THE "SF" SYSTEM OF SEXTUPOLES FOR THE JLAB 10 KW FREE ELECTRON LASER UPGRADE *

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Abstract

The characteristics of the system of "SF" Sextupoles for the infrared Free Electron Laser Upgrade[1] at the Thomas Jefferson National Accelerator Facility (JLab) are described. These eleven sextupoles possess a large field integral (2.15 T/m) with +/- 0.2% field quality over a 120 mm width within a very short effective length (150 mm pole length) and have field clamps for fast field roll-off. The field integrals reproduce extremely well with good absolute resolution (+/- 0.1%). The simple, two-dimensional shape pole tips (directly from the original 3-D RADIA magnetic model) of these "all ends" magnets include the correction for end fields[2]. Magnetic measurements are compared to the model. The system's hysteresis protocol and power supplies were also used for the measurement process to enhance reproducibility in service, a recent initiative at JLab. The intricacies of magnetic measurement using the JLab field probe based Stepper Stand are described. The details of the system's low quality power supplies brought to 50-200 PPM current regulation using in-house designed feedback and of control by CAN-Bus are described.

GENERAL DESIGN

Eleven large bore (26.8 cm pole bore) sextupoles are required by the beam optics of the Bates Bend Arcs and in the UV Branch of the Thomas Jefferson National Accelerator infrared Free Electron Laser Upgrade[1]
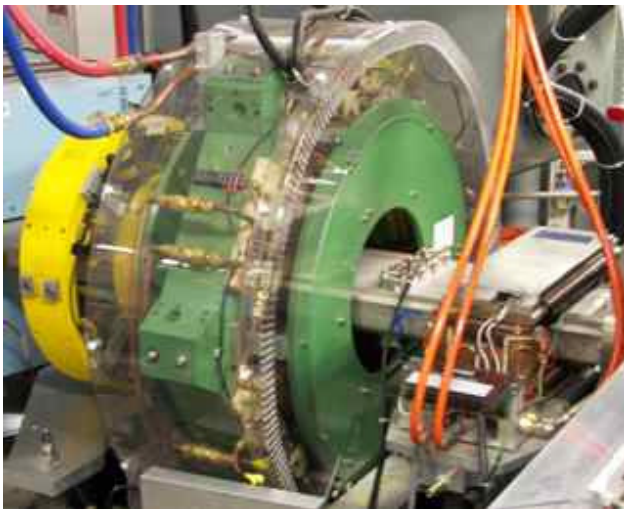

Figure 1: Typical sextupole in a shared drift region.

The sextupole correction of up to 2.15 T/m is applied to an electron beam is nominally 120 mm wide in these high dispersion regions. Required Field Integral at r = 12 cm is 30 kGauss-cm. Required field quality (Sum of error harmonics) is 1 part in 1000 at r = 7.5 cm and 1 part in 100 at r = 12 cm. Fitting over a 27 cm wide by 8 cm high beam chamber, the sextupoles share short 1.25 m drift regions with trim quadrupole elements and in some instances with vertically bending dipole trim[2], and octupole trim elements. Minimal cross talk between elements is required. A typical drift is shown in figure 1.

The Sextupoles were designed by Duly Research using the 3D, finite difference program, RADIA. The pole tips, shaped to a 2D curve based on a decimal fraction exponential expression, have 3D field correction built in[3]. The predicted field quality (exceeding specification) vs. excitation is shown in Figure 2.
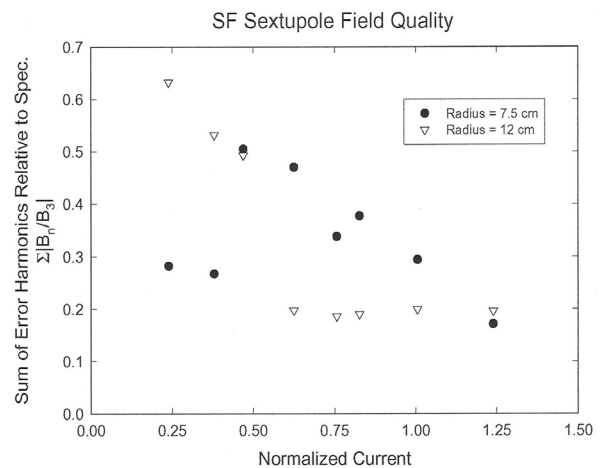

Figure 2: Predicted xextupole field quality vs. current.

Mechanical design features an iron yoke pieced together from tee shaped and hex shaped blocks, pinned and bolted together. Field clamps confine the axial magnetic field. The co-mingled electrical and low conductivity cooling water (LCW) circuits use brass compression fittings and copper tubing for bus between coils. Aluminum oxide tubes, sealed in compression fittings, isolate coils from the grounded LCW manifold.

