The High Level RF System for Transition Crossing without RF Focusing in the Main Ring at Fermilab*

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Abstract

A new method for crossing transition at the Fermilab Main Ring has been developed. Near transition a third harmonic component is added to the fundamental RF voltage producing a flattened RF waveform. To generate this waveform required the development of a third harmonic system consisting of a 159 MHz cavity, a perpendicularly biased tuner, and a 10 kW power amplifier. The cavity is a modified CERN SPS 200 MHz cavity whose frequency was lowered to 159 MHz by inserting two sleeves at the cavity gap. This cavity is electrically tuned over a 60 kHz range by using an orthogonally biased Iron-Yttrium-Garnet ferrite tuner. The power amplifier is a grid driven tetrode that has a 3/4 λ anode resonator and produces a RF cavity gap voltage of greater than 300 kV. The power amplifier drives the cavity by way of a coupling loop. An overview of this high level RF system and the resulting waveform will be given.

I. THE RF CAVITY

The RF cavity design called for a single cavity capable of developing a peak gap voltage of 270 kV over a ± 30 kHz tuning range centered at 159.08 MHz [1]. The cavity would operate for up to 20 ms around the transition time with a repetition rate of less than 0.5 Hz. A tunable, high Q cavity was considered to be desirable in order to reduce the 159 MHz final amplifier power requirements. One of the CERN SPS 200 MHz RF cavities for LEP operation [2] was generously sold to Fermilab for conversion to 159 MHz operation. The bare 200 MHz SPS cavity without its coupling loop and HOM suppressor has a Q of 50,000 and a shunt impedance of 8.5 MΩ. To modify the CERN SPS cavity for the transition crossing experiment the resonant frequency had to be lowered from 200 MHz to 159 MHz, a perpendicularly biased ferrite tuner needed to be attached, and a new input coupling loop had to be installed. A mechanical tuning slug to set the final adjustment of the center frequency and a removable

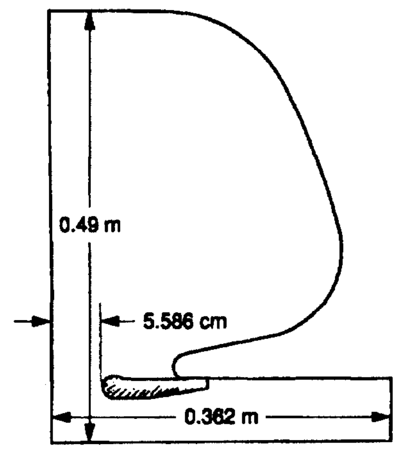

Figure 1. Modified RF Cavity profile with copper extension in nose cone.

cavity gap shorting bar were also added to the CERN cavity.

To lower the cavity resonant frequency to 159 MHz, two different methods of increasing the gap capacitance were considered. One idea was to suspend a large annular metallic ring in the center of the cavity between the nose cones. This method would require inserting the ring in sections through the 6" dia. access ports and assembling it inside the cavity. The tuning ring would require a rigid support structure and a means of external cooling. A simpler approach, shown in Figure 1, was taken of making two new OFHC copper nose cone extensions that could be shrink fitted into the existing nose cones. The existing water cooled nose cones would provide both a rigid support and a means of cooling the new extensions. The installation of the extensions was a two step process. First two aluminum inserts with a slightly smaller diameter than the final copper extensions were machined and inserted into the nose cones through one of the access ports. The positions of the aluminum inserts were then adjusted to maximize the cavity Q at the new cavity center frequency of 159 MHz. Once the aluminum inserts were in their correct positions, retaining stops were placed behind the inserts in the beam tube section of the cavity. The aluminum inserts were then removed. The actual OFHC copper extension sleeves were then cooled to liquid nitrogen temperatures and inserted through the access port into the nose cones until they touched the

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0-7803-1203-1/93$03.00 © 1993 IEEE

retaining stops. With the copper extensions in place, the gap spacing was reduced from 27 cm to 11 cm. The final 100 kHz adjustment of the cavity's resonant frequency was made with a 6" dia. X 3" long cylindrical aluminum tuning slug which was mounted in one of the access ports. The position of the slug could be adjusted under vacuum by a rare earth magnet coupled linear motion feedthrough. After retuning, the cavity's Q was 36,000.

The cavity gap voltage was calibrated using a small B-field loop pick-up embedded in the cavity wall and an HP85024A 3 GHz active probe with a x10 probe tip placed directly across the copper nose cones. The gap monitor pick-up was adjusted to give a gap to monitor voltage ratio of 30,000.

