THE NAL BOOSTER SYNCHROTRON MAGNET POWER SUPPLY SERVO

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Summary

The booster magnet power system operates 48 magnet modules for equilibrium orbit field control.[1] The power system consists of four high current power supplies having a common thyristor firing control chassis. The power supplies were manufactured by Brentford Electric Ltd.[2] The magnet energizing current waveform is

$$I(t) = I_{dc} - I_{ac} \cos 2\pi ft,$$

where f is the 15 Hz series resonant frequency of the high Q circuit. The dc and ac components are generated with one power source, not two as in earlier designs for rapid-cycling synchrotrons (e.g., NINA, DESY, CEA, PPA, and Cornell).

Magnet power system parameters are summarized as follows:

Operation	Energy	B_{Mag}	I_{Mag}	E_{Source}
Injection	200 MeV	488 G	74 A	64 V
Extraction	8 GeV	6.7 kG	1023 A	890 V

Introduction

The system multiloop servo has a slow regulating or current loop to compensate for magnet parameter changes due to environmental effects. The line voltage fluctuations are compensated by the internal voltage or fast regulating loop.[3] Figure 1 shows that the slow loop is divided for control of maximum current (IMAX = 1023 A) and minimum current (IMIN = 74 A). Regulation with respect to the IMAX and IMIN levels permits single power source magnet drive. The cycle-to-cycle and long term servo resolution specification for ΔI/IMAX is one part per 10,000 and ΔI/IMIN is two parts per 10,000.

System Description

The current loop transducer is a second harmonic modulator type transducter which is capable of better than 100 ppm resolution for 1000 A. The transductor MAX output (×1 = 100 A/V) generates the IMAX monitor voltage and error signal. The MIN output (×10 = 10 A/V) provides the IMIN monitor voltage and error signal.

Sample-and-hold circuits follow the IMAX and IMIN signals. The S&H circuits are triggered to hold the IMAX peak and IMIN valley voltages. Synchronized trigger pulses are generated by the zero-crossing detector connected to the $\dot{B}$ coil. The IMAX peak occurs at the negative-going $\dot{B}$ voltage, and the IMIN valley occurs at the positive-going $\dot{B}$ voltage. The S&H outputs are ADC monitored for computer digestion.

Computer-controlled DAC inputs provide the reference levels for error signal generation at the summing junctions. A frequency-compensated gain stage with a feedforward feature operates on the error signal and produces a control level for each half of the slow loop. The IMAX and IMIN control levels are combined by a booster clock controlled FET switch. The 15 Hz clock signal is referenced by a phase-locked loop to the 60 Hz utility power.

The FET switch square-wave output is converted to a trapezoidal wave by the low pass filter. This trapezoidal output is summed with the negative feedback signal of the voltage loop, amplified, and applied to the Brentford power supply thyristor firing circuits for magnet field control.

The summed voltage feedback signal is derived from balanced resistive voltage dividers. The signal is then band-reject filtered to remove the 720 Hz thyristor modulated ripple voltage and summed with the slow-loop control signal. The voltage feedback is taken at the output of each power supply rather than the power filter output to obtain maximum frequency response and consequent best voltage regulation. The power filter attenuates the 720 Hz ripple voltage to eliminate field effects.

The servo design requires high accuracy 14 bit ADC's, DAC's, and compatible S&H's. All operational amplifiers are chopper stabilized units.

Initial efforts at stabilizing the high gain open loop servo resulted in a conventional lag break to set the slow loop bandwidth and an experimentally adjusted lead break to compensate for the complex magnet impedance. Magnet design was such that the dc impedance was lower than the ac impedance. Consequently, the magnet voltage would swing negative at the current minimum if a sinewave input were applied, but the free-wheeling magnet discharge diodes would conduct and clip the voltage waveform at zero. The clipping prevented regulation of IMIN due to the loss of thyristor control. The trapezoidal waveform allowed the firing circuits to maintain a high degree of IMIN control, while the high Q of the magnet circuit produced a sinusoidal magnetic field.

Additional efforts succeeded in measuring the dc resistance and the ac resistance of the magnet circuit and realizing that the L/R_{ac} and L/R_{dc} zeroes had to be separately compensated. The compensation was accomplished with experimental gain adjustments and then calculating the necessary RC compensation. This resulted in dual lag-lead breaks in the slow-loop amplifiers.