POWER SUPPLY SYSTEM

The accelerator quality (50-200 ppm regulation) power supply systems use as a base, "off the shelf" (1000 -10000 ppm) supplies rated for the required voltage and current. The accurate regulation is achieved using in-house built circuits featuring very high quality, zero flux transductors, generating a difference error signal summed with the

input program signal to drive the supply to the correct current. Figure 3 shows the system block diagram. Current scaling for the analog error signals is accomplished by the turn's ratio of the precision transducer and the resistor divider ratios. The power supply system typically is ramped at 20 amps/sec (with very little over shoot) to almost the original maximum current. An external H bridge switch assembly converts the uni-polar supply to bi-polar operation.

Our experience with 8 installed systems shows very good long term stability and repeatability, even after full range cycling. Since the system can be manipulated over a broad range of currents and voltages, we intend to utilize it for future applications. The on-board ADC on

Description of the Measurement

A hall probe, positioned to detect the vertical field component, generated the magnetic field data. The stepper measurement system positioned the hall probe to the multiple grid positions. The magnet was mapped at 9 currents from 95A to -95A. A 20 cm wide x 88 cm long grid of data was taken in 0.5 cm increments, symmetric about its ZXY physical centerline.

We powered the sextupoles identically to their operational use. The EPICs controlled current ramp and hysteresis standardization protocol brought the magnets to their measurement currents using one of the new power supply systems described earlier.

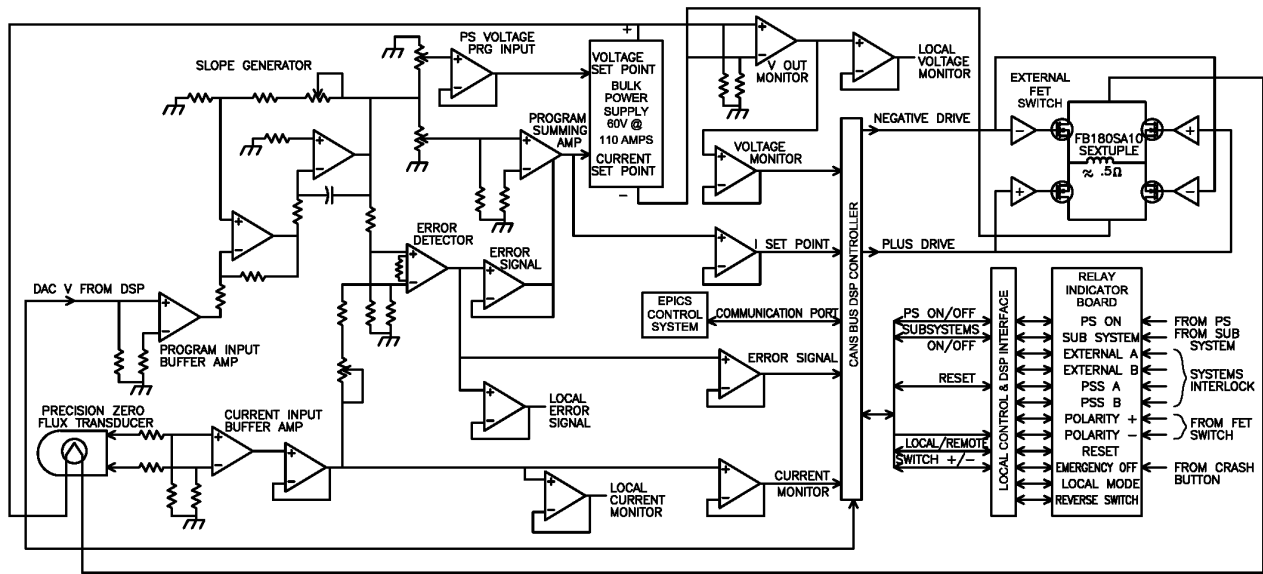At each current, feed down corrections were applied to

Figure 2: FEL sextupole power supply diagram.

the DSP CANs Buss controller card has not lived up to our expectations and this communication format is not universally supported at JLab. We intend is to replace this controller card with the JLab supported, PC104 format.

MAGNET MEASUREMENT

Building a large rotating coil probe and refitting our measurement stand hardware to the large size was impractical for only 11 magnets. Given the electron beam envelope's large horizontal aspect ratio (10 cm width to 0.5 cm height) it was logical to evaluate field quality using hall probes at the horizontal mid-plane only. By fitting the measured data to a pure sextupole field, the measured error harmonics can be extracted and analyzed. However, the higher order harmonic resolution is compromised because the fundamental term is not bucked out (as when using a sextupole bucking rotating coil). The magnet's aperture allowed for data collection across a 20 cm wide swath of the horizontal mid-plane (not the 24 cm width of the specification).

center the transverse measurement centerline to the magnetic axis of the magnet, thus minimizing the linear term. These corrections were compared to verify stability.

