LOW Q ACCUMULATOR STORAGE RING STACKING/BUNCHING CAVITY

A. Moretti, Fermilab*

Abstract

The two H=84 stacking/bunching cavities in the P-bar Accumulator Storage Ring operating at 52.812 MHz are required for beam stability to have a Z/n=350 each. The cavities are operated in two modes: in a long pulse high power mode (250 ms every 2.1 s) to stack and bunch the beam in normal P-bar Source operation, and in a CW mode at moderate power level for aperture diagnostic studies. Furthermore, future internal target experiments in the Accumulator require this to be accomplished over a frequency range of -18%. The above require that the Q-swamping technique be broadband and robust. This has been accomplished by magnetic field loop coupling and electric field capacitive coupling of EM fields from the high Q cavity to external high power water cooled 50 ohm coaxial loads. The tuning has been accomplished by movable large metal slugs, two per cavity. Eight coaxial loads per cavity have reduced the cavity Q to 175 corresponding to a cavity shunt impedance of 30 kOhm, the desired value. In addition to meet system requirements a push-pull final amplifier has been installed using 20,000 kW water cooled triodes.

Introduction

In the Fermilab P-bar Accumulator Ring two H=84 rf cavities are used to adiabatically capture injected P-bars and rf stack them at the edge of the stochastic cooled stack tail.[1] After the proper cooled core density has been achieved and removal of large P-bar bunches from the cooled core by low-frequency rf unstacking, adiabatic rebunching at H=84 is required prior to bunch-to bucket transfer to the Main Ring.[2] A maximum rf voltage of 110 kV is required to meet the system specification described above with the capability to adiabatically turn-on from zero and turn-off to zero. Furthermore the coasting beam instability criterion for the high intensity low momentum spread of the cooled P-bar beam place a limitation on the maximum shunt impedance of the 52 MHz system of 60 kOhm total.[3] In addition all harmonics of the cavity system for beam stability must have Z/n of less than 700 total. To accomplish this a broadband Q-swamping technique is required to damp the Z/n value of the modes below 700 total. In addition the adiabatic processes require this to be accomplished in cavities free of multipactoring.

Damping Technique

The high gradient rf cavity design for the Debuncher Ring has been modified to meet the above requirements.[4] The primary change has been the installation of a double-walled stainless steel beam pipe with a central ceramic gap and corona roll assembly capable of operating in excess of 100 kV peak rf with air outside and vacuum of 10 E-10 torr on inside of beam pipe. This change allows the damping devices to be installed in air through holes or ports in outer cylinder of the cavity, Figure 1. Thus avoiding the need for ceramic feed-throughs and their associated voltage and vacuum problems. In addition the ceramic gap reduces the probability of multipactoring because only a small volume containing high rf fields is in vacuum. After the first pump down less than an hour was required to remove all traces of multipactoring from the voltage waveform. Subsequent conditioning has taken even less time.

*Operated by the Universities Research Association under contract with the U.S. Department of Energy.

The theory of the damping is based on the definition for the Q of a system, i.e., Q is the ratio of energy stored (U) to energy loss per second, Q=2(pi)fU/P, where f is the frequency and P is power loss. If a number of discrete loads n are coupled to the cavity, then the power loss in the n loads, Pn, are summed with the cavity power loss, Pc, to arrive at the system Q given by

$$Q=2(\pi)fE/(Pc+P1+P2+.....Pn)$$

Figure 1 shows schematically how the loads (50 Ohm water cooled coaxial) are coupled to the cavity. Four capacitive pick-ups were installed at 45 and 135 deg near the ends of the intermediate cylinder two per end to capacitivally couple EM energy from cavity to external loads. The gap was then set so that the power dissipated in a individual load, Pi, was equal to about twice the cavity dissipation, Pc. In practice the gap was set on a individual basis so that the 3dB bandwidth with a load attached was equal to three times the 3dB bandwidth of the cavity unloaded. In addition four loops were installed at 0,-37.5,-142.5 and 180 deg in midplane of outer cylinder to magnetically couple energy to external loads. In order to insure that all nearby modes and fundamental were efficiently Q-damped including the higher order azimuthal modes, the pick-ups for the loads were distributed in azimuth and along the length of the cavities. Two types of pick-ups, i.e., capacitive and inductive were used to further insure efficient multi-mode coupling. A picture of one of the cavities in the tunnel is shown in figure 2. The slender dark horizontal cylinders are the 50 Ohm loads.

