

THE RHIC ACCELERATING CAVITY PROTOTYPE TUNER*

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I. ABSTRACT

The RHIC Accelerating System runs at 26.7 MHz and is required to have an operating range of 85 kHz during the acceleration cycle. Since it also must provide sufficient range to cover manufacturing errors and temperature variation, a requirement of 300 kHz has been specified. A mechanical approach acting on the cavity accelerating gap has been chosen for financial reasons over a ferrite approach. A prototype has been constructed and fully tested on the existing test cavity, using the tuning loop feedback circuitry developed for this task. Results from both the loop response and the power tests of the prototype indicate that this design will successfully meet the performance requirements for the RHIC Accelerating Cavity.

II. INTRODUCTION

The RHIC Accelerating system is responsible for several tasks during the cycle: injection, acceleration, transition crossing and rebucketing, when the beam is handed off to the Storage system, that operates at 196.1 Mhz. At present, a Proof of Principle (PoP) quarterwave cavity with a capacitive load has been built [1] and has provided very useful information. The final Accelerating cavity [2] has been derived from these tests, and is now under construction. Among the tests performed on the PoP cavity are all the tuner measurements that are presented here, both at low level and at high power.

III. TUNING SYSTEM SPECIFICATIONS

The 26 MHz acceleration system needs to tune its frequency to accommodate changes in the beam revolution period during acceleration, and to compensate for beam loading. However the beam loading detune is rather small and has negligible impact on the tuner design; the bulk of the tuning goes into synchronizing with the beam acceleration.

The detuning required for beam loading compensation can be expressed as follows:

$$\Delta f_{rf} = \pm \frac{I_0 \times \cos(\phi_s)}{V_{rf}} \times \frac{R}{Q} \times f_{rf}$$

where ϕ_s is the synchronous angle, I_0 is the average beam current, $R/Q = 60$ is a cavity parameter, and the sign of the shift is positive below transition and negative above. Since the relative low beam intensity and high rf voltage, this frequency change is always less than 1 kHz for RHIC parameters.

The rf frequency, is given by:

$$f_{rf} = \frac{hc}{C} \times \sqrt{1 - \frac{1}{\gamma^2}}$$

where c is the speed of light, C is the RHIC circumference, and $h = 342$ is the chosen harmonic number. At the limit of the speed of light the rf frequency is 26.743 MHz. RHIC will accelerate Gold ions from $\gamma = 12.6$ to $\gamma = 108.4$ and protons from $\gamma = 31.2$ to $\gamma = 268.4$. Since Gold ions are slowest at injection, the lowest rf frequency of operation will be 26.658 MHz. The total frequency range required on this basis is then 85 kHz.

The fastest rate of change of the rf frequency is about 18 kHz per second, for gold ions at the beginning of the acceleration ramp. This sets the specification for the response speed of the tuner.

The tuning loop bandwidth can be specified by assuming an allowable detuning of 0.15 degrees during the magnet ramp, which corresponds to 15 degrees after a 40 dB rf feedback is taken into account. The angular velocity, determined from the maximum frequency sweep rate of 18 kHz/s and the cavity Q , was found to be 1092 r/s in rf cycles. A PSPICE model was then used to determine the loop bandwidth requirement to be > 15 Hz.

IV. THE MECHANICAL CONSTRUCTION OF THE PROTOTYPE TUNER

The mechanical tuner will act directly at the gap, by changing the position of the low voltage electrode. This has many advantages, since it affects the only region of the cavity that will be at both relatively low voltage and current. This makes the construction and cooling of the structure very easy. Another important feature of this structure is the use of only

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one small welded bellow which is simple to assemble and very reliable.

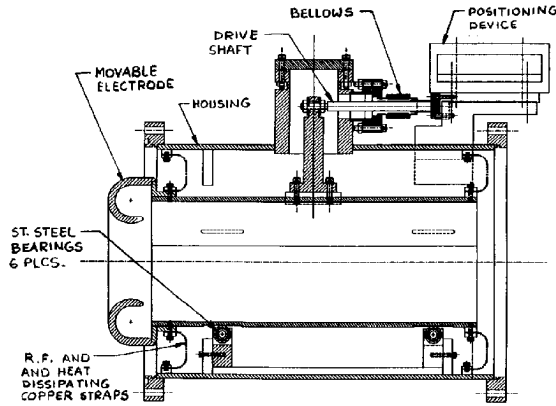


Fig. 1 Prototype mechanical Tuner Assembly

The tuner is made out of an aluminum tank, containing three sets of stainless steel bearings that support an inner cylinder, also made out of aluminum. At one end of this cylinder is mounted a copper tip that is at the low voltage side of the accelerating gap. Grounding copper straps are connected between the gap tip and the outer tank, in order to provide both a good rf ground return and to properly propagate the heat dissipated on this side of the gap. Calculations based upon the code Superfish [1] show that the dissipation at full gap voltage is in the order of 25 Watts which is efficiently carried out by the copper straps. A simplified diagram of the mechanical tuner assembly is shown in Fig. 2.

