A NEW RF SYSTEM FOR BUNCH COALESCING IN THE FERMILAB MAIN RING

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Abstract

A new RF system for improving both the proton and antiproton bunch coalescing efficiencies has been installed in the Fermilab Main Ring. The system consists of five, ferrite-loaded RF cavities operating at a fixed frequency of 2.5 MHz and a second harmonic cavity at 5.0 MHz. Each cavity is driven by a 5 kW solid-state power amplifier and can produce a peak accelerating gap voltage greater than 15kV. An overview of the entire system will be presented along with a detailed description of the RF cavity design including ferrite selection and testing procedures.

I. INTRODUCTION

One of the present functions of the Fermilab Main Ring is to act as a 150 GeV injector for the Tevatron Collider. In this mode of operation, 9 to 13 bunches of protons or antiprotons are combined into a single high intensity bunch before being injected into the Tevatron. This process, known as bunch coalescing [1], is accomplished using two RF bunch rotations. The first rotation, to lower the beam energy spread, takes place in the normal Main Ring RF h=1113 (53 MHz) bucket with some additional linearizing h=2226 (106 MHz). In the second RF rotation, the low energy spread beam is rotated for aquarter of a synchrotron period in an h=53 (2.5 MHz) bucket linearized with some additional h=106 (5 MHz) voltage. This rotated ensemble of bunches is then recaptured into a single h=1113 bucket and injected into the Tevatron. The efficiency of this coalescing process is a function of both the initial longitudinal emittances of the individual bunches and the RF voltage available for the h=53 bunch rotation.

To achieve higher initial luminosity in the Tevatron Collider, the Main Ring has been operating at higher beam intensities and larger longitudinal emittances. To coalesce these higher intensity bunches efficiently, it has become necessary to raise the h=53 and h=106 RF voltages by a factor of 2.5 from 24kV(6kV) to 60kV(15kV). Simulations of beam dynamics and the results of this upgrade are presented in another paper presented at this conference [2].

The previous coalescing RF system consisted of six modified PPA (Penn-Princeton Accelerator) cavities [3] driven by 25 kW power tetrode amplifiers mounted on top of the cavities in the Main Ring tunnel. The accelerating voltage available from these cavities was limited by the high field losses encountered in the PPA cavities' 4C4 NiZn ferrite cores.

