A LOW SHUNT IMPEDANCE 53 MHz RF SYSTEM FOR RF STACKING IN THE FERMILAB ANTIPROTON ACCUMULATOR

J.E. Griffin, J.R. Misek, A. Moretti, and G. L. Nicholls, Fermilab*

Summary

In the Fermilab antiproton Accumulator Ring, injected antiprotons are to be adiabatically captured and rf stacked at the edge of the stochastic cooling stack tail. Also large antiproton bunches which have been removed from the cooled core by low-frequency rf unstacking are to be pre-bunched at 52.813 MHz prior to bunch-to-bucket transfer to the main Ring at 8 GeV. A 100 kV 53 MHz rf system for accomplishing these two tasks is described. Because of the low momentum spread beam to be stored in the ring, a shunt impedance limitation must be imposed on all devices in the ring to prevent microwave instability. Also vacuum pressure in the range 10^{-10} T must be maintained. This report will describe how a normally high Q rf structure has been modified to meet these requirements.

Introduction

The Fermilab antiprotron source[1] consists of two rings, a Debunching (or bunch rotation) Ring in which momentum spread is exchanged for time spread,[2] and an Accumulator Ring, in which antiprotons are rf stacked, accumulated, and stochastically cooled. Antiprotons are delivered from the Debuncher to the Accumulator once each production cycle (2-3 seconds) and they must be adiabatically captured and rf stacked to the momentum edge of the cooled stack tail following each injection. The momentum spread of the injected 8.9 GeV beam will be approx. 0.2 percent and the rotation period of the ring 1.6 microseconds resulting in an injected longitudinal emittance of 28.5 eV-Sec.

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Following stochastic cooling, single bunches of antiprotons of longitudinal emittance 1 eV-sec are rf unstacked from the cooled core to the extraction orbit at a low-harmonic number, where they must be adiabatically rebunched into ensembles of about ten adjacent bunches at 52.813 MHz (h=84) prior to transfer to the Main Ring accelerator.

Both of the above described functions are to be performed by the same 52 MHz rf system. A maximum rf voltage of 100 kV is required. The very low voltage required for adiabatic processes implies that two rf cavities capable of being counterphased should be installed. Storage ring vacuum pressure of 10^{-10}T must be maintained in the ring so that rf cavities with ceramic accelerating gaps and bakeable beam pipes are indicated. Furthermore stability requirements imposed by the relatively high intensity low momentum spread cooled antiproton beam place a limitation on the maximum shunt impedance of an rf system operating at 52 MHz of about 60 kOhms.[3]

RF Cavities

Two of the high gradient rf cavities designed for the Debuncher Ring[4] have been extensively modified to meet the above requirements. The primary change has been the installation of a double walled stainless steel beam tube with a ceramic gap capable of operation at an accelerating gradient greater than 80 kV. The double walled beam tube contains an externally powered heating element, and the ceramic gap corona roll assembly contains within it an expansion bellows capable of absorbing the beam tube thermal expansion. The outer cylinders of the stainless steel beam tube are part of the cavity rf circuit and the poor rf conductivity contributes to

