A BEAM BASED ALIGNMENT SYSTEM AT THE CAMD LIGHT SOURCE

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Abstract

Beam based alignment is being applied to the CAMD light source. It is implemented by a flexible and versatile system of electronic shunts which are applied to each of the storage ring lattice quadrupoles. The essential design features of the electronic shunts are described, also the routine operation of the full system. The improvement to the corrected closed orbit from using the system is shown. Preliminary results are presented of the use of the shunts for correcting the lattice functions.

INTRODUCTION

Beam Based Alignment (BBA) is widely used in synchrotron light sources [1,2,3] and other accelerators. By correlating the magnetic centre of a quadrupole or sextupole with a nearby beam position monitor via the beam, the true centre of the BPM can be physically established to high precision. It is the only technique available with such precision, and is therefore important for accelerators needing very accurate beam alignment, such as light sources and colliders.

To apply a BBA system, the current through a given magnet is perturbed and any resulting shift of the beam orbit is observed. An orbit shift implies that the beam does not pass through the centre of the perturbed magnet. The beam can be aligned through both the centre of the magnet and an adjacent BPM by adjusting the position of the orbit in the magnet until no orbit shift is observed. A BBA system can also be used to measure the amplitude of the lattice functions by measuring the tune shifts resulting from magnet perturbation.

The CAMD lattice [4] is a 4 cell Chasman-Green achromat containing a total of 20 quadrupoles. Adjacent to each quadrupole is a 4 button BPM, except in the injection straight where one BPM is missed out due to space restrictions. The beam orbit is measured by a Bergoz analogue electronic system. Although the orbit is routinely measured to a relative precision of better than 0.1 mm, the absolute position has been uncertain by many mms.

To remove this uncertainty it was decided to install a BBA system using electronic shunts applied to each of the lattice quadrupoles. To allow rapid and accurate data acquisition the system was specified to permit both AC and DC excitation of the shunts thus facilitating both orbit position and beta function measurements. Since BBA analysis is likely to be a regular task, necessitated by drift of accelerator components, the system should be permanently installed and operated via the normal controls.

SHUNT SYSTEM DESIGN

Specification

The quadrupole shunt system is designed to meet the following criteria:

- A shunt for each of the 20 quadrupoles
- Distributed design (5 shunts / quadrant)
- Separate output stage for upgradeable I_{max}
- Voltage controlled shunt current (0-10V ≡ 0-10A)
- >500V isolation between $V_{control}$ and I_{output}
- PLC controlled DC to 5Hz operation
- Interface via main control system

System details

The system consists of four chassis, each containing five shunts. Each chassis is located near one storage ring quadrant. On a chassis the five power circuits are grouped together on one forced air cooled heat sink with over temperature protection. See Figure 1 for a view of the layout.

Figure 1: View of a chassis containing 5 shunt circuits

A schematic of one shunt and its associated control and power circuits is shown in figure 2.

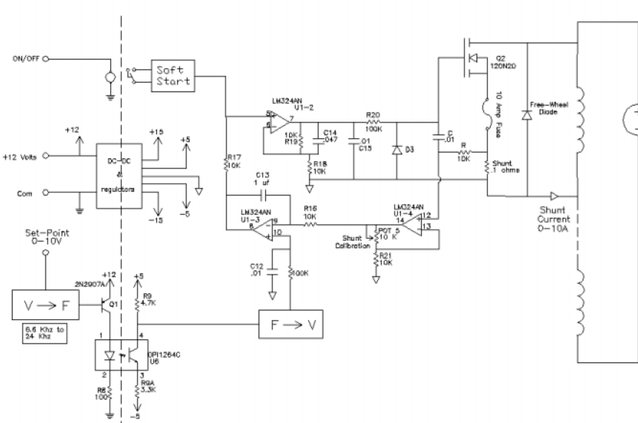

Figure 2: Shunt circuit and associated power and controls.

Isolation to 1 kVdc is provided by the on/off electromechanical relay, the set-point control optoisolator, and the DC-DC converter which provides power for the amplifier circuits. Voltage to frequency converters are employed to overcome the nonlinearity of the optoisolators.

The feedback loop takes a measure of the shunted current from a 0.1Ω metering resistor. All 20 shunts are controlled from one PLC. The PLC provides the interface between the graphical user interface (GUI) in the main control system and the shunt circuits. It also provides logic for cooling fan control and generates a variable sine wave modulation of the current set-point entered into the GUI for each channel.

Control

The program in the central PLC monitors the system status and converts the numerical set-point from the GUI to a control voltage for each channel. Each of the 20 channels can have its own DC current set-point and be active simultaneously. This provides for permanent correction of the storage ring lattice functions.

