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DESIGN AND PERFORMANCE ASPECTS OF A PRECISION HIGH-CURRENT POWER SUPPLY

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Introduction

The Ferrite Bias Supply, in essence, is an error power amplifier in the resonant cavity frequency tuning system. As such, it accepts inputs from a programmed voltage source and from a phase detector. In response to these input signals, it produces dc current in the tuner windings as required for resonant frequency. The resulting ampere-turns saturate ferrite cores, changing the inductance and the resonant frequency of the cavity.

Because of its strategic location, the performance and operational requirements on the bias supply are severe. There are 16 bias supplies in the booster and 16 in the main accelerator, with additional units to be added.

Performance Requirements

Power Rating	100 kW (2500A @ 40V)
Range of Current Control	25 to 2500A
Voltage Compliance	+35 to -15V
Slewing Rate	200,000A/sec
Operating Mode	dc and pulsed at 15 Hz rate
Frequency Response, small signal	5 kHz
Load Inductance	300 to 30 Microhenries
Load Resistance	4 milliohms
Regulation, Ripple and Noise and Dynamic Error for a Constant Input	0.8% (200 mA) at 25A, 0.1% (2.5A) at 2500A

Miscellaneous Requirements

Floating output.

Dimensions not to exceed 36" wide, 78" high, and 66" deep.

Water cooling.

Be reliable and maintainable.

Low cost.

System and Circuit Design

Traditionally, the series pass element approach has been used in the precision current regulators. In our application, the series pass element approach was rejected for reasons of economy and complexity.

In this design, thyristors are used for coarse control and power transistors for fine control of current, as shown in the simplified block diagram in Figure 2. A 12-phase thyristor converter on the secondary side of the voltage step-down transformer, controlled by a fast-firing circuit, provides the required slewing rate of 200,000A/sec into the saturable ferrite. The resultant current ripple, however, is not acceptable and additional filtering is necessary. This filtering is of 2 types, the passive consisting of a 75-microhenries, 4-terminal choke and an active filter. Because of the pulsed type of operation, no capacitors are used in the filter circuit.

An active shunt element is used to bypass or shunt the undesirable currents which do not relate to the input program. These undesirables specifically include the ripple and noise generated by thyristors. By means of negative feedback from the output current to the base of the power transistor type shunt element, the impedance of the shunt element to the undesirable signals is made very small compared to the impedance of the load.

The functional block diagram in Figure 3 shows some of the details. The shunt element, consisting of 180 power transistors in parallel, is connected directly across the load. A steady state current of approximately 250A is supplied by the thyristors and regulated at this level by a closed loop, referred to as the I_Q loop; however, the peak value of current in the shunt element may reach 2500A. The required value of steady state current is set by I_Q reference, compared with a signal proportional to the actual emitter current and the resulting error signal is amplified and fed to the thyristor gate drive circuit. The loop gain of this loop is approximately 10. It is helpful to keep in mind the polarities of various signals in the loop; an increasing I_Q decreases the thyristor gate drive and vice versa.

A 15V power supply, OPS, is connected in series with the collector to provide an operating V_{CE} for the power transistors when the voltage across the load swings in the negative direction.

The shunt element is driven by a subsidiary loop referred to as the E_o loop. A signal proportional to the output voltage is compared with E_o reference and amplified by a factor of 50 at dc in the 2 amplifier stages which also include the necessary phase compensation. The polarity is such that an increasing output voltage increases I_Q and decreases the thyristor gate drive. Thus, an undesirable spike of voltage at the output would be bypassed by the shunt element.

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The output of the output current sensor, having a transfer factor of 10V per 2500A is amplified by a factor of 50 at dc, and is also summed at the first E_O stage thus completing the I_O loop. The dc loop gain of the I_O loop is approximately 150 and the polarity of signals is such that increasing load current, for a constant input signal increases the I_Q and decreases the thyristor gate drive. Thus, the undesirable current as sensed by the current sensor is bypassed by the shunt element.

