*RF Cavities for the Positron Accumulator Ring (PAR) of the Advanced Photon Source (APS)**

Y. W. Kang, A. Nassiri, J. F. Bridges, T. L. Smith, and J. J. Song
Advanced Photon Source, Argonne National Laboratory
9700 South Cass Avenue, Argonne, Illinois 60439 USA

Abstract

The cavities for the dual frequency system of the APS PAR [1] are described. The system uses two frequencies: a 9.78MHz fundamental system for the particle accumulation and a 117.3MHz twelfth harmonic system for the bunch compression. The cavities have been built, installed, tested, and used for storing the beam in the PAR for about a year. The fundamental cavity is a reentrant coaxial type with a capacitive loading plunger and has 1.6m length. The harmonic cavity is a symmetrical reentrant coaxial type and is 0.8m long. Ferrite tuners are used for frequency tuning. During the accumulation period, the ferrite tuner of the harmonic cavity works as a damper to disable the cavity. During an injection cycle the 9.78MHz system accumulates 24 positron bunches in a bucket and the 117.3MHz system compresses the bunch into a shorter bunch. Measurements were made on the rf properties of the cavities.

I. INTRODUCTION

Previously, the two cavities in the PAR of the APS were designed by computer simulation using URMEL codes [2][3]. The 9.78MHz first harmonic cavity employed a capacitive loading plunger for compactness and the 117.3MHz twelfth harmonic cavity employed a reentrant coaxial structure. The PAR of the APS has been operational for about a year and the rf cavities performed as expected to store the beam. The accumulation and compression functions at both frequencies have been performing adequately. Both the fundamental and the harmonic cavities use ferrite tuners for tuning the resonance frequencies. The fundamental system operates in continuous wave (CW) mode with a continuously varying tuner control current. The harmonic system operates with a pulsed rf and tuner control current at about 20% duty cycle. For fast tuning while pulsing the harmonic cavity tuner, the tuner coupling loop has bypass capacitors in the current path. This prevents limiting the tuner frequency response and unnecessary heating of the tuner housing.

Solid-state MOSFET rf amplifiers have been used to power the cavities. In the 9.78MHz system, rf power from four 1kW solid state amplifiers is combined inside the cavity with four couplers; each amplifier feeds a loop coupler. The couplers are mounted in the cavity outer cylinder and separated by 90 degrees circumferentially. In the harmonic system, the outputs of the four 500W solid-state amplifiers are combined through a 2kW 4-way splitter/combiner to use a single cavity input coupler.

* Work supported by the U. S. Department of Energy, Office of Basic Energy Sciences, under Contract No. W-31-109-ENG-38

Each cavity uses a ceramic window at the accelerating gap to save the vacuum pumping; only the inside of the beam pipe is evacuated and the outside of the beam pipe is filled with air. The ceramic windows are identical for both cavities; they have 6" diameter and are directly attached to the circular beam pipe.

Next, experience with the measurement and operation of the cavities will be discussed, and the tuner characteristic in each cavity will be shown. The higher-order mode characteristics of the cavities have been measured: measurements of the higher-order modes of the cavities with the beam-induced frequency spectrums will be shown.

II. 9.78MHZ FUNDAMENTAL FREQUENCY CAVITY

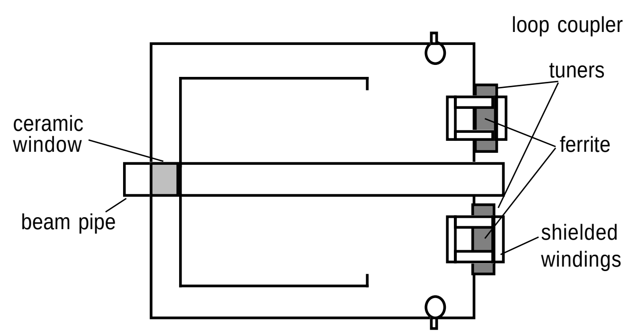

Figure 1: Fundamental frequency cavity construction

The first harmonic cavity was designed with a compact size in mind. A ceramic window is used at the accelerating gap in the beam pipe. Four input loop couplers are used on the outer cylinder and four tuners are used on the end wall. Figure 1 shows the plunger-loaded cavity with the input couplers and the ferrite tuners. A small loop type field probe is used to monitor the amplitude and the phase of the cavity field signal. The outside shell is made of aluminum and the inner conductor is made of copper. The inner conductor is a water-cooled copper cylinder surrounding the stainless steel beam pipe of the ring. Along the end rim of the inner plunger cylinder, a 1” diameter cylindrical corona ring is attached to reduce the chance of arcing inside the cavity. The maximum gap voltage required by the system is 40kV.

Tuner

The fundamental frequency cavity operates in CW mode. The cavity has four ferrite tuners which can tune the cavity resonant frequency up to ±10kHz. Each tuner has six ferrite toroids in a copper housing and a coupling loop. The fundamental cavity employs four tuners separated by 90 degrees in a circular wall of the cavity. The ferrite material used in the tuner has fairly low loss at the operating frequency range so that the damping due to the tuner is almost negligible. Table 1 shows the specifications of the ferrite material used in the tuners.

