DESIGN OF THE 26.7 MHz RF CAVITY FOR RHIC[*]

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Abstract

The accelerating system for RHIC operates at 26.7 MHz (h=342) and must capture the injected beam, accelerate it to top energy, and shorten the bunches prior to rebucketing into the storage (h=2508) system. These different functions set the design parameters of the cavity. The frequency of 26.7 MHz has been chosen in order to provide large enough buckets to capture the injected beam from the AGS and a large linear region for debunching during a bunch rotation at top energy. Provision of the large linear region also dictates the voltage requirement of 400 kV per cavity. The cavity must be tuned ~90 kHz to compensate for the change in speed of the gold beam.

I. ELECTRICAL DESIGN

A. Constraints

The maximum radius of the cavity must be kept under 450 mm so that the cavities in one ring do not encroach upon the beampipe of the adjacent ring. An effort was also made to try and limit the overall length to about 2 meters for ease of fabrication and plating. The 400 kV gap voltage dictated minimum gap dimensions of 53 mm, extrapolated from test data on an existing proof of principle cavity. An EIMAC 4CW150000 tetrode tube was chosen to drive the cavity. The requirement of a feedback gain of 100 predicated a direct coupling of the amplifier to the cavity to minimize the delay in the feedback loop.

B. Final cavity design

The final cavity design has had the benefit of a high power Proof of Principle cavity[1] originally designed to withstand 200 kV across a 40 mm gap. A successful test program has reached 350 kV with 5ms pulses, and 310 kV for 10 s pulses, limited by the present cooling system. For the final design value of 400 kV in the gap, the accelerating and capacitor gaps were scaled to 53.3 mm, while maintaining the peak to average field ratio at 1.6:1. The resulting final cavity design is a capacitively loaded quarter wavelength coaxial

geometry. The major electrical parameters are given in table I.

R_{shunt}=0.95Ω	Q=15750	R/Q=60.3
Power Diss. @400kV (Cu, Theor) 84.2kW	Beam Power (X6 upgrade) 16 kW	Maximum Power density 5.2W/cm^2
Maximum E-Field 11.9 MV/m	Maximum H-field 8930 A/m	Stored Energy 8 J
First Higher Monopole 103 MHz	First Higher Dipole 200 MHz	Beampipe cutoff TM$_{01}$ 945

Table I Accelerating cavity electrical parameters

With relatively mild beam loading, and the decision to use a tetrode with a 50% power margin, the cavity geometry was determined largely by thermo-mechanical considerations. The inner conductor has a radius of 134.9 mm, which provides adequate stiffness for it's length of 1894.8mm. This also provides sufficient gap capacitance for the design of the mechanical tuner which has a sensitivity of 14 kHz/mm at it's null position. The maximum electric field of 11.9 MV/m is on the 40 mm radius of the tip. With the outer radius of the tank fixed by the beamline separation of the collider the last free parameter is the capacitive loading and inner conductor length. A coaxial capacitive loading was used to keep the inner conductor simple. The outer conductor of the capacitor was incorporated with the vacuum tank, allowing cooling channels to be welded to the exterior wall. The amount of loading was influenced by keeping the peak power density at the root of the inner conductor, which increases with increasing capacitance, to ~5W/cm^2. This very conservative value allowed the use of an all steel construction. Rough tuning is to be accomplished by designing the cavity low in frequency, and taking successive machining cuts on the inner diameter of the capacitor assembly to reach the design frequency, taking into account the .005 mm of copper plating to be deposited on both inner and outer capacitor surfaces.

C: Tuner design

The cavity requires a ~90 kHz dynamic tuning range to compensate for the increase in ion speed during acceleration,

from 26.65 to 26.74 MHz. The detuning for beam loading compensation falls within this range. Maximum tuning rate is 18 kHz/s to keep up with the superconducting magnet ramp, and a tuning bandwidth of >15 Hz is required to meet the maximum allowable phase error at the start of the ramp.

