BPM System for Storage Rings, Measuring Beam Position Against Quadrupole Magnets Magnetic Centre

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Abstract

This BPM system measures the beam-position with high precision in a storage-ring with respect to the quadrupole magnets magnetic centre which is used as the absolute position reference. The absolute position of the BPM heads themselves does with this system not affect the beam position measurements so a calibration of the BPM heads absolute position can be done in situ. Results from a working system at the MAX I storage ring is presented.

1. INTRODUCTION

The position of the ideal closed orbit in a storage ring is defined by the field in the quadrupole magnets which usually are very well aligned. These are thus very good as reference points for beam position measurements.

Most existing systems today use the BPM heads position as the position reference. This system measures the beam position relative to the quadrupole magnets magnetic centre which relaxes the design constraints on the rigidity of support structures for BPM heads and the stability requirements of the electronic systems. It can be used to perform an in situ calibration of the BPM heads position. The system uses very little extra hardware which makes it easy to retrofit to an existing machine. As a side effect the extra hardware can be used to measure the β-functions in all q-poles in the machine.

2. BPM's, PICKUP HEADS

Any well functioning BPM system is usable if it has at least two working BPM heads in suitable positions. In MAX I we are using the visible light produced in the main dipole magnets. The light is via a single lens focused onto a BPM that measures the position of the focused lightspot. The BPM can be placed at almost any unused dipole beam port. A typical setup is shown in Fig. 1. The BPM is a Wallmark plate detector which is described in [1].

3. HOW TO MEASURE THE BEAM POSITION IN A QUADRUPOLE MAGNET

If the beam is offset from the centre of a q-pole it will be bent in this q-pole. To determine this offset the strength of the quadrupole magnet is changed slightly. The beam will then be bent a little differently and the closed orbit changes slightly. A BPM head provides the information we need to calculate the beam position in the changed quadrupole.

To calculate the beams offset from the magnetic centre in the changed quadrupole magnet. we need to know the betatron functions of the machine, the field gradient in the quadrupole magnet, the position of the BPM and the position of the changed q-pole magnet in the ring.

3.1 Coefficients

To translate the closed orbit change in one point to beam position in the q-pole the BPM signal is multiplied with a coefficient calculated beforehand. To calculate the coefficient an analytical formula: eq. 1a is used which can be derived from eq. 1 that is found in [2]. We have used the code DIMAT to give us all the needed data.

$$y = \left(\frac{\sqrt{\beta(s)\,\beta_k}}{2\sin\pi Q} \frac{\delta(B\,l)}{B_\rho} \right) \cos Q\varphi(s) \qquad \text{(eq. 1)}$$

The coefficients C_{xj} and C_{yj} are defined as:

$$\frac{1}{C_j} = \left(\frac{\sqrt{\beta_{detector}\,\beta_{quad}}}{2\sin\pi Q} K_{quad}\, k_{shunt}\, L_{quad} \right)$$

$$\times \cos\left(2\pi \left| \nu_{detector} - \nu_{quad} \right| - \pi Q\right) \qquad \text{(eq. 1a)}$$

Where:

K_{quad} is the strength of the undisturbed quadrupole in m^{-2}
k_{shunt} is the size of the disturbance applied to the quadrupole, and $|\nu_{detector}-\nu_{quad}|$ is the advance in betatron phase from the detector to the changed quadrupole.

We can see from eq. 1a that a bigger change in the quadrupole strength will result in a larger beam position change when a shunt is activated, and a smaller C_j. The value of k_{shunt} also influences the lattice by changing the β function and the tune. As an example, here are some of the parameters for MAX I: k_{shunt} is about 0.04 which means that the quadrupole strength is reduced about 4% which is enough to measure accurately and still not disturb the machine too much. The tune changes by about 1 %. Horizontally from 3.16 to 3.14 and vertically from 1.31 to 1.32 when one shunt is activated. The beta function at the shunted quad changes less than 10 %, from 5.83m to 6.33m horizontally and from 3.5m to 3.6m vertically. This is in a horizontally focusing quad.

Tests at MAX I has shown that the disturbance is so small that it is not useful to include it in the calculations.

