SKEW QUADRUPOLES FOR THE CAMD LIGHT SOURCE

V.P. Suller, A. Crappell, D. Launey, T. Miller, P. Jines, Y. Wang
LSU-CAMD, 6980 Jefferson Hwy, Baton Rouge, LA 70806, U.S.A.

Abstract

To control the emittance coupling in the CAMD Light Source, new power supplies have been constructed which adjust the currents in the individual coils of the normal lattice sextupoles, thereby creating skew quadrupole fields. The new power supplies add or subtract current through the pre-energized coils. Performance contributing factors include a summing network with a temperature coefficient less than 1ppm/°C, a water cooled resistive shunt, and linear optical signal isolation. High density & modularity control boards and water cooled power cards are mounted as pull-out units in a 19" rack. Active limiters and fault indicators can provide reliability and portability to higher power designs. The use of these skew quadrupoles in controlling and minimizing the emittance coupling is presented.

INTRODUCTION

With greater emphasis now being placed on a broad based science research program at CAMD, instead of a mainly micro-fabrication based one, there is interest in improving the source brightness. The lattice has been tuned to decrease the horizontal emittance [1] and now attention has been paid to decreasing the vertical.

The vertical emittance is principally determined by coupling from the horizontal and earlier tests with a single skew quadrupole [2] demonstrated that the coupling could be significantly reduced. However, this was also accompanied by a rotation of the beam ellipse so that the effective vertical beam size was different at various locations and for some tangents was actually increased.

What was required to compensate the coupling and align the beam axis with the horizontal was a distributed set of skew quadrupoles. It was decided that the optimum way to achieve this would be to include some form of trim currents on the 16 sextupoles which are distributed in the 4 dispersion straights of the CAMD Chasman-Green lattice.

SKEW QUADRUPOLE IMPLEMENTATION

The need for distributed skew quadrupole elements in the storage ring optics without having the space or funds for additional magnets led to a novel approach of introducing skew quadrupole field elements into the existing sextupole magnetic fields. The two sextupole magnet families (focusing & defocusing) are each composed of eight series connected magnets with a typical operating current of 5A at ~30VDC.

By altering the currents in select sextupole coils, we can introduce a skew quadrupole element into the magnet's resultant field. Proper reordering of the six series connected pole coils in each sextupole magnet allowed two isolated sinking/sourcing power supplies to be used to modify currents in the corresponding coils. Figure 1 below shows the reordered coils and their currents modified by the applied sink/source power supplies. Note that currents in the even and odd numbered coils oppose each other.

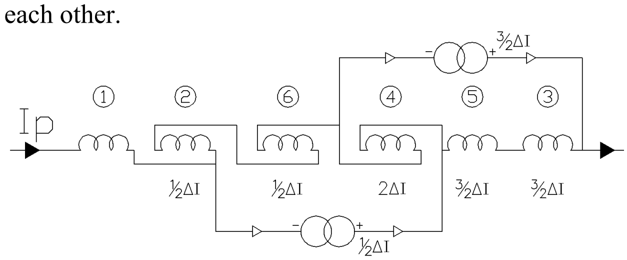

Figure 1: Coil connection.

This required two power supplies per magnet; totaling two times 16 magnets; yielding 8 power supplies per quadrant of the storage ring. A maximum working current of ±5A was proposed.

Since the sextupole magnets are all series connected to a main constant current supply, the external Sink/Source power supplies see a pre-polarized load through which to regulate a supplemental current (ΔI). To cope with the resulting changes in coil terminal voltage, the sextupole family 30V/10A constant current power supplies were upgraded to 120V/10A supplies. Moreover, each sink/source supply must be isolated to allow independent current modification of interconnected coil circuits.

POWER SUPPLY DETAILS

The custom designed sink/source power supplies are built into four, eight channel chassis; being installed one in each quadrant, with maximum output of ±6A at ±13VDC. The supplies are laid out in three modules. The regulator card controls all regulation, limiting, and fault reporting. The isolation card provides an optical isolation barrier for power and control signals to and from the regulator card. The power card allows four H-Bridge configured output transistors and the current metering shunt to reside on a water cooled heat sink. Key design features include:

a) Modular and portable design
b) Linear bipolar output via IGBT H-Bridge
c) Integrating regulator with low Tc summing point
d) Pull down resistors avoid Op-Amp crossover
e) Fine & coarse zero adjustments
f) Water cooled low Tc current metering shunt
g) Active current limiters
h) Extensive fault detection & annunciation
i) Scalable output voltage for larger applications
j) Eight channel chassis with full "rack-out" construction for maintenance