Both ferrite and mechanical tuning options were investigated in detail. The mechanical tuner was chosen by virtue of its significantly lower cost, while still meeting the requirements. The mechanical tuner uses a DC servo to drive the gap electrode and vary the gap capacitance. A prototype tuner is described in detail in these proceedings[2].

C: HOM Analysis and passive damper design

The cavity was designed to incorporate broadband HOM supressors to de-Q the HOM's which may lead to coupled bunch instabilities. The higher order modes were calculated with the 2½-D code URMEL[3] and later expanded to include the amplifier and HOM suppressors which broke the azimuthal symmetry using the 3-D MAFIA code. The resulting HOM impedances and resonant frequencies were incorporated into coupled bunch growth rate calculations using the expression[4]

$$\tau^{-1} = \frac{\omega_\phi}{r_\phi} \frac{I_0 R}{V_T \cos\phi_T} F_m$$

where ω_ϕ is the angular synchrotron frequency, r_ϕ is the bunch half length in radians, I_0 is the beam current, R is the shunt impedance and V_T is the total rf voltage. F_m is a form factor[5] which is a function of bunch length and frequency and is between 0.6 and zero for RHIC parameters. The impedance limits for the HOM's were obtained by setting the growth rate to 2^{-1}, a factor of 5 below the damping rate of the injection error damper, and solving the above equation for the shunt impedance R. The impedance limits for the dipole (dashed) and quadrupole (dotted) instabilities are shown in figure 1, with the undamped higher order monopole modes superimposed.

A loop coupled HOM suppressor reduces these impedances below the imposed limit. It is placed at the shorted wall to get the most coupling with a minimum of self inductance, which limits the high frequency performance. An optimized loop which entered the shorting flange and terminated on the inner conductor was abandoned despite superior performance because of the increased mechanical complexity. The loop is coupled through a folded, coaxial quarter wave notch filter to reject the fundamental and is terminated in a 50 Ω load. An alternate filter approach using a fifth order high pass has been designed and will be prototyped prior to the final design. It has the advantage of a lower fundamental power dissipation (40W versus 1000W for the notch) but presents a low impedance circuit to the coupling loop as opposed to the high shunt resistance for the notch filter. The circulating current in the HOM coupling loop
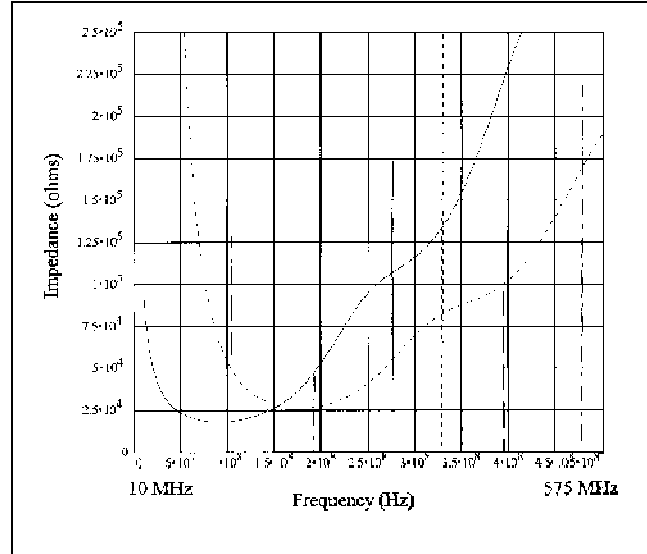

Figure 1 Impedance limits with undamped HOM's superimposed

reaches in this case the value of 85 A rms (less than 0.2 A for the notch), and the current density in the finger stock contacts between the HOM loop and the vacuum feedthrough will be as high as 15 A/cm. The final choice will be made after a high power test program on the existing prototype cavity.