In the table of C_{yj} some coefficients will be very large corresponding to points where the cosine term in eq. 1a becomes very small. If we use more than one BPM, and have some separated by π/2 we will always have a BPM near a point

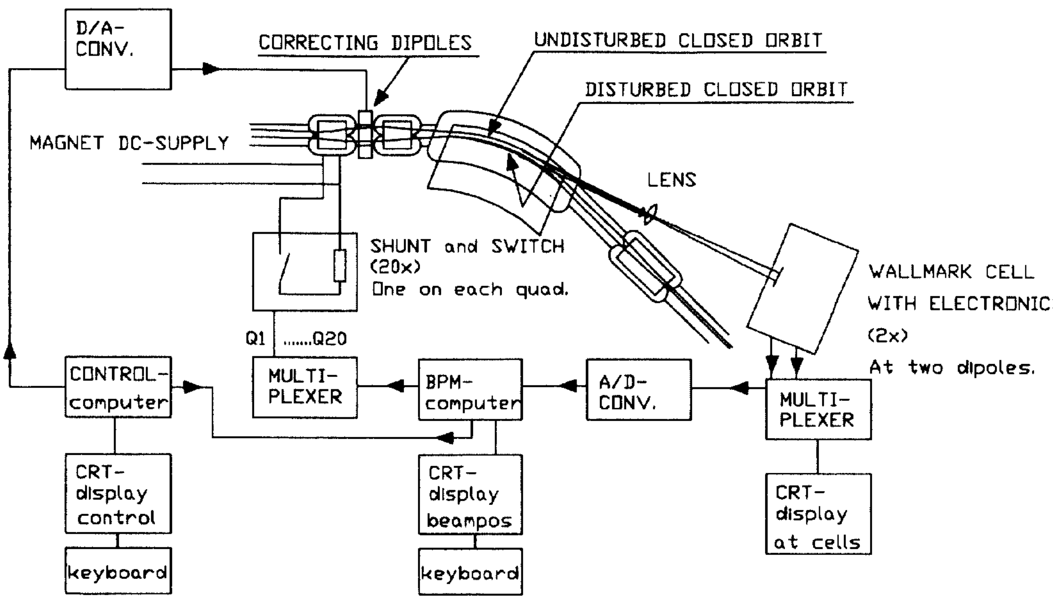

Fig. 1. Block schematic of the measuring system.

where the distance from the q-pole magnet to the BPM gives a cosine term close to ±1. So we can avoid the large coefficients.

One table of coefficients is calculated for each of the BPM's. Signals from the BPM's are weighed together to produce as accurate a measurement as possible. Eq. 2 shows the case with two detectors.

$$y_n = \frac{dy_1\, Cy_1(n)\, Cy_2^2(n) + dy_2\, Cy_2\, Cy_1^2(n)}{Cy_1^2(n) + Cy_2^2(n)} \qquad \text{(eq. 2)}$$

Where dy_1 is the position change signal from detector 1 and dy_2 is the same signal but from detector 2.

When using the system to steer the beam to the centre of the machine the size of the coefficients are not so important. No position shift will occur if the shunt activated is on a q-pole where the beam passes in the centre, since zero signal multiplied with almost anything as a coefficient is zero.

3.2 *β-function measurement*

As a side effect the quadrupole shunts can be used to easily measure the β-functions of the machine from the control room. Just close one shunt in the system and watch the tune shift on a network analyser connected to its pickup electrodes in the machine.

4. HARDWARE

4.1 *Quadrupole shunts and powersupplies*

The q-pole magnets strength changed by reducing the current in the coils a few percent. This is done by connecting a resistor across the coils to shunt off some current. The resistor is switched via a semiconductor switch to insure good reproducibility.

The quadrupole magnet power supplies must be able to within a short time after a quadrupole shunt is switched adjust to the load change presented to them. The settling time in MAX I is 100ms without degrading the precision of the power supplies.

5. EXPECTED SENSITIVITY OF THE METHOD

The measuring sensitivity is on an ideal storage ring equal to the detector sensitivity times the coefficients calculated in eq. 1a. In MAX I the value of the coefficients is around 38 horizontally and 15 vertically. A weighted reading from two detectors is used. This means that with a detector resolution of 0.0024 mm the resolutions will be $\frac{38}{\sqrt{2}} * 0.0024 = 0.065$ mm horizontally and $\frac{15}{\sqrt{2}} * 0.0024 = 0.026$ mm vertically.

5.1 *Verifying the coefficients C_{xj} and C_{yj}*

The coefficients C_{xj} and C_{yj} can be verified in a number of ways. A quick method for the horizontal plane is to measure the beam position at two different acceleration frequencies. The difference between the two orbits should show the dispersion function.

5.2 *Influence of errors on the scale*

The error in scale is dependent on a number of factors. A few factors are: The tolerance of the shunt resistor, the winding resistance of the magnet, how well the tunes and the lattice are known. As a whole it can be said that these errors can be controlled to result in a few percent error. The main importance lies in the fact that the errors do not change over time so that the measurements are reproducible and zero is well defined.