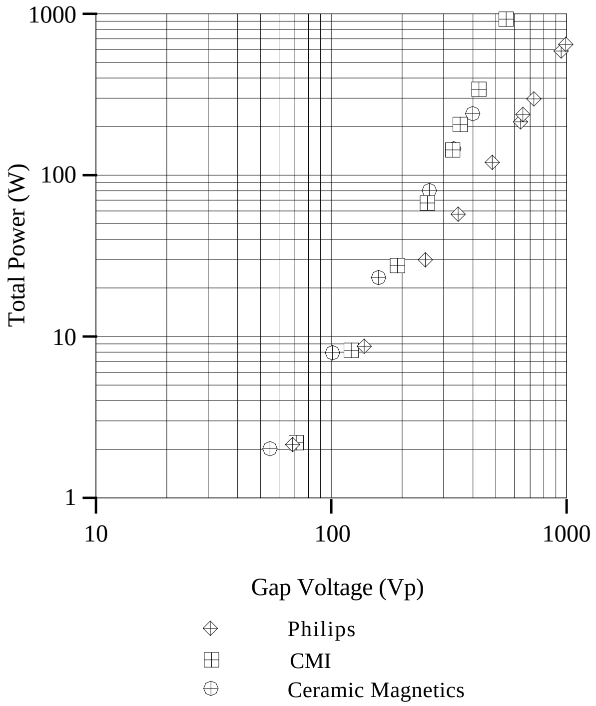

Figure 1: Power Dissipated in Ferrite Cores

II. FERRITE SELECTION AND TESTING

During the initial stages of this coalescing upgrade, a literature search revealed that newer types of NiZn ferrites were commercially available with significantly lower high field losses [4]. A decision was made to test several of these new ferrites to determine their properties and high field losses at 2.5 and 5 MHz. Three different vendors each supplied three full size NiZn rings for our tests. Philips supplied three one-piece type 4M2 rings in their standard size of 500mm OD X 200mm ID X 25.4 mm thick. Ceramic Magnetics delivered three C2025 cores 20″OD X 7.5″ID X 1″ thick. Each toroid was assembled from six wedges bonded together. CMI Technology supplied three type N125 cores in sixteen wedges that formed a 20″OD X 7.5″ID X 1″ thick toroid.

To accurately measure the RF losses in the ferrites at high magnetic-flux density, Brf, a single ferrite core was inserted into a coaxial aluminum resonator test fixture. The test fixture was tuned to 2.5 MHz using several high Q ceramic transmitting capacitors. Energy was magnetically coupled into the resonator with a thin loop made from .003″ thick copper foil. To obtain a 50 ohm input impedance at the coupling loop, each of the test ferrites was sliced in half and the coupling loop area was adjusted between the two halves of the cores. The