D: Drive loop and window design

Both inductive (loop) and capacitive coupling were investigated, and implemented on the prototype cavity. Loop coupling was chosen for the final design primarily for the ease of introducing a variable coupling, which is advantageous for a combined function system whose maximum voltage and power is likely to be changed in different operating scenarios, as well as being mechanically simpler and easier to cool. A prototype loop has been operating with flat rexolite window for the past year. After analysis of both flat and cylindrical alumina window designs a cylindrical window of 120 mm diameter and 70 mm height has been selected. The power dissipation in the cylindrical window is an order of magnitude less and can be designed to be very uniform, whereas the power density in the flat window varied by a factor of four from the inner diameter of the side closest the cavity short to the outer diameter on the side facing the gap. The cylindrical window can be made thinner while still withstanding the vacuum loading, and can be shielded from the direct cavity environment and so be less likely to be effected by multipacting and contamination.

II. MECHANICAL DESIGN

Although the cavity must provide 400kV and dissipate 85 kW, with 55 kW in the inner conductor alone, a very simple mechanical design allows an all carbon steel
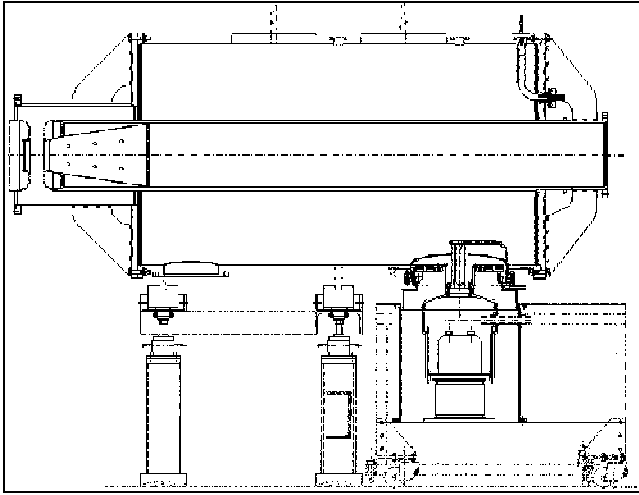

Figure 2 Accelerating cavity with power amplifier, drive loop and HOM coupling loop

construction which is subsequently copper plated. The cavity is composed of three main assemblies, an inner conductor/shorting flange assembly, tank assembly and capacitive spool assembly. The cavity with power amplifier, drive loop and HOM coupling loop is shown in figure 2.

The inner conductor assembly is fabricated from standard steel tubes. The inner part is machined to size and 16 cooling channels are machined into the surface. The outer steel shell is expanded with heating tape and heat shrunk over the inner piece. The two are mig welded together and the part leak checked. After the step which seats the shorting flange is machined into the inner conductor it is installed into the flange and the assembly welded. After all welding of the inner conductor/ end flange assembly the final machining is performed. All distortions caused by the welding are removed in this process, and perpendicularity between the inner conductor and flange assured. The maximum distance from the rf heating to a water channel is 5 mm. This results in a maximum temperature rise of 15 ˚C. with a local variation over the surface of 5 ˚C.

The capacitive spool piece is a cylinder made from rolled plate, mated to a flange made from steel plate. Additional stiffness is provided by welding gussets between the flange and the cylinder. Cooling channels are machined into the end flange with cover plates welded over them, while the cylinder has steel channels welded to the exterior for cooling.

The tank is again a cylinder made from rolled plate mated to flanges of plate steel. All cooling channels are welded to the outside skin of the tank. The rf power coupling port and vacuum port are located on the bottom of the tank. A separate water cooling channel encircles the power coupling

port. The vacuum grill is a separate plate sandwiched between the flange on the tank and the vacuum pump. It is a 6.5 mm copper plate with slots machined parallel to the current flow in the tank. Cooling is provided by brazing a cooling tube to its circumference.

All metal seals are used throughout, shielded by beryllium-copper rf spring seals in the high current regions.

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