Table 1: Ferrite toroid specifications

Material	Toshiba M4C21A
Outer Diameter	8.0”
Inner Diameter	5.0”
Thickness	1.0”
Resistivity	3~10x109 Ω-cm
Relative Permittivity	13.0 @40MHz
Electric Loss Tangent	0.00030 @40MHz
Initial Permeability	40 ~ 47
Magnetic Loss Tangent	0.008 ~ 0.009
Curie Temperature	340°C

The rf coupling is made with a single-turn rectangular hollow copper loop which has control windings inside. Forty turns of #12 high-temperature wire were used and the current was limited to 25A for safe operation of the tuners without damaging the insulation. The frequency drift of the cavity due to the rf heating is about 15°F and can be covered by the tuning range of the tuners.

III. 117.3MHZ HARMONIC FREQUENCY CAVITY

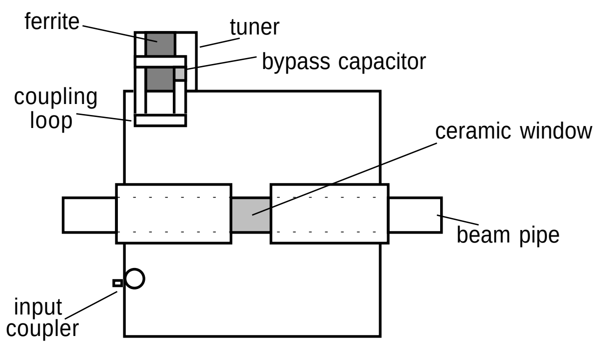

Figure 2: Harmonic cavity construction

Figure 2 shows the 117.3MHz harmonic frequency cavity. The cavity was built using stainless steel for the outer shell and aluminum for the center conductors. Like the fundamental cavity, the accelerating gap has a cylindrical ceramic window. Since the harmonic system operates in pulsed mode, the multipactor on the ceramic at a certain rf power level caused the nonlinear rf reflection at the input coupler and difficulty in normal operation of the automatic gain control (AGC) feedback control loop. The ceramic was replaced with a titanium-coated one to eliminate the problem. The system requires a 30kV maximum gap voltage.

Tuner

The ferrite toroids used in the harmonic cavity tuner are identical to the ones used in the 9.78MHz tuners. Three toroids are stacked inside a copper cylinder to construct a tuner. An rf coupling loop is used to couple rf to the tuner housing. The rf coupling loop also has control current windings inside. In the rf coupling loop, a bypass capacitor was used to maintain fast response with the pulsed tuning current. The harmonic cavity employs one tuner on the cavity outer shell. The tuner has 80 turns of control winding. For safe operation of the tuners without overheating, the tuner control current was limited to 35A. The system requires damping by ~5 and detuning by -180kHz for the off state compared to the on state.

IV. MEASUREMENTS

9.78MHz Cavity

The cavity fundamental resonant frequency vs. the tuner current is shown in Figure 3. The cavity Q vs. the tuner current at the resonance is found to be almost constant. This shows that the ferrite material has low loss at the frequency. Measured Q is about 4,800. The cavity was tested to 36kV and the tuning range was measured as ±10kHz.

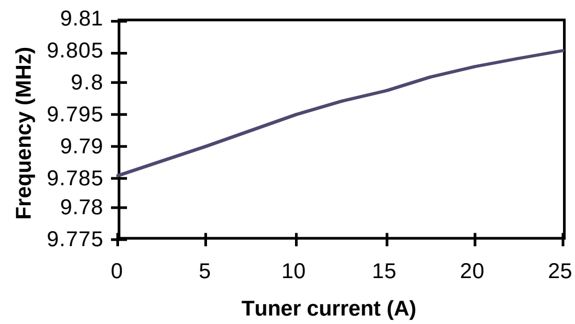

Figure 3: Fundamental cavity frequency vs. tuner current

117.3MHz Cavity

Detuning and damping the cavity are done with a single ferrite tuner at the same time. This can be achieved with the loss characteristic of the ferrite toroid at this frequency; the ferrite is lossy with no bias but lower loss when saturated. The cavity fundamental resonant frequency vs. the tuner current is shown in Figure 4. The cavity Q vs. the tuner current at the resonance is shown in Figure 5. Measured Q at full design current is about 2,400 with maximum control current. Since the ferrite is much lossier at this higher frequency with no bias current, the ferrite tuner works as a damper. The cavity was tested to 30kV gap voltage. The damping factor was 4 and detuning range was -170kHz.