The cavity is installed in the FØ straight section of the Main Ring in place of one of the normal h=1113 accelerating cavities. The 159 Mhz power amplifier and anode resonator are located in the FØ service building directly above the cavity in the Main Ring tunnel. Power is transmitted to the cavity through a 1-5/8" 50 Ω transmission line to a coaxial feedthrough with a 6" OD X 2" ID X .75" thick alumina ceramic disk window. This coaxial structure is terminated in a coupling loop whose impedance is nominally matched to the 50 Ω output impedance of the power amplifier anode resonator. It is not necessary to water cool the coupling loop due to the low duty cycle for this experiment.

II. PERPENDICULARLY BIASED TUNER

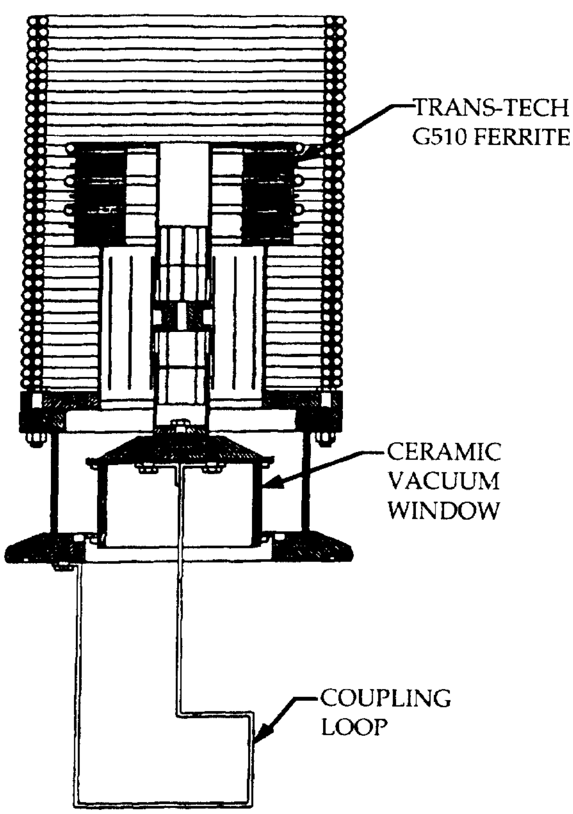

Figure 2. Perpendicularly biased ferrite tuner.

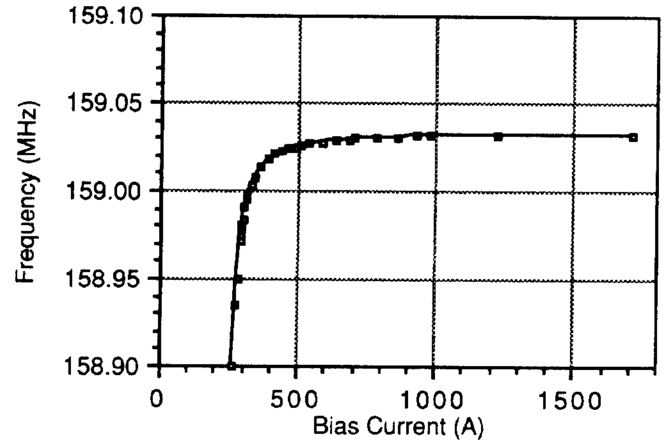

Figure 3. Tuner Frequency vs. Bias Current.

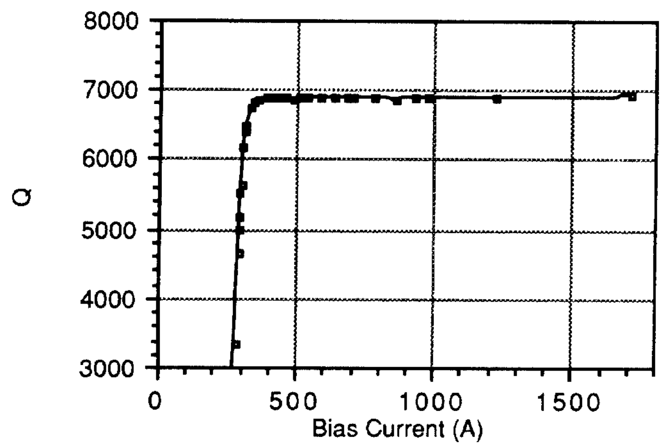

Figure 4. Tuner Q vs. Bias Current.