The frequency response thus critically adjusted underscored the transductor resolution limits. The IMIN output has poor resolution due to noise generated by an internal high gain amplifier. An attempt is presently underway to reduce the noise on IMIN by affecting the scaling factor with a transductor modification. The rework requires feedback core substitution and changing the metering resistor to give a higher sensitivity. The operating resolution for IMAX is better than one part per 10,000. IMIN resolution is limited to five parts per 10,000 because of the transductor accuracy limits. The transductor modification should correct this deviation and permit resolution better than that specified.

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Acknowledgment

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References

1. Booster Synchrotron (E. L. Hubbard, Editor), National Accelerator Laboratory Internal Report TM-405, January 1973.

2. Brentford Electric Ltd., Power Supply Manual, CX69.1112.

3. A. R. Donaldson, Booster GMPS Servo, National Accelerator Laboratory Internal Report TM-411, February 1973.

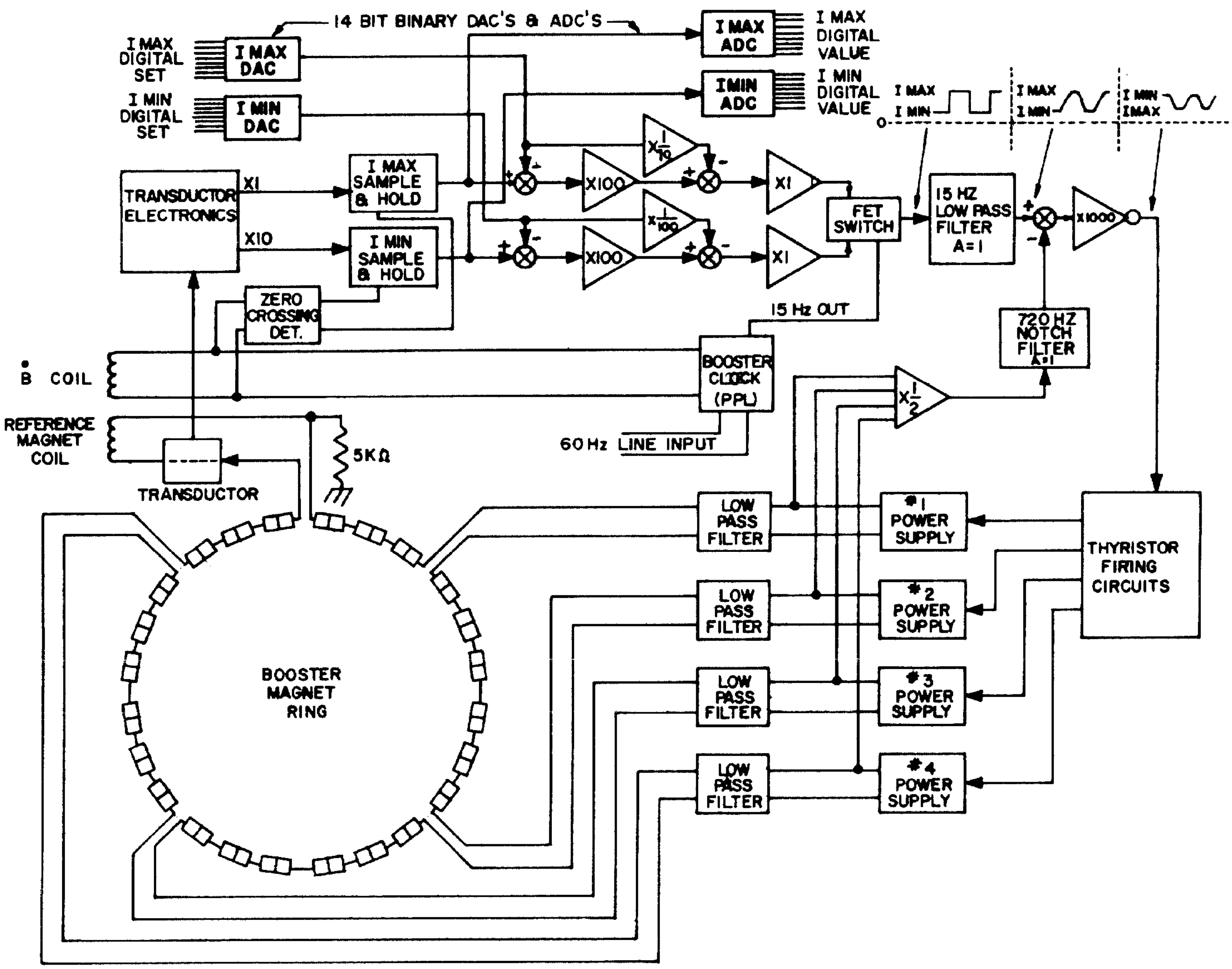

Fig. 1. Booster magnet power system block diagram.