FAST-FERRITE TUNER OPERATION ON A 352-MHZ SINGLE-CELL RF CAVITY AT THE ADVANCED PHOTON SOURCE*

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Abstract

A 352-MHz fast-ferrite tuner, manufactured by Advanced Ferrite Technology, was tested on a single-cell rf cavity at the Advanced Photon Source. Low-power rf testing was performed on the tuner-cavity combination to evaluate tuning range, bandwidth, stability, and compatibility with existing Advanced Photon Source low-level rf hardware. The test system comprises a single-cell copper rf cavity, a bipolar DC bias supply for the ferrite tuner, a water flow and temperature metering and interlock system, and a low-level rf cavity tuning loop consisting of an rf phase detector and a PID amplifier. Test data will be presented.

INTRODUCTION

A 350-MHz fast-ferrite tuner, manufactured by Advanced Ferrite Technology, was purchased by the Advanced Photon Source (APS) RF Group in 1996 for evaluation as an rf cavity tuning device. Several potential applications for this tuner were considered, based on the fast tuning speed that such a device could deliver. Two of the main applications involved using the fast tuner in conjunction with a standard motor-driven piston tuner, thereby gaining the following advantages: [1] eliminating unnecessary rapid motion of the mechanical tuner, reducing the wear on mechanical tuner components and improving their operational lifetime, and [2] providing compensation for fast beam-loading effects. Operational experience with the APS rf systems has shown that both advantages factor more in the operation of the 7-GeV booster synchrotron 5-cell cavities than in the case of the storage ring single-cell cavities. Software controls were implemented in the mechanical tuner drive systems to eliminate unnecessary motion over the synchrotron ramp, but severe beam loading at injection is still a performance issue with the APS booster synchrotron. Improving control of cavity phase during the injection period would enhance capture and injection efficiency [1]. A fast-ferrite tuning device could be used in conjunction with the existing mechanical piston tuners to glean both advantages.

The ferrite tuner internal design consists of a ferrite-loaded, short-circuited coaxial transmission line, where the electrical length of the tuner is controlled by the amount of magnetic bias field impressed on the ferrite material. This bias field is generated by a combination of permanent and electromagnetic sources, with the electromagnetic bias coils consisting of parallel AC and DC paths. The tuner has a power handling capability of 150 kilowatts, and full tuning range can be achieved by varying bias current over a range of ±100 amperes.

LOW-POWER RF TEST CONFIGURATION

The ferrite tuner test setup is shown in Figures 1 and 2. A 352-MHz, single-cell, copper cavity, identical to cavities used in the APS storage ring, was fitted with a conventional mechanical piston tuner (manually adjusted for coarse tuning adjustments) and two one-turn coupling loops. One loop is used to couple incident power to the cavity and is adjusted for best match into 50 Ω (Zo). The other loop couples the ferrite tuner to the cavity and is adjusted to be perpendicular to the cavity fundamental mode magnetic field to achieve maximum coupling. Both coupling loops are identical to those used in the APS storage ring, designed to form immediate transitions to a WR2300-half-height waveguide. Waveguide-to-N-type coaxial transitions are used on both cavity coupling loop waveguide flanges to allow a coaxial connection to incident power and the ferrite tuner. For high-power rf applications, the rf connection to the ferrite tuner is made utilizing 6-1/8″ coaxial line (see Fig. 1). However, to facilitate low-power rf testing, the opposite end of the directional coupler was fitted with a 6-1/8″-to-N-type transition to allow for a manual coaxial phase shifter to be installed between the tuner and the cavity (see Fig. 2).

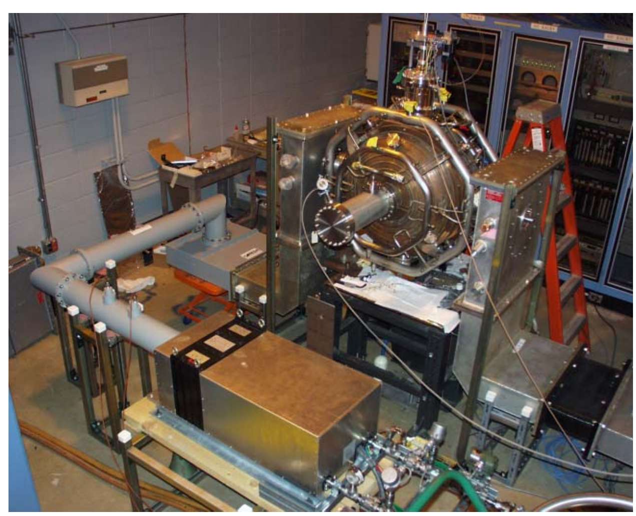

Figure 1: Photo of test setup.