Test Results

The slewing characteristics of the bias supply are shown in Figure 4. As can be observed from the actual photographs, the output current tracks the input voltage with a relatively small dynamic error from 0 to 2500A in 12.5 milliseconds. The output voltage rises steeply to 35V, then drops to negative 10V as the current is forced to zero. The shunt element current varies about its steady-state value as required to maintain the load current closely related to the input program.

Figure 5 shows the photographs of current and the voltage ripple when the output current is set to 500A (worst ripple condition), and using the Fermilab developed current sensor. Finally, the frequency response is shown in Figure 6. The difference in 3 curves is due primarily to the type of current sensor used. Curve A was obtained using a commercially available transductor; Curve B using the Fermilab-developed transductor; and Curve C using a resistive current sensor with a commercially available isolation amplifier having limited bandwidth. The present plans are to replace this amplifier with an optio-isolated amplifier now in development.

Equipment Design

A photograph of a completed bias supply is shown in Figures 1 and 7. To satisfy the requirements of reliability and maintainability in addition to performance, special components and subassemblies were developed. The specially developed components include the power transistor modules, solid-state contactor and a precision current sensor. These items are subjects of separate papers.[1, 2, 3]

The ease of maintenance is particularly important in this equipment because the downtime has to be kept to a minimum, once installed, the servicing can be performed through the front door only, as can be seen from Figure 1, and because of the large number of delicate components used. The ease of maintenance was designed-in by analyzing the probability of occurrence and the corrective steps required for various types of failure, and then building the equipment for minimum downtime and minimum corrective effort.

The maintainability game plan was based on the assumption of a worst case type of failure which would probably require the following corrective steps:

1. Diagnosis from a remotely located control center.
2. Diagnosis from a local position, using the built-in deflection type meters and a selector switch.
3. Diagnosis from a local position, using an external single-ended oscilloscope and the built-in test points.
4. Replacement of defective components or modules within the cabinet.
5. Replacement of the entire unit with an operational spare.

The reliability of operation is achieved by:

1. System and circuit design based on fail-safe concepts.
2. Judicious selection of high quality industrial grade components.
3. Operating all components within their safe operating areas.
4. Fault isolation and protective circuitry for quick power disconnect.
5. Ease of maintenance.

Acknowledgements

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References

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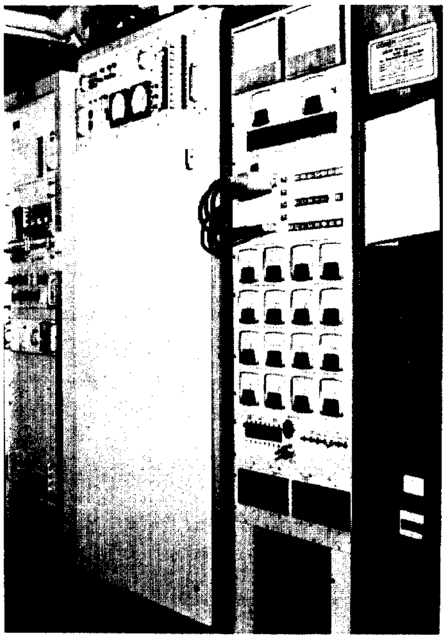

Fig. 1. Bias Supply Installed.

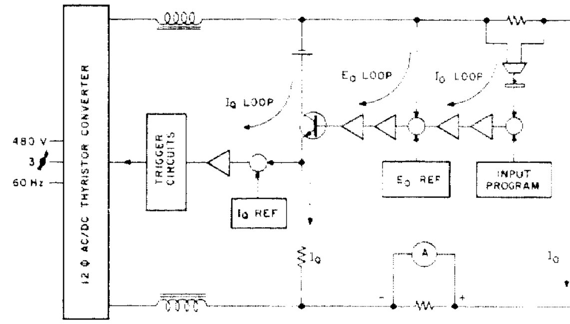

Fig. 3. Function Block Diagram of the Ferrite Bias Supply.