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

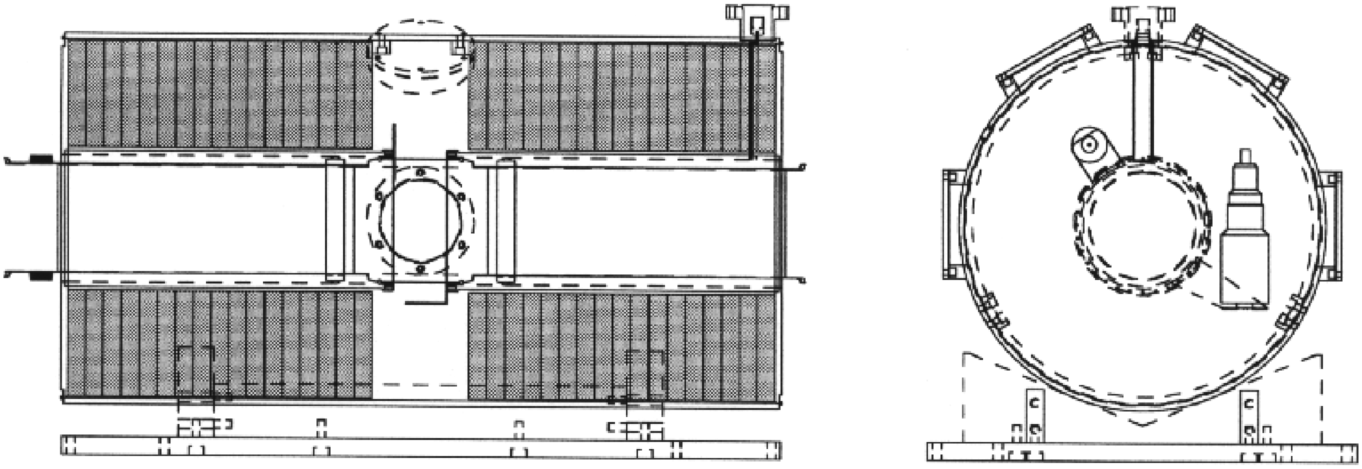

Figure 2: 2.5 Mhz Coalescing Cavity

test fixture was excited using either a 250 watt or 1 kW power amplifier. The power deposited in the ferrite core was measured as the excitation frequency was swept through resonance at 2.5 MHz. The power loss in the ferrite was calculated from the measured forward and reflected power from a calibrated high power directional coupler (Werlatone model C2784) inserted into the drive line. All power measurements were made using an HP 8753C network analyzer. The voltage developed across the test fixture gap was measured using a specially designed capacitively coupled monitor and several different commercially available voltage probes (Tektronix 6015A, HP 85024A, or HP 1124A.) A plot of power lost vs. gap voltage is shown in Fig. 1. for each of the three different cores (Note: the three CMI cores showed significant differences between cores.) A test fixture gap voltage of 600 volts corresponds to an average <Brf> of 100 gauss and a maximum Brf of approximately 164 gauss in the ferrite core. All of the manufacturers cores exhibited similar losses at low <Brf>. However; the Philips 4M2 clearly showed significantly lower losses at the highest Brf and was our choice for the new cavities. In fact, the losses were low enough to allow us to consider driving the new cavities with all solid-state amplifiers. An additional advantage of choosing solid-state power amplifiers is that they could be easily located in an above ground service building; providing easy access for maintenance and repair during a colliding beams store.

III. CAVITY DESIGN

A diagram of the final cavity design is shown in Fig.2. Each cavity consists of two fore-shortened, coaxial, quarter-wave resonators with a single accelerating gap at the center of the cavity. The entire resonator is made from 6061T-6 aluminum components which are TIG welded together. The outer shell is a piece of 5/16″ thick aluminum stock, rolled and welded into a 40″ long cylinder with an inner diameter of 19.9″ ± 0.1″. The inner conductors consist of 7.5″OD X 7″ID X 18″ long tubes which are joined at the shorted ends of the cavity by 3/8″ thick flanges. The cavity has a separate 6″ diameter stainless steel vacuum beam pipe with a 6″ ID cylindrical ceramic window (Ceramaseal # 13652-03-W) which slides inside the resonator’s inner conductors. Two strips of beryllium copper finger stock, mounted around the outside of the vacuum beam pipe, center the beam pipe inside the inner conductors and prevent any RF leakage out of the cavity. Four 4.5″ dia. ports are located around the center of the outer cavity shell to allow access to the gap tuning capacitors. The cavity is supported by two V-blocks mounted on a 1″ thick aluminum plate.

The 2.5 MHz and 5 MHz cavities are identical except for the number of ferrite rings and the gap capacitance. The 2.5 MHz cavity has a total of 34 ferrite rings, 17 in each half. The 5 MHz version has 24 ferrites, 12 in each half. Due to the extremely low average power dissipated in the cavities (< 6 watts), direct cooling of the ferrites was unnecessary. The ferrites were placed adjacent to one another (with the exception of the ferrite located at the 50 ohm tap position which has a 1/8″ polyethylene spacer ring.) To help cushion the ferrites during transport and installation, the interior of the outer shell was lined with a sheet of 1/8″ HDPE and the ferrites were secured at the gap region by six UHMW polyethylene blocks. This polyethylene liner along with the ferrites and a small air gap surrounding the inner conductor forms a coaxial transmission line with a characteristic impedance of 260 ohms. The ferrite rings are maintained at a constant temperature by 95°F water circulating through 0.5″ square aluminum tubing (0.25″ dia. inner water channel) welded directly to the outer shell.

The cavities are driven by a single 1″ wide aluminum coupling loop at one end of the cavity which enters through a standard 1-5/8″ EIA flanged port and is welded to the inner conductor. For the 2.5 MHz cavities, the correct 50 ohm tap point was achieved by machining a 1″ wide slot, approximately .75″ deep, in the second ferrite from the shorted end. A 1/8″ thick

HDPE ring was also inserted in these cavities between the second and third rings to reduce the imaginary component of the cavity input impedance. In the 5 MHz cavity the input loops a single ferrite which is spaced from the other ferrites by a 1″ thick HDPE ring.