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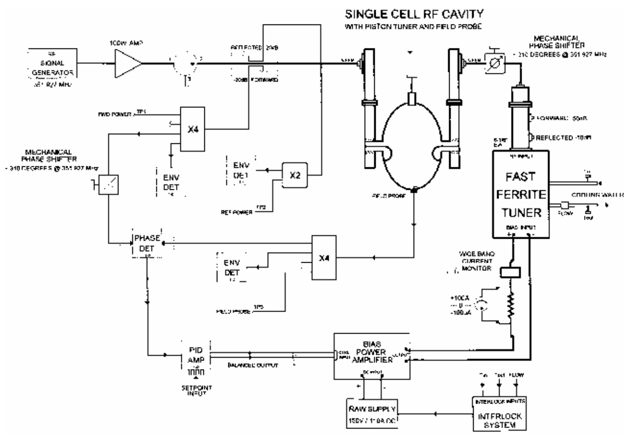

Figure 2: Schematic of test setup.

The test setup low-level rf system utilizes standard VXI-based rf components, identical to those used in the APS 350-MHz rf systems. An analog rf phase detector and PID amplifier are used to form a tuning loop across the cavity to maintain a constant phase relationship between the cavity forward power and field probe output. The output of the PID amplifier is used as the input control signal for the ferrite tuner bias supply. A 100-W, 350-MHz rf amplifier is used to develop sufficient input power for the cavity. The ferrite tuner bias current is generated using a model 232P power amplifier manufactured by Copley Controls Corporation, which can deliver ±120 amperes continuous output current and has a 3-dB bandwidth in current mode of 5 kHz. The power amplifier is supplied raw DC power from a regulated DC power supply capable of 100 amperes @ 150 volts DC. An rf and DC interlock system, necessary for high-power rf operation, is used to protect the tuner against rf arcing, insufficient cooling water flow, insufficient cooling air flow, and excessive return water temperature.

TEST RESULTS

The first test involved using a control system analyzer to measure the ferrite tuner relative rf phase shift while modulating the tuner bias current with a frequency-swept sinusoid stimulus signal, without the tuner being connected to the cavity. For this test, a 100-W, 350-MHz power amplifier was used to drive the tuner rf input at approximately 50 watts. The relative amount of rf phase shift generated by the tuner was detected using a resistive splitter to combine the forward and reflected signals from a directional coupler in-line with the tuner input, then peak-detecting the output of the splitter. The ferrite tuner bias supply was operated with a raw DC input of 90 volts, and the bias current was sine-modulated by the control system analyzer from 100 Hz to 10 kHz for the swept-frequency measurement. The sinusoidal stimulus signal amplitude for the test was 1.75 volts peak, an amplitude which produced ±50 A peak of tuner current when applied to the bias supply input under DC conditions, ±1.75 V. The results of this test are shown in Fig. 3. The upper trace (channel 1 input) is the tuner bias current, and the lower trace (channel 2 input) is the resulting rf phase shift generated by the tuner. These tests indicate that the tuner phase shift frequency response is being limited to some degree by the slew rate of the bias supply, as the inductance of the tuner bias windings is approximately 400 µH @ 1 kHz. The same measurement sweeping from 10 Hz to 100 Hz was flat to within 1 dB on both traces.

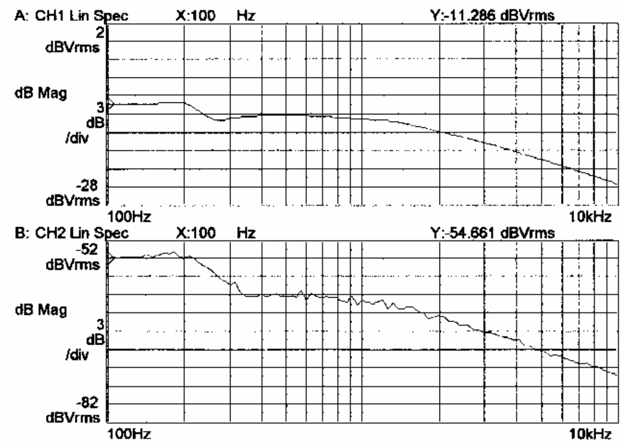

Figure 3: Phase shift and current response plots. The upper trace is tuner bias current, and the lower trace is relative rf phase shift.

Tuning tests with the single-cell cavity were conducted after determining the optimum electrical length between the ferrite tuner and the cavity, which resulted in a cavity tuning range of approximately 25 kHz. This range was necessary to allow the ferrite tuner to operate alone in maintaining cavity resonance during the low-power tests. A manual phase shifter with approximately 310 degrees of range at 351 MHz was used in this adjustment, and the system was set for best compromise between overall tuning range and effect on the cavity input coupler match. This resulted in a variation of loaded cavity Q from approximately 16,000 to 18,000 at tuner bias currents of +100A and –100A respectively, apparently caused by cable losses in the manual phase shifter assembly. The PID amplifier was adjusted for a proportional gain of 4, with integral and derivative values both set at minimum. The tuner bias raw DC power supply was 100 volts DC. This arrangement was maintained for all further low-power rf tests.