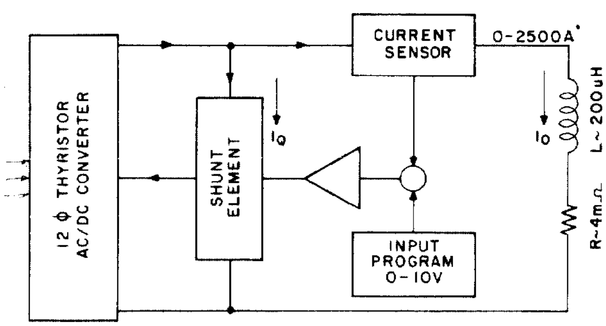

Fig. 2. Simplified Block Diagram.

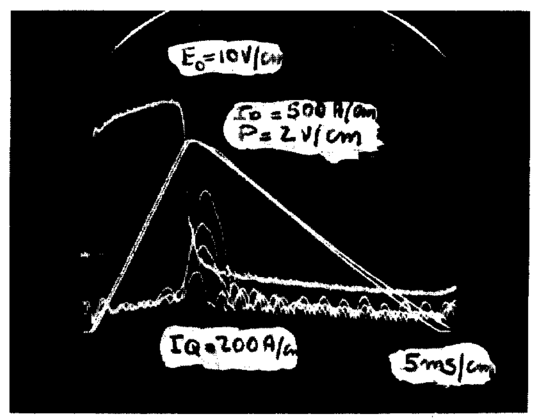

Fig. 4. Ramp Waveform Response.

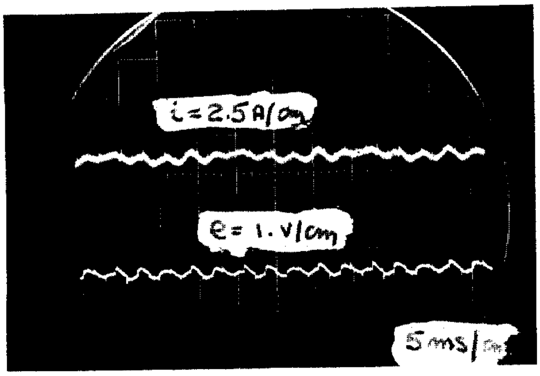

Fig. 5. Current and Voltage Ripple.

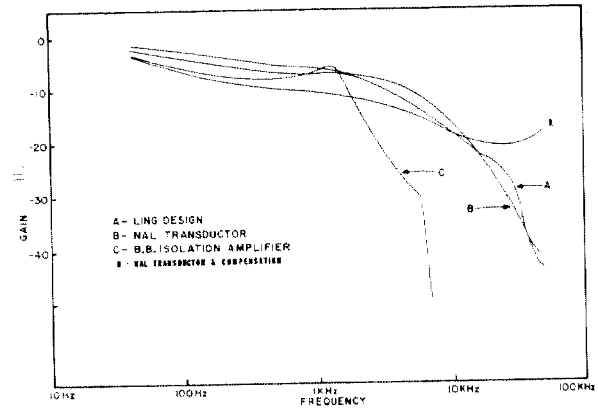

Fig. 6. F/R of the Ferrite Bias Supply (Io/E in).

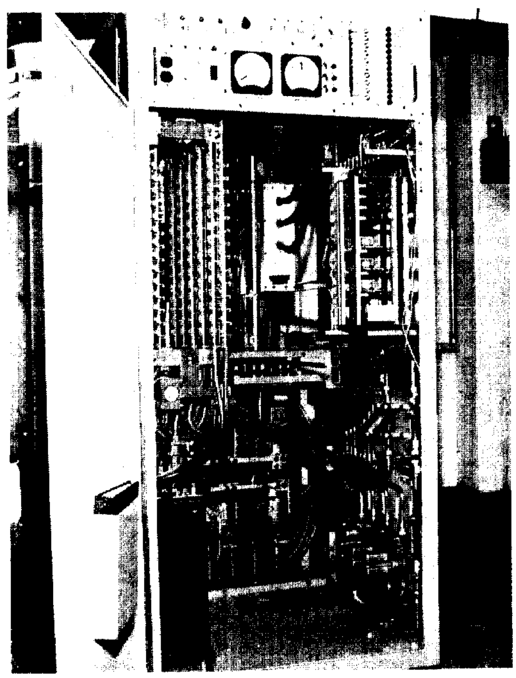

Fig. 7. Front View of Bias Supply.