The 2.5 MHz cavities were tuned to resonance with a gap capacitance of approximately 110pf. Two 100pf ceramic transmitting capacitors (Philips 859S-100Z) in series, combined in parallel with a 7-75 pf variable vacuum capacitor (Jennings CVFA-75-0030), provided a simple method of tuning the cavity. In the final cavity tuning process, the cavity was deliberately tuned 10 kHz higher in frequency at low power to compensate for the small frequency shift observed with the cavity RF power level. The cavity gap voltage is monitored by two capacitively-coupled probes symmetrically placed 2-1/4″ on either side of the gap. The monitors are made from 3/32″ diameter machined brass rods, 3″ long, soldered to N-type coaxial feedthroughs extending through the outer cavity shell wall. The monitors were calibrated using two HP 85024A high frequency probes connected to an HP 8753C network analyzer. One high frequency probe was placed directly across the accelerating gap, while the other probe was attached to the gap monitor. The nominal ratio of gap voltage to monitor voltage for the cavities is 15,000/1. This calibration was verified after installation in the Main Ring by observing the synchrotron period of the proton beam rotating in the 2.5 MHz bucket.

The unloaded Q of the 2.5 MHz cavities was 125 ± 5. The 5 MHz cavity had a slightly lower Q of 95. Using low level RF signals, the cavities' shunt impedances were found to be in the range of 48-52 KΩ using an HP 4193A vector impedance meter probe placed across the accelerating gap. These values agree with the shunt impedances calculated from the measured gap voltage and the power deposited in the cavity from directional coupler measurement in the input transmission line. At cavity gap voltages in the range of 12kV to 17kV, the shunt impedance slowly declined by approximately 10%.

IV. THE AMPLIFIER

Each cavity is powered by a Lambda RF Systems model PA5K-30LC, water cooled, solid-state linear MOS FET amplifier which was specifically designed for Fermilab. Each amplifier consists of 6 power amplifier modules, three 48 volt dc power supplies, one RF combiner, and a system control unit. The amplifier, shown in Fig. 3, has a nominal gain of 60 dB. The total output power is greater than 5 kW into a 50 ohm load over a frequency range of 2.5 to 5 MHz. The amplifier modules can be easily modified for operation at 7.5 and 15 MHz to accommodate future changes in Colliding Beams bunch spacing.

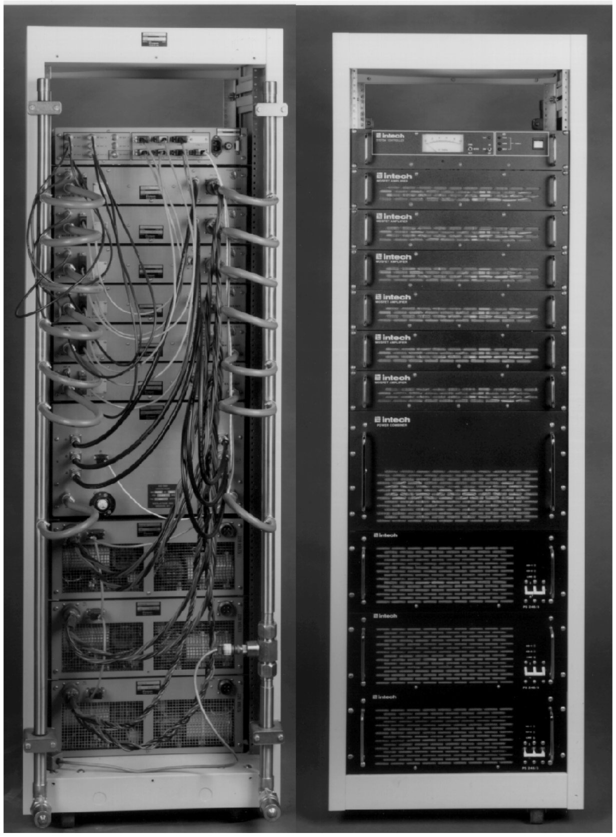

Figure 3: Front and rear views of the 5 kW solid-state power amplifier.

The amplifiers are connected to the cavities in the Main Ring tunnel by approximately 200 ft of 7/8″ coaxial transmission line (Andrew LDF5-50A). To obtain the best possible 50 ohm matching conditions, open and shorted tuning stubs, made from lengths of 7/8″ coaxial cable, have been added at the 5 kW amplifier outputs.

V. REFERENCES

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