V. THE FEEDBACK LOOPS AROUND THE TUNER

A linear position stage, driven by a DC motor, moves the mechanical tuner. Two feedback loops are closed around the system (Fig. 2):

- one inner loop around the DC servo system
- one outer loop around the cavity itself

The DC servo system has been chosen to meet the following requirements [2]:

- tuning sensitivity: 11.7 μm
- maximum tuning rate: 18 kHz/s
- time to reach maximum tuning rate: 0.001s
- loop unity gain frequency: > 15 Hz

The inner loop is composed of a digital PID, incorporated in the servo controller; where only the gain part of this is used.

It is a position loop, the input of which being the motor position (encoder signal).

The outer loop filter is composed of a phase advance network, in order to compensate the phase lost due to the mechanical delay. The loop input is the relative phase between the final power amplifier and the cavity voltage, phase which depends on the frequency $\Delta\omega$ by which the cavity is detuned. Its output is used as a input command for the digital PID. A schematic of the studied system is given on Fig. 2.

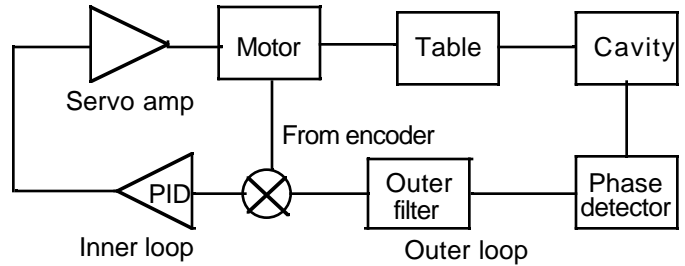


Fig. 2 Schematic of the tuning loops

VI. LOW LEVEL MEASUREMENTS

The system described above was tested at small gap voltages to measure the characteristic response of the system. The open loop measurements show a 35° phase margin and a 8 dB amplitude margin. The 0 dB frequency is 22 Hz. The implementation of the system has shown a 40 Hz mechanical resonance. To avoid exciting it through the tuning loop, a notch filter has been added. Fig. 3 shows the loop measurement result.

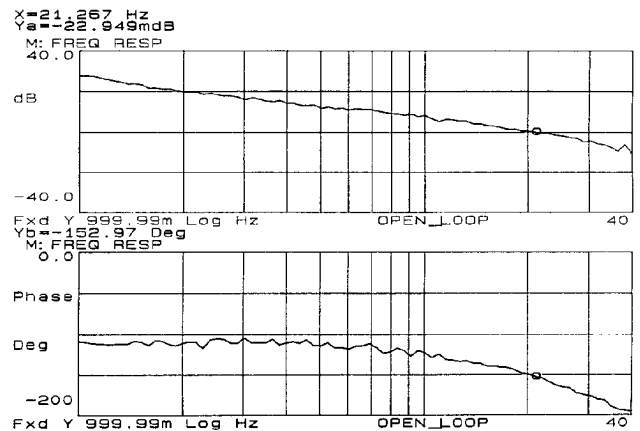


Fig. 3 Measured Open Loop Frequency Response of the Tuning Servo

Static measurements of the cavity resonance have also been done. The tuner changed the natural resonance of the PoP cavity by 273 kHz with its full 2.54 cm travel [2]. This is in excellent agreement with the predictions made with the

Superfish codes. Since the final Accelerating cavity will have a larger gap capacitance, and therefore a more sensitive tuner, this result is very encouraging.

VII. POWER MEASUREMENTS

The PoP system was also run under high power to evaluate the tuner's cooling and high voltage performances. The test cavity was operated at gap voltages around 200 kV in CW for extended periods of time to allow for a full test. Thermocouples installed in a few places inside the tuner were used to monitor the temperature distribution. Preliminary results from testing the cavity with about 30 kW total were consistent with computer modeling [3] and seem to indicate that the cooling of the tuner is adequate. Still, these tests are underway and will be continued until full power is reached.

VIII. CONCLUSIONS

The prototype tuner for the RHIC Accelerating cavity was built and tested both at low and high power. The necessary tuning loops were also developed and used in the setup.

A tuning bandwidth better than 20 Hz was achieved, with a DC gain greater than 20 dB. This meets the requirements for beam dynamics, considering that the Accelerating system will benefit from a 40 dB rf feedback loop.

High power tests indicated that the cooling of the gap electrode has so far been adequate. A stress test of the system,

cycling the tuner many times is planned to insure durability of the device.

To improve the loop performance, a feedforward system which would drive the system according to the frequency ramp could be used. In parallel, the feedback system would remain to correct the static error.

IX. ACKNOWLEDGMENTS

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X. REFERENCES

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