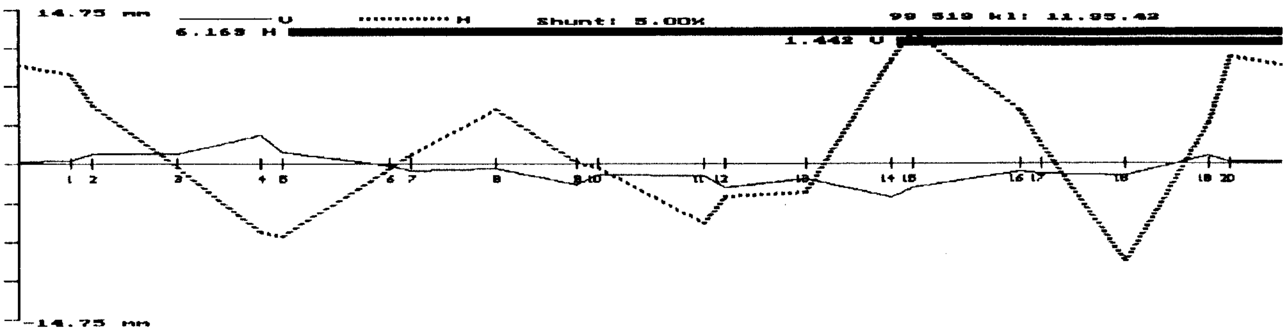

Fig. 2. Uncorrected closed orbit in MAX I. Each mark on the horizontal axis is a quadrupole magnet.

6. Closed Orbit Correction Results

Fig. 2 shows the closed orbit in MAX I before correction and with all correctors at zero strength. The numbers on the horizontal axis are the number of the q-pole magnets in the machine. The dotted line shows the position in the horizontal plane and the solid line the position in the vertical plane. The two bars near the top are the RMS of the position errors in the h- and v- planes respectively.

To correct the beam position the earlier measured response matrices are multiplied with the beam position in the machine. This produces a set of strengths for the correcting dipoles. Fig. 3 shows the beam position after one iteration. The inability to correct the beam position in the horizontal plane is a result of using too few correcting dipoles and of alignment errors internally in the doublet pairs. The horizontal tune is 3.16 and requires theoretically at least 10 correction dipoles, while MAX I has only 8.

The points where the highest beam stability is required are in the two undulators. Both undulators are positioned in long straight sections and are surrounded by one horizontally focusing quadrupole on each side. The beta functions in this quadrupole which is quite strong is in the order of 6.5 m horizontally and 3.5 m vertically. The coefficients C_{xj} and C_{yj} are smallest in this magnet family resulting in high resolution in the beam position measurements.

To correct the closed orbit even better in the critical points the beam position are measured only in the 8 most sensitive points of the machine. Fig. 4. shows a final corrected closed orbit using only 8 measuring points. Note that the vertical scale is expanded more than a factor of 10 relative to fig. 3. The correction of some alignment errors of the quadrupoles resulted in a closed orbit deviation after automatic orbit correction that touches the sensitivity limit of the BPM system. The plot in fig. 4 shows the achieved closed orbit.

7. Calibration of BPM Heads

The shortest time scale involved in position drift of BPM heads is probably the time constant of the temperature in the machines vacuum chamber. By determining the difference between direct readings of the BPM's and readings done by shunting q-poles a table of offsets can be stored and subtracted from direct measurements with the BPM's.

8. Future Plans

At MAX-lab there is being built another storage ring, MAX II refs. 3,4. It will be equipped with a similar BPM system. The electronics for the button pickups will also be of conventional type. We will use the method described above to continuously calibrate the standard BPM system to eliminate all kind of long term drifts in the pickup system.

9. References

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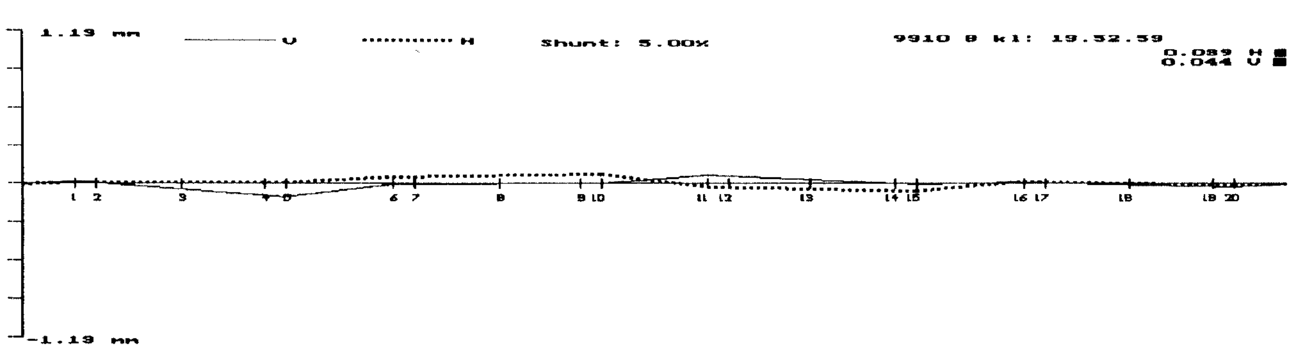

Fig. 3. The closed orbit after realignment of quadrupoles and automatic correction.