A LOW-FREQUENCY HIGH-VOLTAGE RF-BARRIER BUNCHING SYSTEM FOR HIGH-INTENSITY NEUTRON SOURCE COMPRESSOR RINGS*

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Abstract

A Los Alamos design for a 1-MW pulsed neutron source incorporates a ring utilizing an rf-barrier bunching system. This bunching concept allows uniform longitudinal beam distributions with low momentum spread. Bunching cavities are operated at the revolution frequency (1.5 MHz in our case) and each of the 2nd, 3rd, 4th, and 5th revolution frequency harmonics. Their effects combine to maintain a beam free gap in the longitudinal distribution of the accumulated beam. The cavities are driven by low-plate-resistance common-cathode configured tetrode amplifiers incorporating local rf feedback. Additional adaptive feed-forward hardware is included to reduce the beam-induced bunching-gap voltages well below that achievable solely with rf feedback. Details of this system are presented along with a discussion of the various feed-back and feed-forward techniques incorporated.

1. INTRODUCTION

A 1 MW pulsed neutron source ring design developed by a Los Alamos team incorporates an rf longitudinal-barrier [1] to maintain a beam free gap in the circulating beam. An rf Barrier consists of a series of high-voltage bipolar pulses applied across a gap in the beam pipe timed to occur just before and after the beam passes this barrier gap. Beam is forced out of the beam gap by these pulses. Longitudinal beam distribution within the bunch remains essentially uniform and the beam does not suffer the increased momentum spread imposed by a conventional bunching scheme. With a Longitudinal barrier scheme, if some increase in momentum-spread is desired, the energy of the injected beam may be swept. Figure 1 shows a preferred RF barrier pulse train taylored to one particular Los Alamos ring design and gives idealized beam distribution and timing.

Pulse waveforms may be generated by adding several harmonically related sinusoidal waves of appropriate magnitude. We have chosen this approach to provide the longitudinal RF barrier pulses for this bunching system design. A series of harmonically related frequencies are added to produce the equivalent barrier pulse of Figure 2. Table 1 lists the harmonic amplitudes and frequencies needed to produce this equivalent pulse.

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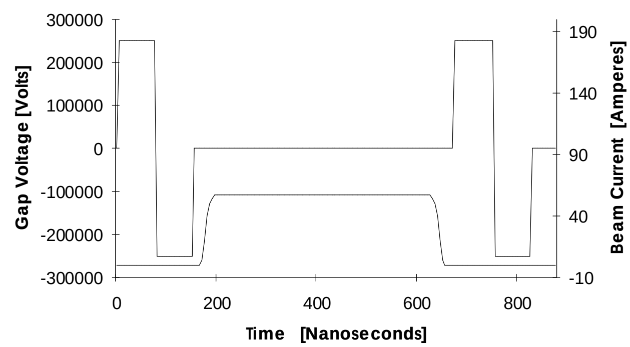

Figure 1: RF Barrier Pulses and Beam Current

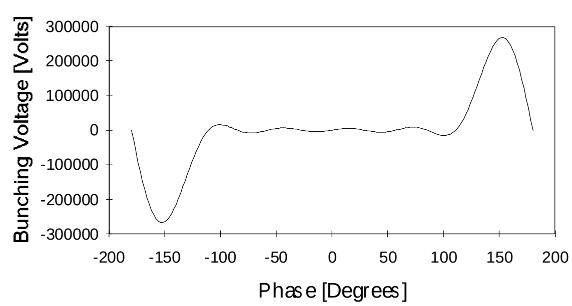

Figure 2: Composite RF Barrier Waveforn

Table 1: Longitudinal RF Barrier Harmonic Voltages

Fundamental .... 1.49 MHz .... 61.38 kV
Second Harmonic ... 2.98 MHz ... -98.45 kV
Third Harmonic ...... 4.47 MHz .... 99.00 kV
Fourth Harmonic ....5.96 MHz ....-70.30 kV
Fifth Harmonic ....7.45 MHz .... 29.58 kV
Harmonics are all in phase with respect to the fundamental.

It is not necessary to actually add the frequency components within one cavity structure. Separate single-resonant-frequency cavity structures may be installed with an accumulated effect on the beam equivalent to that of the composite waveform.

The waveform of Figure 2 is a worst-case-design RF barrier waveform resulting from a particular set of ring parameters. By relaxing some of the requirements for beam loss and selecting different ring operating parameters major reductions in the peak required voltage can be achieved. Lower peak voltages would allow simplification of the system by reducing the number of rf stations operating at each harmonic and in the total power required to operate the system..

II. GENERAL PARAMETERS

To provide a 250 kV peak barrier waveform this design uses a total of 13 active RF cavities and 1 spare cavity. The cavities are dual-gap single-ended structures with each of the sections driven by its own power amplifier. Cavities that operate on the two lowest frequencies, 1.5 MHz and 3 MHz, are 2.4 meters long while the higher frequency cavities are 1.8 meters in length. The cavities are installed with their ferrite sections downstream of the gaps allowing beam current to add to the forward current of the power amplifier tube. Bias conductors are included in the cavities to provide electronic fine tuning. Gap shorting switches are included in each cavity so any cavity may be removed from service without adverse effects on the circulating beam. The spare cavity can operate on any of the normal cavity frequencies to replace a failed cavity.

Amplifiers consist of a pulsed, class A biased, grounded-cathode super-power tetrode and two driver stages all physically located at the cavities in the beam channel. Bunching gap impedance is kept at a low impedance by the low plate resistance of the output tube, active RF feedback around the three power amplifier stages and feed-forward beam compensation. Each of the two cavity gaps is driven by an independent amplifier, but each amplifier can drive both cavity gaps allowing continued operation in the case where one amplifier fails.