Figure 3 shows the measurement system resolution of the transverse magnetic centerline across currents. The dipole offset found by evaluation of the constant term was minimal in each case. Therefore, no Y adjustments were made prior to
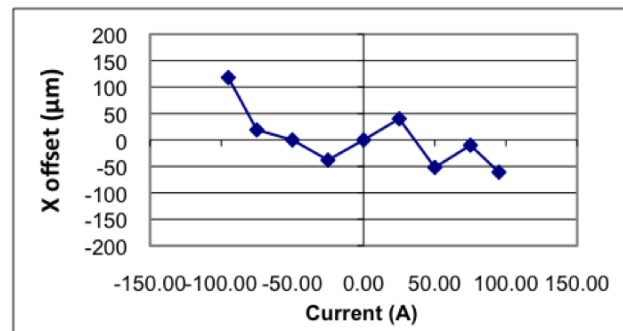

Figure 3: SF004 transverse CL offset at each current.

measurement. Optical tooling was used to tie the physical offset of the hall probe location to magnet fiducials.

Measurement Results

Data from testing the power supply controls showed reproducible pole tip field to 60 ppm. We corrected hall probe field readings for earth field and integrated along the beam axis for each transverse position. Analysis of integrated data showed repeatability of the sextupole term to 1 part in 1000 at full excitation. The integrals were fit to a ninth order polynomial and the coefficients extracted from the resultant series. The coefficients of the harmonic spectrum at the various radii were then extracted according to Equation 1.

$$Bdl_{meas} = a_0 + a_1 r + a_2 r^2 + a_3 r^3 + ...a_n r^n \quad (1)$$

The error harmonic contribution was then calculated at the specified radius using Equation 2.

$$\Delta Bl / Bl = \sum_{n>3}^{\infty} a_n R^{n-1} / a_m R^{m-1} \quad (2)$$

Field strength measurements of the 11 SF magnets show the sextupole strength average at a 10 cm radius is 29598 Gauss-cm, exceeding the required strength at this radius of 20992 Gauss-cm. Figure 4 shows the deviations in relative strength of the family. All deviations were under 1% and each magnet operates under independent power supply control and an individual field map.

Figure 4: Relative sextupole strengths .

Field quality was evaluated at 10 cm (Figure 5) and 6 cm (Figure 6) radii, slightly smaller radii than the original 7.5 cm and 12 cm of the specification. At the critical 6 cm radius, field quality of most of the sextupoles was about double the 1 part in 1000 specification ratio (at 7.5 cm) and approximately 10 times worse than the Model's predicted quality shown in figure 1. Much of this error is noise in the measurement technique because the fundamental term was not bucked. Judging from the less than 1 part in 100 error at 10 cm radius (see Figure 5) the error at 6 cm should be less than the analysis concludes.

Acceptance by Beam Physics

Given the inherent error of these (non bucked) stepper stand readings, their strength qualification, and the urgent need to substitute design quality sextupoles for the work-around sextupoles already in use, the magnets were installed for accelerator operation. Sextupoles exhibiting the best field quality were placed in the more critical locations of the beamline. Confidence in the magnet performance proved to be well based; in subsequent service no beam aberrations or performance impediments are attributed to the sextupoles.
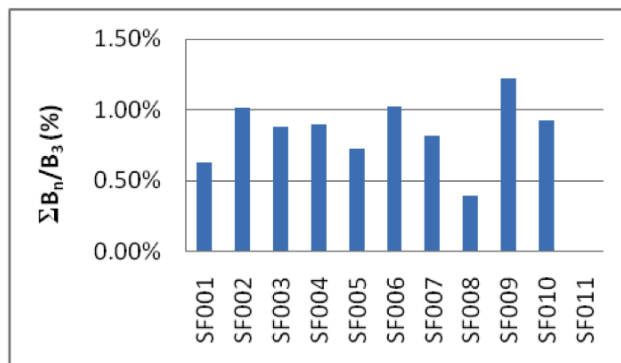

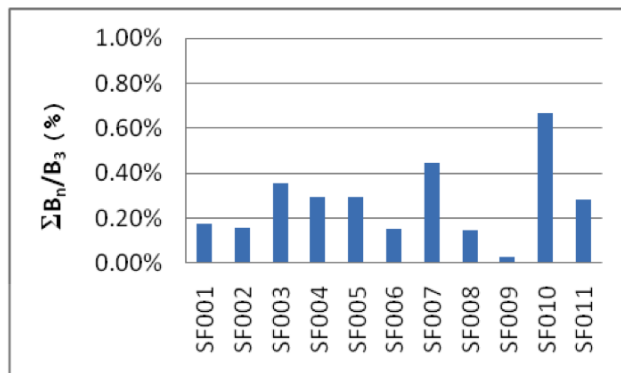Figure 5: Field quality at 10 cm and 95 A.

Figure 6: Field quality at 6 cm and 95 A.

CONCLUSION

Magnetic modeling was instrumental in showing us how to make these "all ends" magnets. The two-dimensional pole-tip incorporating three-dimensional correction made manufacturing easier. The Power Supply Systems utilizing "off the shelf" supplies with in-house built correction are viable. The hall probe measurements were noisy at about the level the specifications but did give us the confidence to place the magnets into service.

REFERENCES

[1] George R. Neil et al., "The JLab High Power ERL Light Source", Nuclear Instruments and Methods in Physics Research A557, 9–15 (2006).

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[3] D. Yu et al., "Short Multipole Magnet Designs for JLab FEL Upgrade". Proceedings *PAC 03* IEEE (2003) Pages 2135 - 2137