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# Magnet Power Supplies for the Advanced Light Source

L. Terry Jackson and Ivan C. Lutz

Accelerator and Fusion Research Division  
Lawrence Berkeley Laboratory  
1 Cyclotron Road  
Berkeley, California 94720

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# MAGNET POWER SUPPLIES FOR THE ADVANCED LIGHT SOURCE\*

L. T. Jackson and I. C. Lutz

Lawrence Berkeley Laboratory  
University of California  
Berkeley, California 94720

## Abstract

The Lawrence Berkeley Laboratory (LBL) is building an Advanced Light Source (ALS) to produce synchrotron radiation. An electron linear accelerator, and a booster synchrotron are used to accelerate the electron beam to 1.5 GeV to fill the storage ring. This paper describes the power supplies used for the magnets in the booster and the storage ring and the interface requirements for computer control and monitoring of the power supplies and magnet currents.

Magnet	Amps	Volts	Tracking
Bending	800	1175	na
Quad QF	460	245	0.1%
Quad QD	460	245	0.1%
Sext SF	6	130	0.5%
Sext SD	6	92	0.5%
Correction			
Dipoles	+/-6	36v ea	0.5%

Table 1. Booster Magnets Power Supplies

## Booster Bending Magnets Power Supply

The 24 bending magnets in the booster are electrically connected in series and powered by an unregulated, SCR controlled, power supply capable of operating in the inversion mode as well as the rectification mode.

The booster operates at 1 cycle per second. At the start of each cycle the SCRs are phased for full output voltage and the current builds up in the magnets on the magnets L/R time constant from 0 to 738 amps in about 0.45 seconds (accelerating the electron beam from 50 MeV to 1.5 GeV) at which time the SCRs are phased for inversion transferring the energy stored in the magnets back to the power line and the magnets current decays to zero in time for the next cycle. (see Figure 1)

The bending magnets current does not need to be regulated (eg a linear ramp) if the magnetic fields of the other magnets in the booster track the magnetic field of the bending magnets to the required accuracy during the beam acceleration portion of the cycle.

## Booster Tracking Accuracy

The tracking accuracy requirements during the beam acceleration portion of the cycle are 0.1% for the quadrupole magnets and 0.5% for the sextupole and correction dipole magnets. There are no tracking requirements during the magnets de-energization portion of the cycle.

The specified tracking requirements applies at the beam injection energy of 50 MeV as well as all during the beam acceleration to 1.5 GeV portion of the machine operation cycle. Referred to peak magnet current, the tracking accuracy is about 3.3E-5 for the quadrupoles and 1.67E-4 for the sextupoles and the correction dipoles.

A precision DC current transducer (DCCT) monitoring the bending magnets current is used to generate a voltage proportional to current. This voltage is used as a reference

signal for the power supplies of the other magnets in the booster. Since the magnet current is monitored instead of the magnetic field, if the magnetic field is not linear with the magnet current to the degree required a software program will be written to generate a correction voltage to be mixed with the DCCT output voltage to make the reference voltage linear with the magnetic field (see Figure 2). This provision is made for each of the magnets in the booster.

## Booster Current Monitoring

The magnet current of each of the magnet families in the booster is monitored with a DCCT or a resistor generating a voltage proportional to current. Each of the voltages are connected to a separate sample and hold circuit so that all of the currents can be read at the same time within a window of less than 100 microseconds. The output of the sample and hold circuits are then read by ADCs and compared in the computer to see if they are tracking to within the required accuracy.

## Current Range Control

As the bending magnets current increases from zero to 738 amps each cycle (increasing the beam energy to 1.5 GeV) the current in the other magnets may not be required to increase to the maximum listed in the above table. For example, the quadrupole current at 1.5 GeV needs to be adjustable from 200 to 460 amps.

This range change is done by feeding the reference voltage from the bending magnets DCCT thru an analog multiplier with a transfer function of  $(VxVy)/10$ . The reference voltage is  $Vx$  and  $Vy$  is obtained from a digital to analog converter (DAC) in the Intelligent Local Controller (ILC) [1] allowing the computer to control the peak magnet current at 1.5 GeV. This range control feature applies to all of the magnets (except the bending magnets) in the booster.

## Analog to Digital Converter (ADC) Requirements

The tracking accuracy of the quadrupole magnets is 0.1% at injection as well as all during the acceleration portion of the cycle. The minimum range current at injection is about 6.5 amps. The DCCT monitoring the quadrupole current is rated 10 volts at 480 amps so at injection the DCCT voltage is only 0.135 volts and 0.1% of 0.135 volts is 135 microvolts. 135 microvolts is 1 part in 74,000 of 10 volts. A true 17 bit 0 to 10 volt ADC with a resolution of 1 part in 131,000 is required to be able to read the magnet current with sufficient resolution to compare it to the bending magnets current to see if the quadrupoles are tracking to within 0.1%.