Table 2 gives the main system parameters for a 250 kV peak barrier.

Table 2: System Parameters

Revolution Period................................ 671 nsec
Number of Bunches 1
Fundamental Bunching Frequency ..... 1.4901 MHz

RF Cavities
- Total Number 14
- Gaps per Cavity 2
- Maximum Voltage per Cavity 35kV
- Maximum Voltage per Gap 17.5kV

  - Fundamental .... 3 each....20.6kV/Cavity
  - Second Harmonic .... 3 each....32.8kV/Cavity
  - Third Harmonic .... 3 each....33.0kV/Cavity
  - Fourth Harmonic......... 3 each.....23.4kV/Cavity
  - Fifth Harmonic............ 1 each.....29.9kV/Cavity
  - Spare (any harmonic) .. 1 each

Ferrite Type ....Phillips 4M2
- Core Size
  - Inner Diameter .... 30 cm
  - Outer Diameter .... 60 cm
  - Thickness .... 2.71 cm

Final Amplifier
- Total Number ....28 (2 per cavity/ 1 per gap)
- Configuration ..... Common Cathode, Low Rp Tetrode, Class A Pulsed
- Tube Type .... Eimac X2242
- Active Rp ....450 ohms (dependent on bias choices)
- Maximum DC Dissipation ..... 100 kW/Amplifier
2.6 MW Total
- Nominal Operating DC Dissipation ... 48 kW/Amplifier
1.25 kW Total
- Duty Factor .... 8 %

III. RF CAVITY

A conventional ferrite loaded structure employing parallel DC bias has been chosen. Separate cavities will operate at each of the first five harmonics of the 1.5 MHz revolution frequency (1.5 MHz to 7 MHz). Setting a peak voltage-per-cavity of 35 kV will allow a 250 kV peak waveform to be generated with 12 cavities. An additional 1.5 MHz cavity is desirable and increases the total operational complement to 13. A Spare cavity has also been provided for bringing the total installed cavities to 14.

The cavities are configured as single-ended structures. Configuring the cavities this way allows a single, class-A biased, power amplifier tube to be placed directly across the gap. The amplifier provides the required RF bunching voltage and also acts as a resistor connected across the bunching gap to maintain a low gap impedance.

A pair of single ended cavities are combined within one housing with a common bias winding The bias winding forms a single turn around each ferrite core stack. The complete winding is routed such that the RF voltage induced by one core stack bucks that induced by the second core stack. As long as both core stacks are operated at the same RF voltage level the induced voltages on the bias windings will cancel.

A single design that can be used for all five frequencies is desirable. Bias windings that are included for fine control of cavity resonance can also provide this feature. To reduce the total permeability swing needed we would remove some of the ferrite for the higher frequency cavities. This also saves some ring space. Assuming type 4M2 ferrite [2,3,4] with 60 cm OD and 30 cm ID rings we would fill the two lowest frequency cavities with 1.26 meters of ferrite, the amount needed to keep the B field below 200 gauss at 1.5 MHz. The remaining higher harmonic cavities would be filled with 0.87 meters of ferrite. The spare cavity would be filled with the full ferrite load and include shorting pins to effectively remove the excess ferrite when operated ha the higher frequencies.

IV. AMPLIFIER

The high circulating beam currents of our reference design impose a severe beam loading requirement on the final amplifier design. For the fundamental component of beam current we must provide control for currents in the 30 ampere range. Our reference design places a low-output-impedance-amplifier directly across the cavity bunching gap providing a low-impedance shunting path for the beam current and keeping the beam induced voltage within reasonable limits. The amplifier is effectively acting as a water-cooled resistor connected across the bunching gap. Assuming an amplifier output impedance of 450 ohms the beam induced voltage would be limited to 13.5 kV. Utilization of RF feedback techniques [5,6,7] would further reduce the effective output impedance. We have estimated a reduction factor of 7 for our lowest frequency so we believe we can achieve effective cavity gap impedances in the 35 to 55 ohm range.

An adaptive feed forward techneque developed for our Ground Test Accelerator project (GTA) has demonstrated effective impedance reduction factors better than 40 times [8,9]. The technique uses stored error data from previous beam pulses to predict and correct-for beam induced signals on the present beam cycle. The technique is self adjusting to accomodate slowly changing beam conditions and has the potential of reducing the effective impedance well below the 10 ohm range anticipated with a beam-feed-forward approach.

V. ADAPTIVE FEED-FORWARD

A conventional feed-forward technique involves using a direct measurement of the beam current to perform a correction. This technique requires that a correction based upon the measured beam current signal be applied before the beam arrives to compensate for the delays in the amplifier chain. This requires the measured beam current signal to be transmitted over a shorter distance with a faster propagation velocity than the beam itself. If the beam current is measured just after its corresponding cavity, there is sufficient time to apply the correction because one full revolution occurs before the beam returns to that cavity.

The adaptive feedforward device observes errors in the gap voltage and phase for each bunch revolution, and over time, adaptively determines a correction function that is applied at the RF driver to oppose those effects. In essence the past fluctuations in gap voltage and phase are used to predict the current fluctuation and a corresponding correction function to negate any deviations from the desired operating point. Because this is a feed-forward technique, the apparent longitudinal coupling impedance is reduced over the entire band of interest including all five harmonics and the synchrotron sidebands. Modeling simulations and experimental data are necessary to determine the exact reduction in longitudinal coupling impedance.

VI. REFERENCES

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