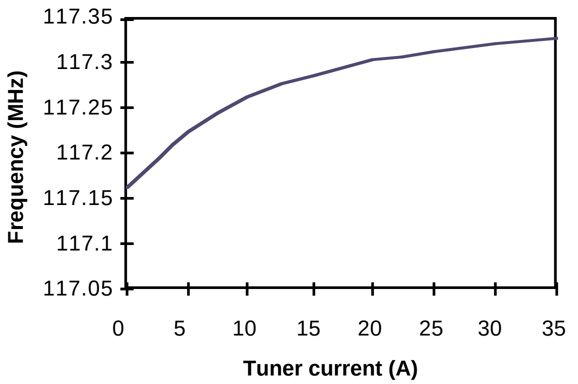

Figure 4: Harmonic cavity frequency vs. tuner current

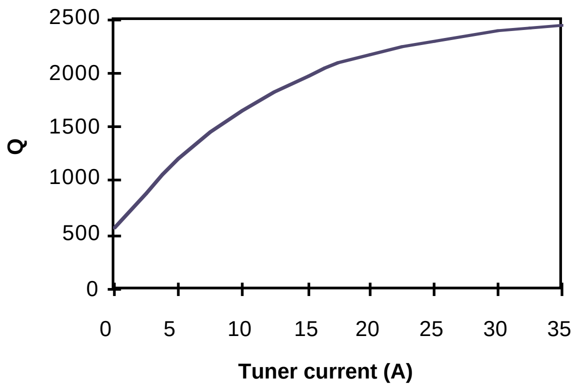

Figure 5: Harmonic cavity Q vs. tuner current

V. HIGHER-ORDER MODES

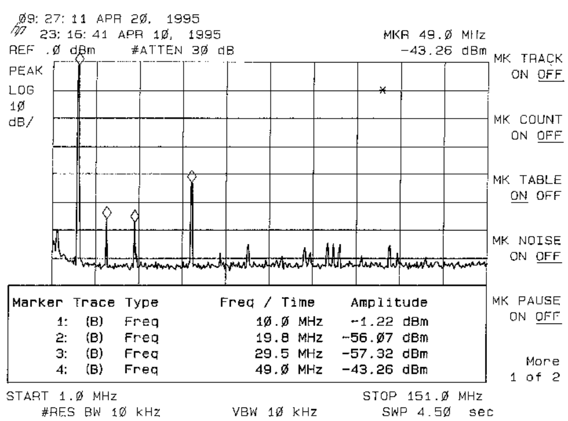

Figure 6: Beam-induced field spectrum of 9.78MHz cavity

Frequency, Q-factor, and shunt impedances of the cavity higher-order modes were found by computer simulation for the cavities [2][3]. Computer simulations were possible for the cavities without accessories such as the tuners and input couplers. The spectrum of the beam-induced higher-order modes of the fundamental cavity and the harmonic cavity have been measured with the field probes and are shown in Figures 6 and 7, respectively. Figure 7 also shows that the revolution harmonics of the fundamental frequency and most higher frequency components are damped. The bunch current was ~2*nc* and the bunch length was ~0.6*ns*.

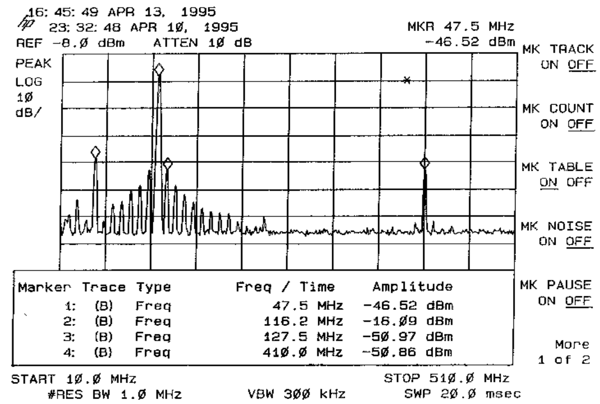

Figure 7: Beam-induced field spectrum of the 117.3MHz cavity

VI. CONCLUSION

The fundamental cavity operates in CW mode while the harmonic cavity works in pulsed mode. During the ‘off’ state, the tuner detunes and damps the cavity. By adjusting the coupling between the tuner and the coupler, the required damping and detuning could be obtained. The fundamental and the harmonic cavities have been working well so far, but some improvement is required in the fundamental cavity: a higher gap voltage and a greater tuning range. The accelerating gap voltage can be increased if the distance between the two concentric cylinders for capacitive loading is increased. The position of the rf coupling loop of the tuners affects the tuning range of the tuners. For more tuning range the position of the loops must move closer to the center conductor of the cavity.

VII. ACKNOWLEDGMENT

The authors express thanks to E. Wallace, D. Bromberek, J. Maj, G. Waldschmidt, and J. Cho for their efforts in installation and measurement of the cavity systems.

VIII. REFERENCES

[1] M. Borland, “Commissioning of the Argonne Positron Accumulator Ring,” these proceedings.

[2] Y. W. Kang, R. L. Kustom and J. F. Bridges, "Twelfth Harmonic Cavity of the Positron Accumulator Ring of the Advanced Photon Source," Light Source Note, ANL/LS- 211 (1992).

[3] Y. W. Kang, J. F. Bridges, and R. L. Kustom, "Reduced Length Design of 9.8MHz RF Accelerating Cavity for the Positron Accumulator Ring of the Advanced Photon Source," *Proc. of the IEEE Particle Accelerator Conference*, pp. 1054-1058, 1993.