In order to tune the cavity over its 60 kHz tuning range an orthogonally biased ferrite tuner shown in Figure 2 was built. The tuner uses three 5" OD X 2.75" ID X 0.5" thick Trans-Tech G510 aluminum-doped, Iron-Yttrium-Garnet ferrite toroids. These high frequency, low loss ferrites are separated by water cooled, radially slotted OFHC copper plates which are welded together to form the outer conductor of the tuner structure. The OFHC copper coupling loop has an area of 54 cm^2 and is attached to the tuner center conductor through a 3.5" dia. cylindrical alumina ceramic vacuum window. This design allows the ferrite loaded section of the tuner to be removed from the cavity while the cavity remains under vacuum. The biasing magnetic field is generated by a solenoid formed from a double layer of 32 turns of 0.25" OD X 0.049" wall , water cooled, copper tubing wound on a 6.5" diameter. The current to the solenoid is supplied by a 0 - 2500 A pulsed dc supply. The output current of the supply is controlled by a feed-forward program which is a function of time in the acceleration cycle and a feedback circuit which compares the phase of the cavity gap monitor signal to the phase of the low level RF drive signal. These two circuits allow the cavity phase to be controlled to within ± five degrees of its required value throughout the tuning cycle.

The measured frequency tuning range and tuner Q as a function of the solenoid bias current are shown in Figures 3 and 4. The frequency tuning data shown in Figure 3 was taken before the final adjustment of the mechanical tuning slug in the cavity which accounts for the lower center frequency value. Assuming a maximum allowable ferrite power dissipation of 0.5 W cm^{-3}, the total Q is only allowed to change from 5000 to 7000 during the tuning cycle. This restriction on the tuner Q limits the cavity tuning range at high power to 62 kHz.

III. POWER AMPLIFIER AND ANODE RESONATOR

The power amplifier final tube is an Eimac 4CW25000B water cooled tetrode. It is operated class C in the grounded cathode, grid-driven configuration. The tube is mounted in a modified Eimac SK-360 air cooled socket with 11 - 1000 pf screen bypass capacitors. The dc plate voltage is supplied by a 9 kV, 18 A dc anode supply. The output power level is adjusted from 0 - 10 kW by varying the RF drive level to the tuned grid input circuit.

The anode resonator circuit consists of a fore-shortened 3/4 λ, 50 Ω coaxial aluminum transmission line shorted at one end. The lower quarter wave section of the resonator has an adjustable output tap point and is separated from the rest of the resonator by a 2000 pf dc blocking capacitor. The tap point is nominally set for a 50 Ω output impedance. The anode dc voltage lead and the water cooling tubes for the 4CW25000B anode are attached to the center conductor of the resonator at an RF voltage minimum. The resonator is designed so that the peak RF voltage developed in the resonator is approximately twice the RF plate voltage swing on the power tube. A 3" dia. aluminum tuning slug, mounted through the side wall of the resonator, is used to adjust its center frequency. The unloaded Q of the final tube and anode resonator circuit is 2000.

IV. THE RF WAVEFORM

To produce a non-focusing RF waveform, the amplitude of the third harmonic should be kept at 13% of the fundamental 53 MHz component which itself is increasing from 1.85 to 2.08 MV during the transition crossing time [3]. The amplitude of the third harmonic grid drive low level signal is controlled by a time dependent amplitude program and an amplitude feedback error signal. This error signal is derived by comparing the amplitude of the diode detected RF signals from the Main Ring RF fanback 53 MHz sum and the third harmonic gap voltage monitor. The error signal is then used to adjust the 159 MHz grid drive amplitude to maintain the constant 13% ratio. Figure 5 shows the result of summing the 159 MHz and 53 MHz fanback signals to produce the required non-focusing waveform.

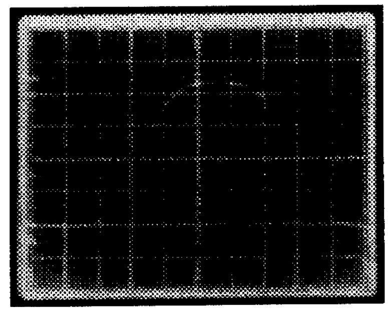

Figure 5. Oscilloscope trace (2 ns/div.) of non-focusing RF waveform.

V. REFERENCES

[1] Synchrotron Phase Transition Crossing Using an RF Harmonic, J. Griffin, Fermilab TM 1734 (1991).

[2] The New RF System for Lepton Acceleration in the CERN SPS, P. E. Faugeras, H. Beger, H. P. Kindermann, V. Rödel, G. Rogner, and A. Warman, Proc. 1987 IEEE PAC, Washington D.C., 1719 (1987).

[3] Operational Experience with Third Harmonic RF for Improved Beam Acceleration Through Transition in The Fermilab Main Ring, C. Bhat, J. Dey, J. Griffin, I. Kourbanis, J. Maclachlan, M. Martens, K. Meisner, K. Y. Ng, and D. Wildman, these proceedings.