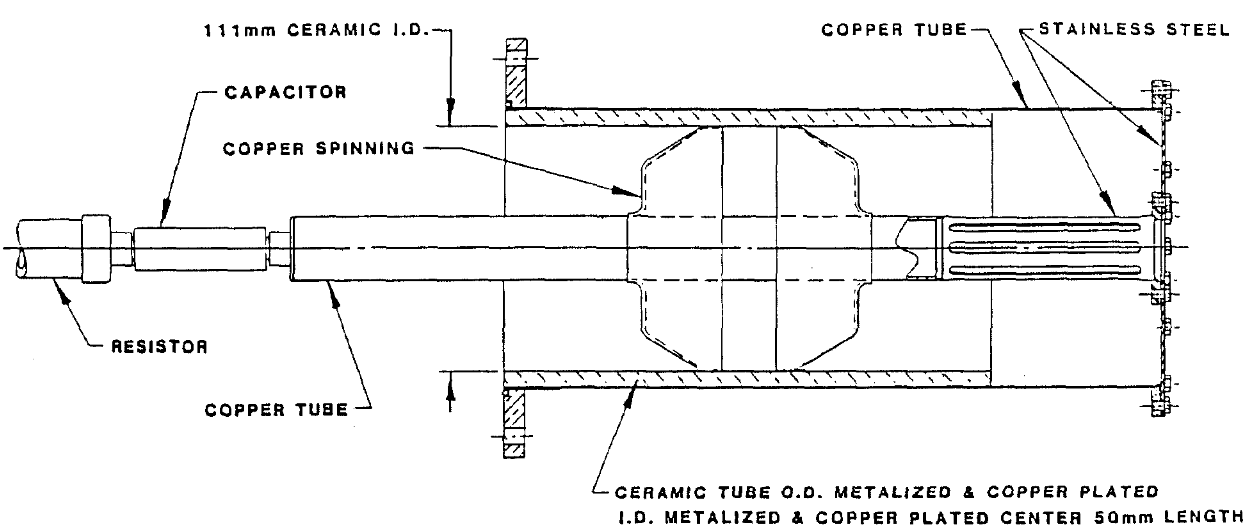

Figure 1. Externally mountable impedance damping device. Essentially a low Q resonator.

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the required reduction in cavity shunt impedance. A further reduction in shunt impedance occurs when the size of the input power coupling loop is increased to reduce the anode-to-gap voltage ratio to the required value. These changes result in a cavity with Q of 5000 and R/Q of 152. The shunt impedance near resonance is still far too high for stability.

Introduction of a vacuum tight beam tube allows installation on the rest of the cavity body of various ports or holes through which probes or other devices may be inserted easily. The voltage between the ends of the intermediate cylinder and the cavity endwall is 0.6 of the half-gap voltage, i.e. 15 kV for 50 kV gap voltage. The cavity fundamental shunt impedance could be reduced to the required 30 kOhms by placing 5.6 kOhms of resistance between each end of the intermediate cylinder and the endwall. Each such resistor would dissipate 20 kW peak power. The cavity duty factor is less than 0.1 so the average power dissipation is only 2 kW. This technique, with slight variation, is adopted to reduce the shunt impedance.

Each endwall of the cavity is fitted with three "damper boxes" each of which is a primarily lumped low Q resonator tuned to the operating frequency. The shunt impedance of each such circuit is about 15 kOhm and each must dissipate a peak power of about 7 kW. The damper assembly is shown in Fig. 1. It consists of a metallized ceramic tube coaxial capacitor in parallel with a short coaxial inductor. The center conductor of the inductor and the endwall are made of stainless steel to achieve the required shunt impedance. Each damper is mounted on the cavity endwall and may be coupled to the cavity fields either by loop coupling or by direct coupling to the intermediate cylinder through a 3 pF capacitor in series with a 100 Ohm resistor. The resistors dissipate negligible energy at the fundamental frequency since they are small with respect to the damper shunt impedance. The dampers are easily mounted or removed and the heat is dissipated at a location outside of the cavity volume where it may be removed easily. Using this technique the cavity shunt impedance can be set at any desired value by varying the number or shunt impedance of the externally mounted dampers. Fig. 2 shows the essential features of a cavity modified with a ceramic gap beam tube and endwall dampers.

Higher Order Modes

In addition to reduction of the cavity fundamental frequency shunt impedance it is, of course, important that the cavity be inhibited from presenting to the stored beam a high impedance at any frequency. The Z/n threshold for instability[3] is a function of stored beam intensity and momentum distribution allowing a few kOhm resistive but only 500 Ohms inductive reactance. Any resonant impedance (with a displaced circular impedance plot or Smith plot near resonance) must be limited to Z/n < 800 Ohms shunt resistance at resonance.

The structure of each damper causes it to appear at its input essentially as a shunt capacitance at frequencies above the fundamental resonance. Therefore the 100 Ohm coupling resistances appear as terminating resistors on the short section of transmission line between the gap and the end of the cavity. This reflects a low real resistance to the gap at most higher frequencies. At frequencies above 500 MHz SUPERFISH and/or URMEL[5] computations indicate that the presence of the stainless steel beam pipe alone damps all resonances to well within the