Mode Identification and Measurement

The computer program URMELT[5] was used to determine the first fifteen resonances for the fundamental type TEM modes as well as the next two higher azimuthal modes, i.e, the azimuthal dipole and quadrupole modes. In addition to frequency, the program determines the shunt impedance R=V*V/P, Q and R/Q where V is the integral of the modes electric field along the axis of the cavity through the accelerating gap. One can see from the above definitions for Q and R that R/Q is independent of power loss and only dependent on the mode and geometry of the cavity. This then allows us to determine the impedance of the mode by measuring its Q and taking the product of Q with R/Q. The technique actually used to measure the impedance of the modes was to excite the cavity from a well padded signal source and then measure their 3dB bandwidth with a small pick-up loop. The signal source was introduced from several different points on the cavity to insure that no resonances were missed.

CH2387-9/87/0000-1845 $1.00 © IEEE

PAC 1987

Table I shows the results of the measurements for frequencies below 500 Mhz. Above 500 MHz SUPERFISH and URMELT computations have shown that the presence of the stainless steel beam pipe alone damps all resonances well below the stability criterion. The fundamental at 52.8 MHz has been damped to a Z/n value of about 350. The remaining resonances are all well below this number and tending to decrease with increasing frequency.

Freq. MHz Number	Nearest Harmonic Ohms	Z/n Undamped Ohms	Z/n Damped
52.8	84	10,200	354
129.8	206	983	3.6
217.2	344	995	16
319.1	506	75	0.4
368.6	583	429	2.6
431.9	683	153	0.6
504.6	799	138	1.5

Table I. Resonances up to 504 MHz with their damped and undamped Z/n values.

Power Amplifier and Tuner

Each cavity is driven by two zero bias water cooled 20,000 kW triodes in a grounded grid push-pull configuration. The amplifier delivers in excess of 60 kW peak rf at a duty factor of 20%. At maximum drive a voltage of 60 kV peak rf is developed across the accelerating gap of the cavity. The amplifier has been in operation for a long enough period to demonstrate that it is reliable and robust. The filament choke, Figure 1, is in the form of a spiral resonator the inner conductor of which is a rigid coaxial line made of copper tubing. The rf input is a short 1/2 in. coax with a variable tuning capacitor at the rf input connector. This has proven to be broadband and reliable.

The cavities are currently running fixed tuned. Because they are broadband they have not required any retuning. They have demonstrated that they are very stable with time and temperature. However, future colliding beam experiments in the accumulator ring require that the cavities be tunable down in frequency by 18% over a period of several minutes. Because the period is long, a mechanical system was chosen for the tuner. The tuning capability has been provided by two large movable copper slug tuners surrounding the beam pipe on opposite sides of the accelerating gap. The slug tuners are hollow closed cylinders 15 cm I.D., 28 cm O.D. and 25 cm long. Silver-plated spring fingers are used to make rf electrical connection to the beam pipe. The tuners have been tested by moving them with the required rf voltage impressed on the gap without observing waveform breaks or frequency jumps. Servo mechanisms and feedback loops are to be provided so that the cavity frequency can be phased-locked to the P-bar beam and the ring's magnetic field.

A novel technique was used to match the amplifier to the cavity. Because the system is balanced, a balanced device must be used for this matching. The technique takes advantage of the fact that a balanced 3 dB 180 deg hybrid coupler is a impedance transforming device. First a set of matched pairs of impedance loads were connected via strip lines to the outputs of the coupler and its input impedance measured as a function of frequency. Next the input impedance data was plotted on a Smith chart at fixed frequency with load impedance as a parameter. The coupler was then connected to the anodes of the tubes via the same above strip lines and then a measurement of its input impedance versus frequency was taken. Subsequently, the data was analyzed and the length of power coupling loop adjusted until the desired match of 1000 Ohms balanced at 52.8 MHz was achieved.