The ADC requirements for the sextupole and correction dipole magnets is essentially the same even though the tracking accuracy is relaxed to 0.5% because these magnets may be required to have a range greater than that of the quadrupoles.

## Booster Quadrupole Magnets Power Supplies

There are 16 focusing quadrupole magnets and 16 defocusing quadrupole magnets in the booster array. The focusing quadrupoles (QF) are electrically connected in series and powered by one power supply and the defocusing quadrupoles (QD) are electrically connected in series and powered by another power supply.

The power supplies for these two magnet families are custom built for this application and are current regulated by means of

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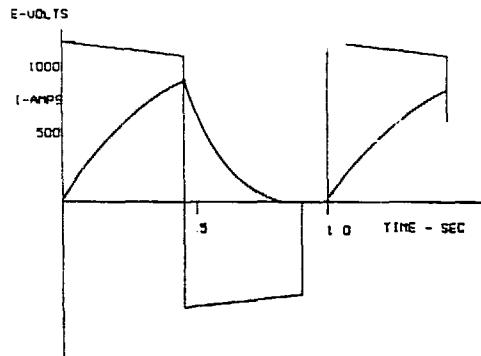
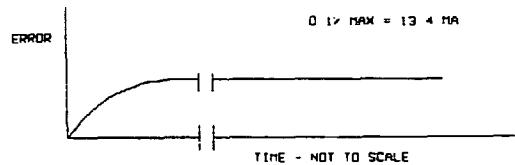
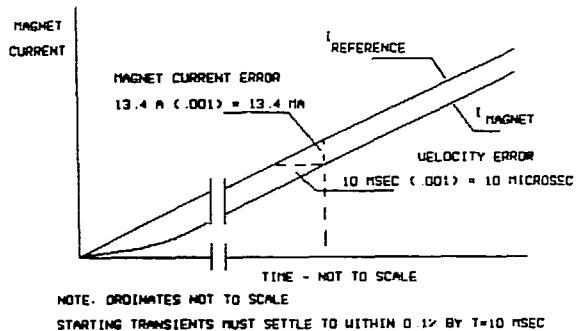


Figure 1. Booster Bending Magnets Voltage and Current Waveforms



The velocity error is equivalent to the time constant of the step response of the closed-loop system. Therefore the closed-loop bandwidth must be,  $\frac{1}{c} = (2\pi T)^{-1} = (2\pi 10^{-5})^{-1} = 16 \text{ kHz.}$

Figure 3. Booster Quadrupole Tracking Requirements

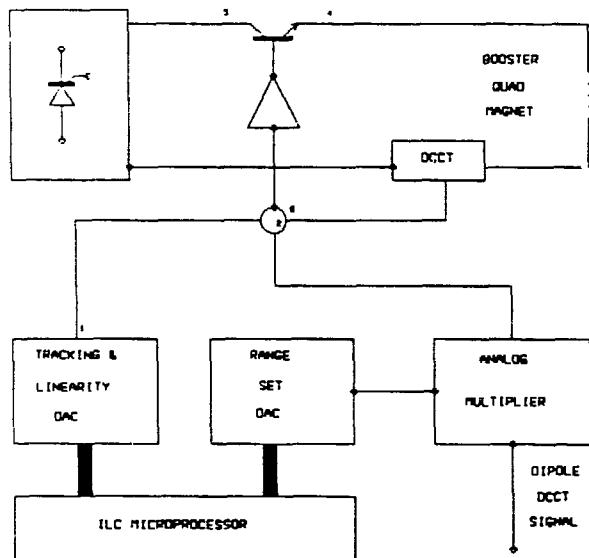


Figure 2. Typical Booster Power Supply Dynamic Reference System

series transistors driving the magnets in an emitter follower configuration to obtain the closed-loop bandwidth of about 16 kHz required to meet the tracking requirements (see Figure 3). A precision DCCT with a wide bandwidth is used to derive a voltage proportional to magnet current for use as the feedback signal for the current regulator and for the computer to monitor the current. The two supplies are identical.

#### Booster Sextupole Magnets Power Supplies

There are 20 sextupole magnets in the booster magnet array. These magnets are connected into two families of 12 and 8 magnets each and powered by two power supplies or if suitable power supplies cannot be purchased, the magnets can be connected in groups of less than 12 and 8 and the computer can monitor the tracking accuracy of the groups. Commercially available power supplies are presently being evaluated for this application, however, the requirement for a tracking accuracy of 0.5% at beam injection (about 50 mA or less) is beyond the capabilities of most power supplies in this range.

