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CATHODE-FOLLOWER RF SYSTEM FOR PROTON SYNCHROTRON AND COMPRESSOR RINGS

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ABSTRACT

A model RF system with a cathode-follower was tested in its two operational modes without beams. One was for a synchrotron, where the frequency was modulated in the 1-4 MHz range at 40 Hz; the other was for a compressor ring, where a barrier bucket was generated. The oscillations were quite stable, which showed feasibility for a high-intensity accelerator.

1. Introduction

Although the cathode-follower RF system (CF-RF) has a special merit of a low output impedance, the inherent instability and the fact that the voltage gain is less than unity have made it difficult to be applied to a high-intensity proton synchrotron, which requires as high an RF voltage as possible. Apart from the poor gain, one of the purposes of this paper is to show how well the CF-RF oscillates under frequency modulation. Simple analyses [1,2,3] imply that an instability may occur when the load cavity is tuned capacitive. However, the model system proved to be insensitive to the cavity tuning and oscillated without any instabilities.

In the compressor ring, the barrier bucket preserves the beam gap for extraction, and keeps the momentum spread uniform in the longitudinal direction; no enlarged spread exists at the bunch center. An RF field is applied for only a part of the rotation period, the rest of which it is suppressed. Such a system had been investigated in the antiproton facility of FNAL [4]. However, in a high-intensity machine a lower output impedance is more preferable. A test with the CF was then performed, giving clear and stable waveforms.

2. Frequency modulation

2.1 RF system

Fig. 1 shows the experimental setup, which is similar to that described in a previous report [3], except for a low-pass-filter (LPF) at the output of the level-controller. The transconductance (g_m) of the CF amplifier is 0.05 Ohm^{-1} ; the output impedance is approximately given by $g_m^{-1} = 20 \text{ Ohms}$. The two ferrite cavities are coupled by a bias loop, each having a resonant structure with capacitors across the gap. The bias power supply for ferrites generates a dc-biased sinusoid at 40 Hz repetition. Because of a limited ac amplitude, the bias current was divided into three bands (150-550 A, 700-1200 A and 1300-1700 A) in order to examine in a wide frequency range. The tuning procedure of the VCO frequency was straightforward by viewing the phase difference between the voltages of the input/output of the CF valve, and adjusting

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the control voltage of the VCO via an IBM personal computer.

2.2 Results

The gap voltages and cathode currents are shown in Fig. 2. Each column corresponds to the band of the bias current. A maximum voltage of 500 Volts per one gap was obtained, ie 1 KV was available for the present two-gap system. Although the voltages seem to be reasonably sinusoidal, significant distortions can be seen in the current waveform at 2-2.6 MHz. These distortions are probably due to resonances in the input network. However, it was stable and no build-up oscillations were observed over the entire frequency range.

It is a natural consequence of a low output impedance that the current waveform is highly distorted rather than the voltage. If (V_1, I_1) and (V_n, I_n) are the fundamental and harmonic components, respectively,

$$\frac{I_n}{I_1} / \left(\frac{V_n}{V_1} \right) \approx \frac{1 / g_m + R}{1 / g_m + 1 / jn\omega C}, \quad n \geq 2,$$

where R and C are the shunt resistance (120 Ohms) and the gap capacitance (5.25 nF), respectively. The estimation at 1 MHz gives 7 for the second and third harmonics, which are consistent with measurements [3].

3. Barrier bucket

The Fourier spectrum for a unit single-sinusoid of period T_{rf} in a repetition period of T , where $T = hT_{rf}$, is given by

$$u(t) = \frac{2h}{\pi} \sum_1 \frac{\sin(n\pi / h)}{h^2 - n^2} \sin(2n\pi t / T).$$

For $h = 2.5$, the maximum amplitude of the harmonics is 0.42 at $n = 2$; 0.34, 0.29 and 0.16 for $n = 3, 1$ and 4, respectively. A wideband cavity is then required. Modifications were made on the above-used cavity as well as the amplifier system.

3.1 RF system

In order to avoid an additional resonance through a bias loop [3], a single cavity was used for the test. The resonant capacitors were removed and the ferrite rings were replaced by low-Q ferrites of the same kind (Ni-Zn). A solid-state amplifier having a group-delay within ± 5.6 nsec between 1.5 and 20 MHz directly drove the CF. The resistor across the grid and ground was also lowered in order to expand the bandwidth of the input network, and especially to match the output impedance (50 Ohms) of the solid-state amplifier. A commercial function generator was used as a master oscillator to produce a single sinusoid of 3.25 MHz with a repetition frequency of 1.3 MHz.

3.2 Results

Fig. 3 shows the broadband impedances of the single cavity and the gap, which is given by the parallel impedance of the modified cavity and the CF valve. The impedance seen by the beam is well reduced by the CF. Fig. 4 shows the RF voltages and currents to form the barrier

Fig. 2. RF voltages and currents at 40 Hz. From top to bottom line in each photo: grid-input and gap voltages (500 V/div) and cathode current (4 A/div for left and 5.6 A/div for middle and right columns)

Fig. 3. Broadband impedance of the cavity gap.

Fig. 4. RF voltage of the barrier bucket (100 V/div).