Figure 4 shows the result of a closed-loop frequency-response test of the cavity tuning loop configuration using the ferrite tuner to shift the cavity phase. A frequency-swept sinusoid loop stimulus signal of 1 volt peak was used, an amplitude which produced ±30A of tuner current when applied to the bias supply input under DC conditions, ±1 volt. The sinusoid stimulus signal was mixed with the tuning loop PID amplifier output using an isolation amplifier, and was also applied to the channel 1 input of the control system analyzer as the measurement reference. Figure 5 indicates the tuner response to a step-change in the cavity tuning loop setpoint. The scope traces shown are tuning loop signals, from top to bottom, setpoint voltage (trace #1), phase detector output (trace #2), PID amplifier output (trace #3), and ferrite tuner current (trace #4, 100 A/div). The horizontal time base is 2 ms/division. It can be seen that the cavity reached a tuned condition at the new setpoint value in approximately 6 ms, with the tuner current changing from approximately –85 A to +10 A. The PID amplifier output momentarily clipped at the positive rail during this period due to the slew-rate limitations of the bias power supply.

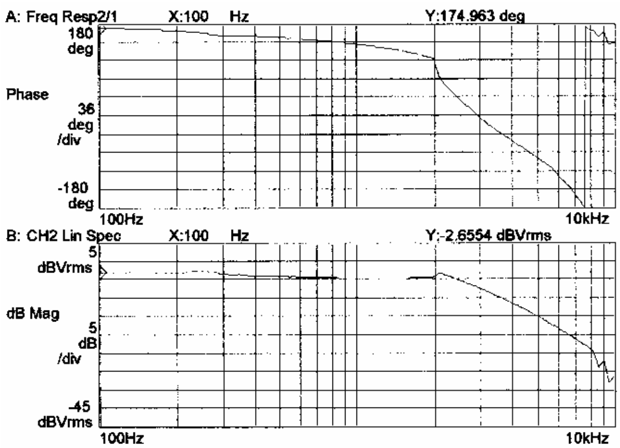

Figure 4: Cavity tuning closed-loop frequency response.

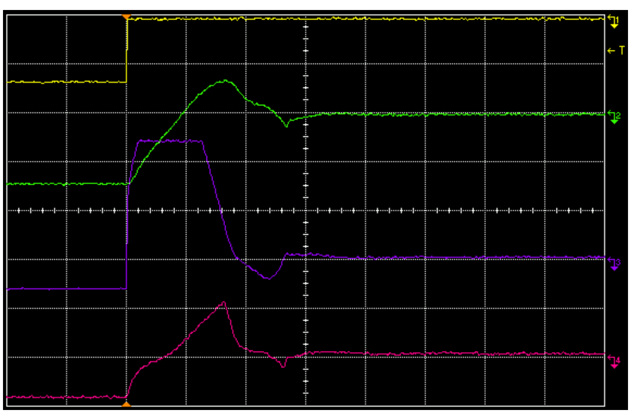

Figure 5: Scope trace of loop setpoint step-change response. Top to bottom, the traces are tuning loop setpoint voltage (#1), loop rf phase detector output (#2), loop PID amplifier output (#3, 5 V/div), and tuner bias current (#4, 100A/div). The horizontal time base is 2 ms/div.

CONCLUSION

The fast-ferrite tuner proved to be effective in tuning a 350-MHz, single-cell rf cavity. It provided much-improved tuning speed over the standard mechanical tuner and was easy to implement in a tuning loop made up of existing APS low-level and high-level rf hardware. The tuner demonstrated the bandwidth necessary to be effective in reducing mechanical tuner motion and tracking relatively fast beam loading phase effects in the booster synchrotron. However, for best results in a practical application, the ferrite tuner should be used in conjunction with a standard mechanical piston tuner to maintain cavity resonance under all operating conditions. In such an arrangement, the mechanical tuner would be used to compensate for slow cavity effects, such as beam loading and temperature changes, while the ferrite tuner could compensate for faster phase distortions. In this way, the ferrite tuner coupling to the cavity could be optimized for a more narrow tuning range. Measurements also indicate that using 6-1/8″ rigid coax to connect the tuner to the cavity resulted in less degradation of cavity Q, with loaded Q values of 22,063 and 22,263 at tuner bias currents of +100A and –100A, respectively.

Optimizing transmission line length between the ferrite tuner and the cavity for this compromise could be made more practical by the addition of a mechanical phase shifter capable of full-power operation. Such a configuration is being considered for future high-power rf tests on this tuner, as space restrictions inside the APS rf test stand bunker severely restrict adjustments in transmission line length.

FUTURE PLANS

Further low-power rf tests are planned to study the effects of optimum transmission line length between the ferrite tuner and the test cavity. The ferrite tuner assembly will then be installed on a 350-MHz, single-cell test cavity in the APS rf test stand, where it will be tested at power levels up to 150 kW CW. Possible further high-power rf tests of the ferrite tuner on a 350-MHz, 5-cell cavity is being considered for booster synchrotron applications. This work is tentatively scheduled for the summer of 2003.

ACKNOWLEDGEMENTS

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REFERENCES

[1] N. Sereno, "Advanced Photon Source Booster Synchrotron RF Capture Design," these proceedings.