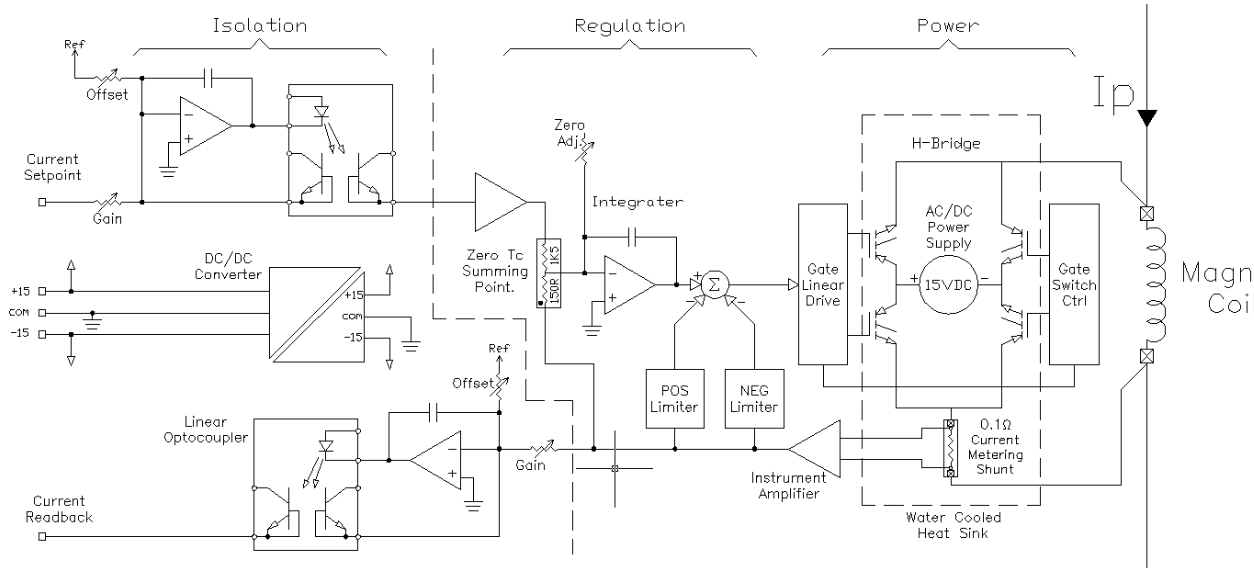

Figure 2: Simplified power supply schematic.

This modular design enables the control electronics to be scalable to larger applications. A separate voltage supply to the IGBT gate drive circuits allows for up-scaling of the top bridge transistors' gate drive to accommodate higher load voltages. Employment of a regulator summing point with T_c < 1ppm/°C and a water cooled current metering shunt with a T_c < 30ppm/°C contribute significantly to the unit's high degree of output stability.

Regulation

The heart of the regulator is kept simple employing an input buffer and an integrating Op-Amp with a bulk metal film summing point resistor made by Vishay/Texas Components. The ultra low temperature coefficient of resistance (TCR) of T_c < 1ppm/°C is achieved by clever pairing of competing temperature coefficients of expansion of the resistive alloy and the component's substrate material. The feedback portion of the regulation loop is provided by a resistive shunt made by Isotek. Etched Manganin (copper-manganese alloy) foil and copper terminals provide for a low TCR and long term stability. A planar structure with optimized current density permits a low-inductance design and a very low thermal internal resistance of <4K/W; assuring low self-heating at the 10W rating. As isolation from the prepolarized load is paramount, the shunt voltage is fed back to the regulator via an eight pin instrument amplifier. Careful selection of these components has yielded a stability coefficient of 0.03% over 1hr at a maximum output current of 6A.

Isolation

The isolation card employs dual output DC/DC converters to supply control power to the regulator. The NDTD model converter, made by C&D Tech, was chosen for its active current limiting and no load operation capability. Passive L and C filtering on input & output of the converters insure quiet power rails. The setpoint and readback signals to and from the regulator are piped through linear optocoupler IC's, model LOC110 by Clare Micronix, employing active current feedback for improved temperature stability. Linear optical isolation was chosen over the more common switching methods to avoid noise in the signals. Heat from the LED affects the transconductance of the device by unequal heating of the two matched phototransistors; resulting in a 10 minute warm-up time. Reduction of the working range of the LED via the driving Op-Amp's gain effectively reduces the warm-up time to 1 minute; but, at the small expense of a tighter overall gain.

Testing

Testing was performed using two Hp 34401 DMMs, automated with LabView, implementing repetitive ramp testing while recording Stability, Gain error, Offset error, and nonlinearity over time. Table 1 below summarizes the performance results over a one hour test.

Table 1: Performance Figures

	ISO	REG	Total	
Stability	523	11	534	ppm
offset	316	55	371	ppm
gain error	375	205	580	ppm
nonlinearity	33	1	34	ppm
zero offset	2.2	0.3	2.5	mA
Total	0.12%	0.03%	0.15%	

BEAM RESULTS

Coupling Reduction

Although the intention is to equip each of the 16 sextupoles with skew quadrupole power supplies, at the time of writing there are only 8 operational in CAMD. For best symmetry these are installed in two dispersion straights which are diametrically opposite. It has been found straightforward to optimize each individual skew quadrupole by manual adjustment to minimize both the vertical beam size and the angle of the beam ellipse to the horizontal by reference to the beam image at 2 separate locations. These are a focused visible light image and an x-ray image using a pin-hole camera.

