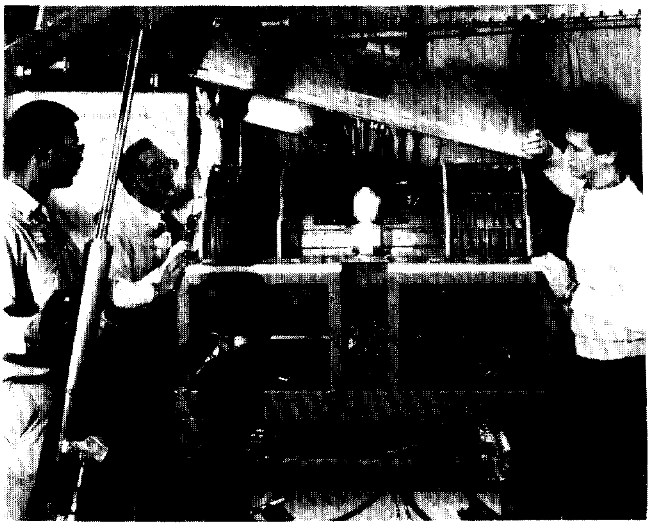

Fig. 3, A photograph of the rf cavity with the top half of the outer conductor raised. The 16 ferrite rings are in place with their cooling plates interspaced. Vacuum capacitors are connected across the accelerating gap.

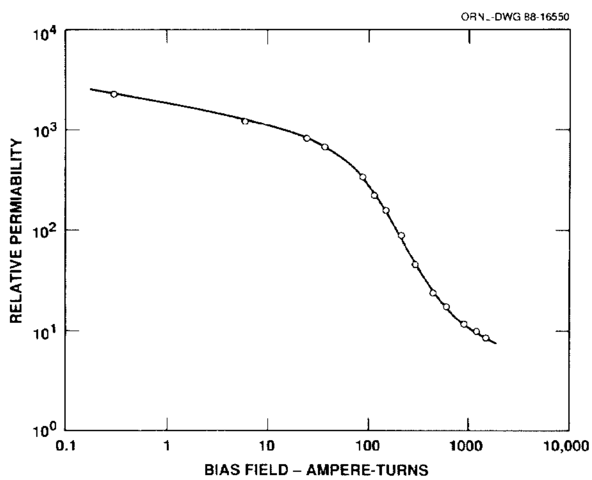

Fig. 4, Relative permeability of the SY7 ferrite rings as a function of toroidal dc excitation.

The cavity has operated with rf excitation levels up to about 400 W. Excitation to full input power requires a driver system which is not available at this time. Data obtained at the 400 W level is shown in figure 5. The shunt resistance of the cavity as seen across the accelerating electrodes is nearly constant throughout the required tuning range at about 80 ohms. Values of Q are directly proportional to frequency and go from less than 1 at the minimum frequency to about 10 at the maximum frequency. The low Q characteristic is especially desirable for loading the planned broadband driver amplifier system. At the low end of the tuning range, it is difficult to determine the actual resonant frequency, but it is possible to drive the cavity at frequencies substantially below resonance. The Q dependence on frequency provides a good compliment for the ferrite magnetization dependence in that Q is lowest in the frequency region where the permeability is the steepest function of bias.

It has been suggested[4] that ferrite instabilities such as the "Q Loss" effect can be avoided by keeping the rf field-frequency product below 15 mT-MHz. For worst case conditions in the HISTRAP cavity, the maximum field- frequency product is about 10 mT-MHz.

RF POWER DRIVE SYSTEM

A 20 kW broadband rf power amplifier is planned for driving the HISTRAP cavity. The amplifier will be mounted close to the cavity to simplify coupling. Impedance matching will be accomplished through the use of an impedance transformer. The rf drive signal is derived from a programmable frequency synthesizer. Bias current for the cavity's ferrite will be obtained from a programmable dc power supply. Analog programing signals for both the synthesizer and the bias power supply will be derived from a field probe in one of the eight dipole magnets.

SUMMARY

Feasibility of operating an rf cavity with the tuning range required by HISTRAP was demonstrated. Characteristics of the cavity were measured. Development of appropriate tuning and drive circuitry is under way. Demonstration of cavity operation at full rf power will be attempted in the near future.

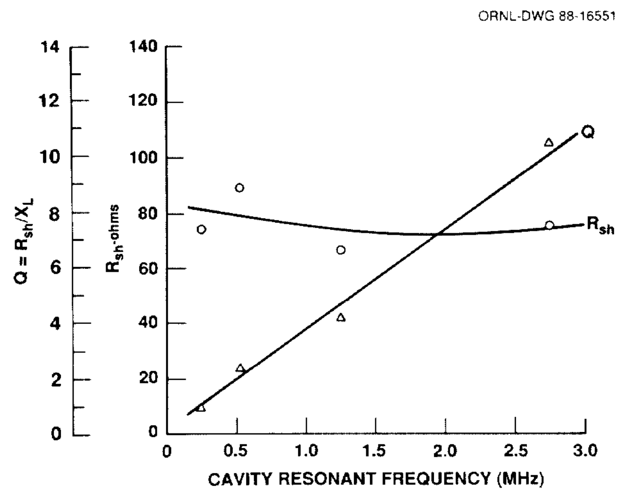

Fig. 5, Cavity "Q" and shunt resistance as a function of frequency.

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