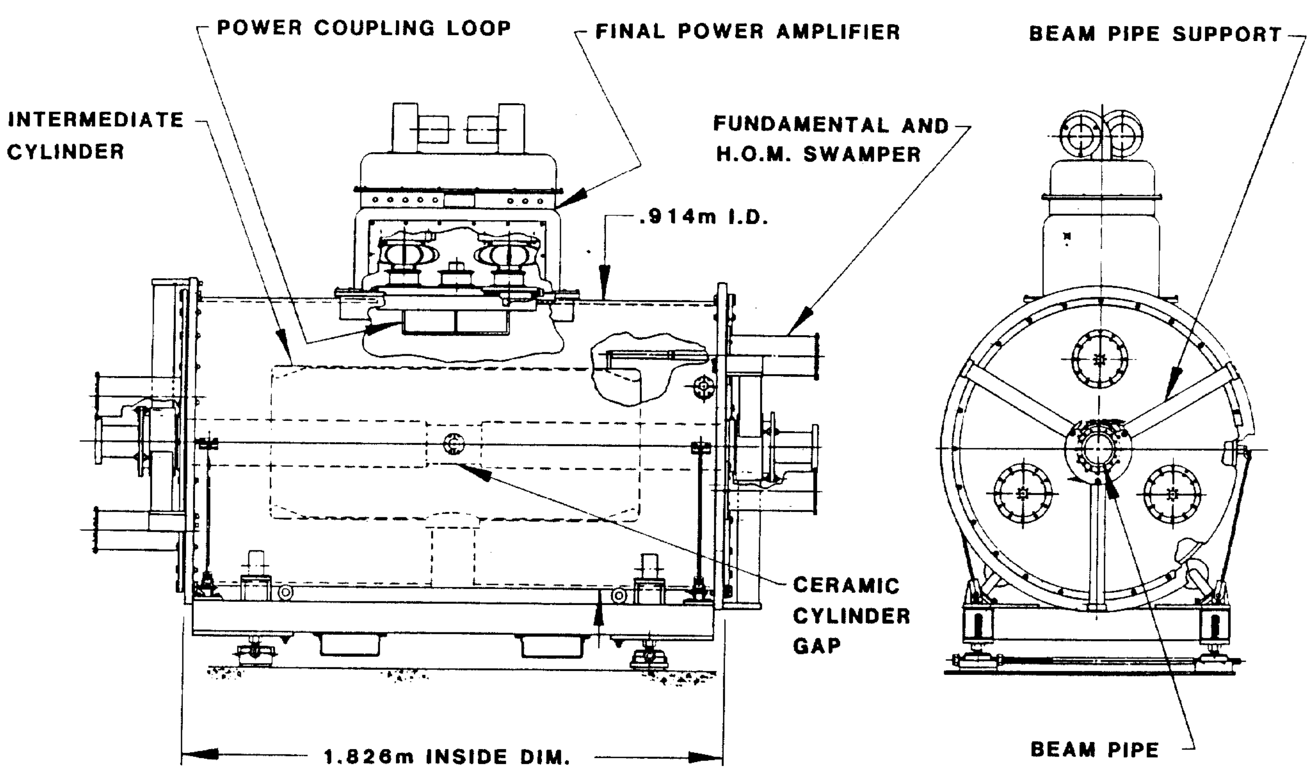

Figure 2. Debuncher rf cavity with adaptations for low Q high vacuum operation.

stability boundary. There may be ultra high frequency resonances where fields are concentrated mainly in the region of the ceramic gap corona roll assembly region. No resonances of this kind have been observed but if they arise and can be identified as such, it will be a relatively simple matter to damp them by ad hoc antennas inserted into the gap region from the cylinder support post.

Resonance Identification and Measurement

A computer search for resonances below 1 GHz was done using SUPERFISH and URMEL field computations. Fifteen resonances including the fundamental operating frequency were identified and their shunt impedances calculated. Three separate measurement techniques were employed on the cavity. Transmission absortion measurements were made using a matched tapered transmission line and two separate network analyzer measurements were made. In one case a small antenna was placed near the accelerating gap and absorbtion measurements were recorded. In the other case a receiving antenna was placed near the gap opposite the excitation antenna and transmission measurements were made.

Damping of the fundamental 52.8 MHz resonance to the required shunt impedance is straghtforward. At this writing tests have been completed using only two damping boxes, one on each end of the cavity. This lowered the fundamental Z/n of the cavity to about 550 so another factor of two will be required and easily obtained. All resonances above the fundamental were damped sufficiently by a single damper at each end. In Table 1 resonant frequences below 500 MHz are listed with their damped and undamped Z/n.

Freq. MHz	Nearest Harmonic Number	Z/n Undamped Ohms	Z/n Damped Ohms
52.817	84	10.2×10^3	547
130.161	207	983	106
223.11	371	995	110
385.C7	612	429	81.7
436.12	693	153	72
513	816	138	19.6

Table 1. Resonances up to 513 MHz with their damped and undamped Z/n.

Cavity Power

Each cavity is driven by two 10 kW grounded grid triodes identical to those used in the Debuncher Ring cavities.[4] The amplifer is capable of delivering the required 40 kW at the very low duty factor, which never exceeds 10 percent. With no dampers on the cavity the amplifier is easily able to develop gap voltage in excess of 100 kV. The alumina gap seals break down longitudinally on the air side at about 118 kV but operation at 100 kV for periods of 100 msec at low duty factor have produced no ill effects in the ceramic seals so routine operation at 50 kV seems assured.

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