A measure of the reduction in coupling has been obtained by measuring the betatron tunes as the working point was moved across a coupling resonance as one of the quadrupole families was adjusted. CAMD is operated in the region of tune space crossed by the coupling resonance Qh - Qv = 2.0. Figure 3 shows the measured tunes with the skew quadrupoles off and on. It is seen that the minimum tune separation is reduced from 0.007 to 0.0015 when the skew quadrupoles are on at their optimized settings.

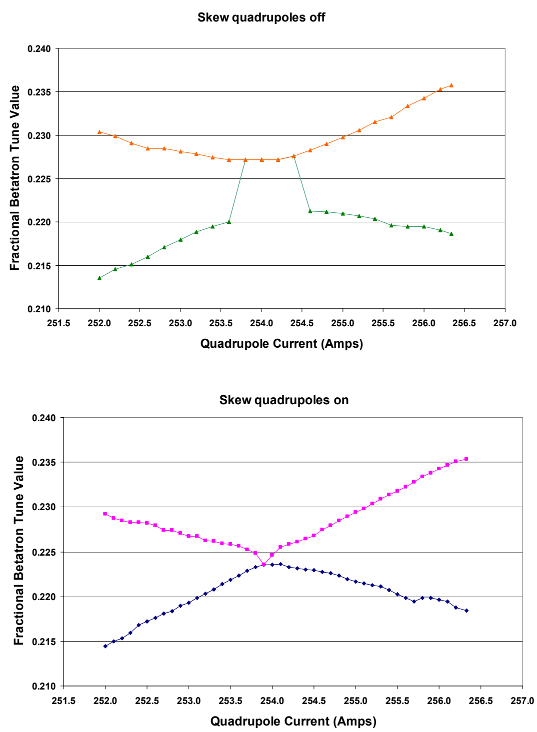

Figure 3: Betatron tunes measured crossing a coupling resonance with skew quadrupoles off and on.

Vertical Beam Size Reduction

The vertical beam size in CAMD is measured using an x-ray pinhole camera. X-rays emerge from the storage ring through a 2 mm thick beryllium window and are focused by a 60 micron pinhole onto a YAG screen. The magnification ratio is almost exactly 1:1. The beam image, as viewed by a CCD camera, is captured and analyzed by software shown in figures 4 & 5. These figures illustrate the beam sizes with the skew quadrupoles off and on.

From the analysis the vertical beam sigma at the pin-hole camera source point is 180 microns with the skew quadrupoles off, and 130 microns with them on. This corresponds to horizontal/vertical coupling ratios of 1.2% and 0.7%, which shows that the skew quadrupoles are giving a significant improvement to the source brightness. However, a much bigger beam size difference could be expected from the coupling resonance minimum tune split data. This is the subject of ongoing study.

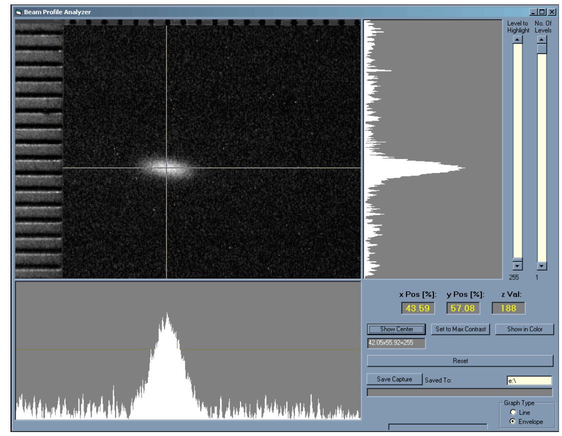

Figure 4: Analysis of the x-ray pinhole camera image with the skew quadrupoles off.

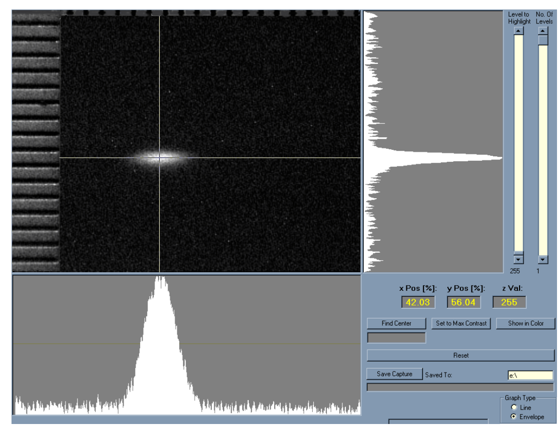

Figure 5: Analysis of the x-ray pinhole camera image with the skew quadrupoles on.

CONCLUSIONS

Producing skew quadrupole fields by modifying the current distribution in the coils of the sextupoles has proven to be a cost effective and easily implemented technique. With only 8 sextupoles so equipped it has been possible to achieve a significant reduction in vertical beam size. In the near future the remaining 8 sextupoles will be fitted with similar power supplies.

REFERENCES

[1] VP Suller et al, Proc EPAC04, Lucerne, 2004, THPK069, p. 2424; http://www.JACoW.org.

[2] VP Suller et al, Proc EPAC06, Edinburgh, 2006, THPLS024, p. 3329; http://www.JACoW.org.