#### Booster Correction Dipole Magnets Power Supplies

There are 16 horizontal and 16 vertical correction dipole magnets in the booster magnet array. Each of the magnets is to have its own bi-polar power supply which can be computer controlled. The maximum current at 1.5 GeV is +/- 6 amps. The maximum voltage required for tracking the bending magnets current waveshape is about +/- 9 volts. It is desired to have the capabilities of changing the  $dI/dt$  of the correction magnets during the beam acceleration portion of the cycle to approximately four times normal so a power supply voltage of about 36 volts is being considered.

Commercially available bi-polar power supplies are presently being evaluated for this application, but as mentioned above for the sextupole magnets, the requirement of a tracking accuracy of 0.5% at the beam injection energy of 50 MeV is beyond the capabilities of most catalog item power supplies.

<u>Magnet</u>	<u>Amps</u>	<u>Volts</u>	<u>Stability</u>	<u>No.</u>
Bending	970	536	+/-5.0E-5	1
Quadrupole				
Family QFA	507	350	+/-1.0E-4	1
QF	113	45	+/-1.0E-4	24
QD	113	33	+/-1.0E-4	24
Sextupole				
Family SF	395	200	+/-1.0E-3	1
Family SD	395	200	+/-1.0E-3	1
Skew Quad	15	30	+/-1.0E-3	4
Vert. Corr.	+/-19	40	+/-5.0E-4	24
Horiz Corr.	+/-21	45	+/-5.0E-4	48
Correction				
Horizontal	+/-33	25	+/-5.0E-4	48
Vertical	+/-116	15	+/-5.0E-4	48

Table 2. Storage Ring Magnets Power Supplies

#### Storage Ring Magnets Current Control and Monitoring

The control and monitoring of the current in the storage ring magnets is done by dedicated DACs and ADCs for each magnet power supply. There is no tracking requirements. When the beam in the storage ring is ramped from 1.5 to 1.9 GeV the ramp is slow enough that the computer can adjust the magnet currents on an individual basis. There is no need for sample and hold circuits to read the magnet current.

The dedicated ILCs mounted in the power supply racks each contain four ADCs and four DACs and can monitor and control four magnet power supplies.

Precision DCCTs are planned for monitoring the bending magnets current, the quad family QFA current, and the sextupole families SF and SD currents. The method of monitoring the magnet currents in the auxiliary windings on the sextupole and the correction dipole magnets has not yet been decided.

#### Storage Ring Bending Magnets Power Supply

The 36 bending magnets in the storage ring array are electrically connected in series and powered by one power supply. The total circuit inductance is about 0.6 henrys and the resistance is about 0.55 ohms. The design operating range for the storage ring is from 1.0 to 1.9 GeV which results in a current range from 477 to 924 amps. The current stability of +/-5.0E-5 applies over the entire range. This power supply will be built to LBL specifications and is anticipated to use series transistors for current regulation and will use a precision DCCT to monitor the magnet current.

#### Storage Ring Quadrupole Magnets Power Supplies

There are 24 horizontally focusing quadrupole magnets electrically connected in series in the storage ring magnet array known as quadrupole family QFA. These magnets are powered by one power supply. The inductance of the total circuit is about 133 mH.

The magnet current stability requirements are +/-1.0E-4 so a series transistor current regulated power supply will be custom built per LBL specifications. A precision DCCT will be used to monitor the magnet current.

The storage ring also has 24 horizontally focusing quadrupole magnets (known as QF) and 24 vertically focusing quadrupole magnets (known as QD) each with individual power supplies. The required magnet current stability is 1.0E-4 and the configuration of the power supplies and the method of monitoring the magnet current has not yet been decided.

#### Storage Ring Sextupole Magnets Power Supplies

The 48 sextupole magnets in the storage ring each have four windings: sextupole, horizontal corrector, vertical corrector, and skew quadrupole windings.

Twenty-four of the sextupole windings are connected in series (known as family SF) and are powered by one power supply. The other 24 are connected in series (known as family SD) and are powered by another power supply. These power supplies are planned to be current regulated by means of SCRs. The current monitor has not been chosen at this time.

Each of the vertical and horizontal corrector windings has a separate power supply which needs to be bi-polar with current stabilities in the order of +/-5.0E-4.

Sixteen of the skew quadrupole windings are connected in four families of four magnets each. Each family of magnets will have its own power supply.

#### Storage Ring Correction Dipole Magnets Power Supplies

There are 96 correction dipole magnets in the storage ring. The power supplies for these magnets and the ones for the correction windings on the sextupole magnets are required to be bipolar with smooth transition thru zero. Commercially available power supplies are being evaluated at this time. The addition of external current stabilizing loops around commercial power supplies as well as open loop periodic zero drift cancellation circuits are being considered.

#### Reference

[1] S. Magyary, et al, "Advanced Light Source Control System", this conference