The operator can also, from the GUI, cause any one channel to operate in AC mode, whereby the PLC will superimpose a sinusoidal modulation of selected amplitude and frequency (0.2-5Hz) on top of a steady current of separately selected amplitude. This capability provides a very sensitive method for centering the beam in an individual quadrupole and an adjacent BPM.

Performance

The system can shunt up to 10A of current around each quadrupole magnet continuously. Under test, with a typical current of 250A through a quadrupole family, when one magnet was shunted with 10A (about 4%), no decrease in stability or increased ripple in the main magnet current could be measured.

In AC mode operation, the main quadrupole power supply must be able to compensate for the changes in its load resistance with a shunt circuit operating. Thus, the shunt circuit must not make changes faster than the power supply can compensate. Figure 3 shows a comparison of the varying current in one quadrupole while the current supplied by the main power supply to the family exhibits no variation.

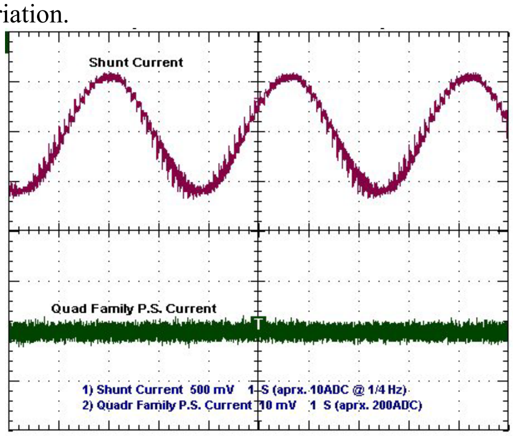

Figure 3: Stability of main power supply.

BPM OFFSET MEASUREMENTS

The shunt system has been very effective in determining the true positions of the BPMs. The technique used is to energize each shunt individually with an amplitude of 5 A (peak) at a frequency of about 3 Hz. The resulting closed orbit movement can be seen very clearly on the fast beam orbit plot, as shown in figure 4.

The fast beam orbit plot, based on the Array Display Tool software from APS, displays the data from each of the 19 BPMs, both horizontal and vertical, taken at a complete orbit sampling rate of 1 kHz. The amplitude of any variation is displayed as sequential orbits, seen in figure 4. The advantage of this technique is that the effect of the shunt modulation can be observed on the entire orbit, thereby avoiding inaccurate data if a BPM at a node had been inadvertently selected.

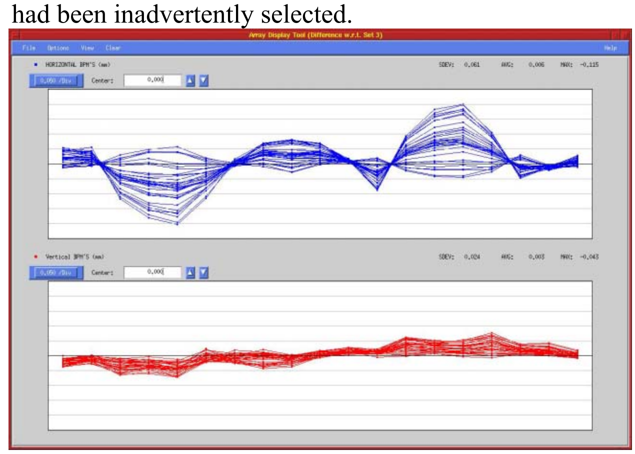

Figure 4: Horizontal (top) and vertical orbit modulation with a single shunt AC excited.

A suite of closed orbits bumps has been developed to allow for precise displacement of the beam. There are horizontal bumps localized to the QF and the BM magnets, and vertical bumps at the QD and QA magnets. There are also well defined bumps at the long straight sections; a parallel bump in which the beam is displaced parallel to the zero plane, and an angled bump crossing the straight centre at some angle. Each bump has been experimentally optimized to produce best localization. This set of localized bumps, shown in table 1, allows good orbit control at each quadrupole.

Table 1: Available Local Bumps

Center Magnet	Trims Used	Maximum Orbit Displacement
Horizontal Plane		
QF	QF,QF,BM	5.8 mm
BM	QF,BM,BM	2.7 mm
Par/angle straight	BM,QF,QF,BM	6.7 mm
Vertical Plane		
QD	QD,QD,QA	6.7 mm
QA	QD,QA,QD	1.6 mm
Par/angle straight	QA,QD,QD,QA	4.9 mm

A localized bump is used to move the beam orbit at the shunted quadrupole until the fast orbit display shows minimum modulation. The horizontal and vertical planes can be optimized independently. The localized bump can be optimized to a precision of ±20 μm.