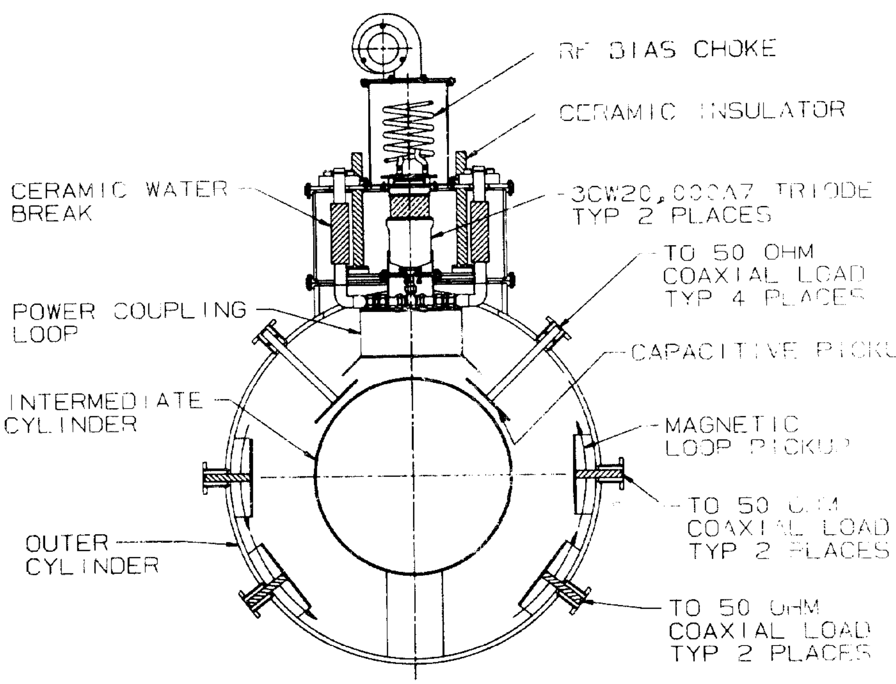

Figure 1. Sideview of Cavity, Final Amplifier, and Pick-ups.

Acknowledgement

I wish to acknowledge the many contribution of Jim Griffin to the success of the H=84 cavity. Also John Krider contributed a great deal in the design of the dampers and measurement of their properties. The contributions of Gil Nicholls on the amplifier and especially the input circuit are gratefully acknowledged.

References

1. J. Peoples, The Fermilab Antiproton Source, IEEE Trans. on Nucl. Sci. NS-30, No. 4 1970 (1983).

2. V.K. Bharadwaj, et al., Beam Transfer from Debuncher to Stacking Orbit of Accumulation in the Fermilab Pbar Source, paper L5, this conference.

3. J. Marriner, Stability Criterion and Wall Impedance for the Antiproton Accumulator, E Note 422, Fermilab (1985).

4. J.E. Griffin, J.A. MacLachlan, J.E. Misek, A. Moretti, and V.K. Bharadwaj, IEEE Trans. on Nucl. Sci. NS-32, No. 5, 2806 (1985).

5. T. Weiland, On the Numerical Solution of Maxwell's Equations and Applications in the Field of Accelerator Physics, ISSN 0418-9833 DESY, Hamburg (1984).

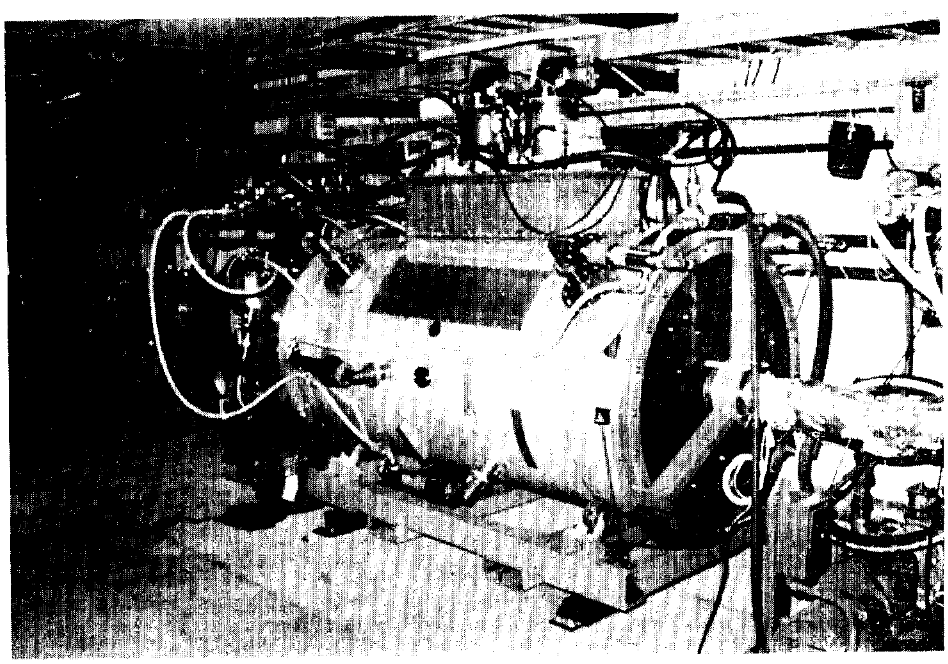

Figure 2. Picture of H=84 Cavity in the P-bar Tunnel.