Table 2: Measured BPM offsets in mm.

BPM	Horizontal	Vertical	BPM	Horizontal	Vertical
1	0.49	-0.50	11	9.99	-7.19
2	-0.23	0.22	12	0.85	0.85
3	0.58	1.68	13	-0.12	2.64
4	-2.93	-1.03	14	-3.27	0.45
5	0.65	0.18	15	1.36	0.54
6	-9.87	-8.03	16	-0.18	-1.05
7	-0.20	0.40	17	-0.65	-0.05
8	-0.57	0.27	18	0.56	-0.93
9	-0.55	1.31	19	-0.90	-0.15
10	-0.17	1.85			

The measured offsets for each of the BPMs are given in table 2. The apparently large offsets shown for BPM6 and 11 are to be expected because these non standard monitors have a completely different button position geometry. The other offsets are generally in accordance with the positions of the vacuum chambers in which they are mounted.

Using this data the orbit can be corrected using a combination of an SVD algorithm and local bumps to within ±400 μm, as shown in figure 5. This represents the existing relative misalignments between the magnetic centres of adjacent quadrupoles, which have not yet been corrected.

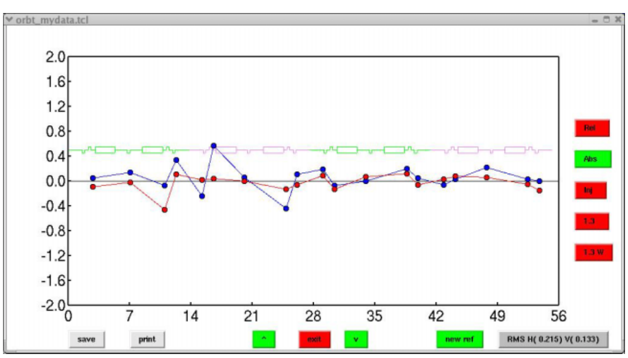

Figure 5: Orbit correction to the measured BPM offsets.

LATTICE FUNCTIONS

The storage ring lattice beta functions have been measured by using the shunts in the DC mode. With an individual quadrupole shunt set to a nominal value of about 7 A, the resultant tune shifts were measured simultaneously in both the horizontal and vertical planes. The tune data were derived semi-automatically from a network analyzer fed with a signal from a diagnostic beam pick-up, and could be measured to an accuracy of ±0.0005 with tune shifts in the range 0.004 to 0.02. Thus the accuracy of the measured beta values corresponds to ±0.45 m for the least sensitive family of quadrupoles.

The beta values computed from the measured tune shifts and from the calibrations of the quadrupole families for the CAMD lattice operated in the symmetric mode are shown in figure 6. The solid lines are the calculated beta functions from the lattice model for the exact tune values at which the measurements were made. The individual symbols are the measured beta values.

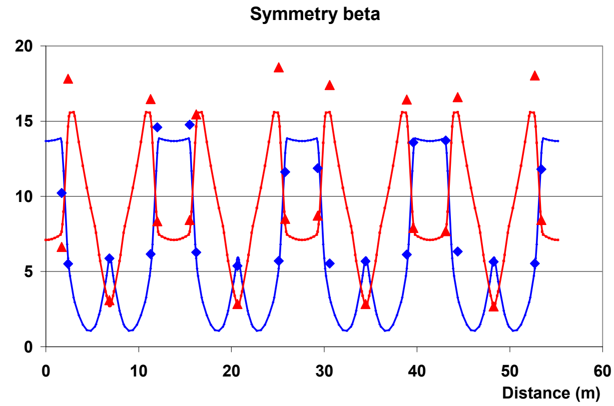

Figure 6: Measured beta values (points) compared with the model lattice (solid lines).

Figure 6 shows quite good agreement between the calculated and measured beta values around most of the ring, but there is a significant discrepancy in both the vertical and horizontal planes in straights 1 and 3 which are diametrically opposite. The reasons have not yet been established. Preliminary measurements of the lattice in the much less symmetric minibeta configuration [5] show a similar level of agreement. After further analysis it is intended to use the shunts in DC mode to minimize the beta discrepancies seen in figure 6.

CONCLUSIONS

The BBA system based on individual quadrupole shunts recently commissioned at CAMD has already shown its usefulness in determining BPM offsets and measuring lattice functions. The facility for using the system in either AC or DC mode is very convenient and simple to use, and the interface via the normal control system allows data to be taken flexibly and rapidly.

It is planned to use the system to establish a well referenced orbit position to which the beamlines can be aligned with confidence in its long term stability. It is also planned to study further the lattice beta functions, especially in the minibeta configuration, and correct them with the shunts in DC mode in conjunction with an improved lattice model.

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