BEAM BASED ALIGNMENT USING THE QSBPM SYSTEM

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Abstract

The new generation of accelerators becomes more and more dependent on alignment accuracy [1] for reaching their performance goals. The precision of the conventional surveying techniques is no longer sufficient. After the initial alignment whose precision allows an initial beam to pass through the machine. The beam itself is used as the instrument to fine tune the machine alignment. The QSBPM system [2] is especially suitable for this alignment since it measures the beam position relative the quadrupole magnets magnetic centra. Measurements made on the MAX I machine as well as a comparison of these measurements to computer simulations of alignment errors is presented.

1. INTRODUCTION

The QSBPM system measures the beam position with high precision relative to the quadrupole magnets magnetic centra. This is the basis of beam based alignment.

Most existing BPM systems today use the BPM pickup elements position as the reference against which the beam position is measured. The quadrupole magnets in a machine determines where the position of the beam should be.

2. DETECTORS, ’PICKUPS’

Any kind of position pickups can be used. Any well functioning BPM-system is usable. In MAX-I is it easy to with high accuracy measure the electron beam position at a fixed point in a dipole bending magnet. The synchrotron light is via a single lens focused onto the position sensitive detector. The setup used in MAX I is shown in Fig. 1. The position sensitive detectors in the MAX I storage ring are Wallmark plate detectors [3]. The resolution of the Wallmark plate detectors used is 0.001 mm or better on the surface of the detector element.

3. HOW TO MEASURE THE BEAM POSITION WITH RESPECT TO A QUADRUPOLE MAGNETS MAGNETIC CENTRE

If the beams centre of gravity is offset from the centre of a quadrupole the whole beam will be bent in the quadrupole. To determine this offset we change the strength of the quadrupole magnet slightly. The beam will then be bent a little differently and a new orbit is created. The BPM pickups provides information about the shifted beam position. In a circular machine we can use a BPM pickup close to the changed quadrupole. Thus we can directly read the beam position change in the quadrupole.

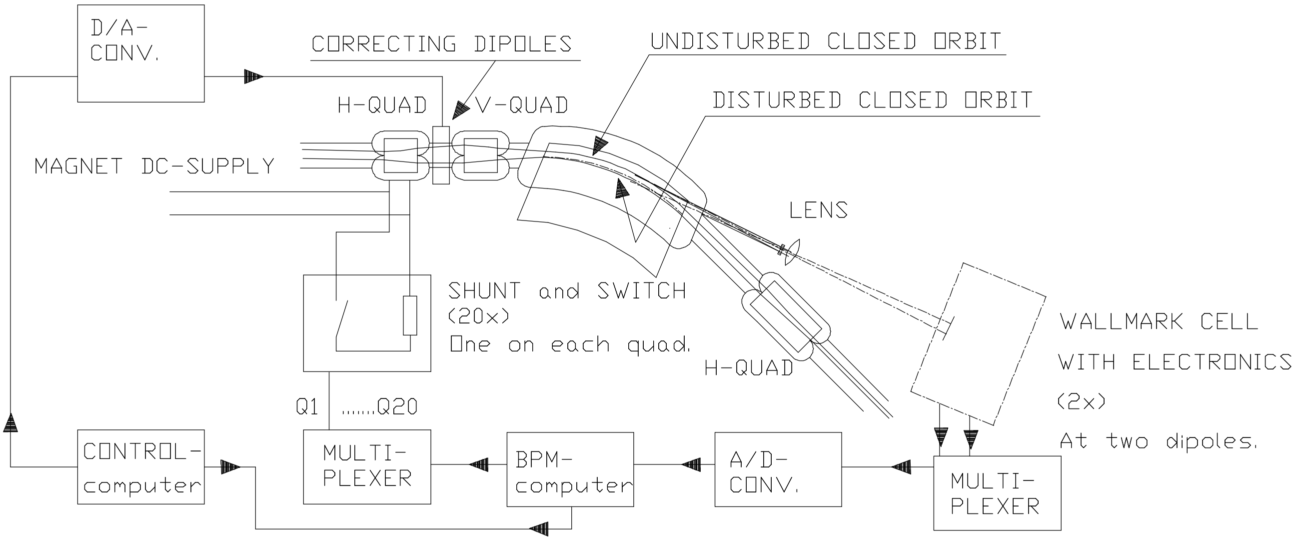

Fig. 1. Block schematic of the measuring system in MAX-I.

3.1 Calculations

To calculate the beam position in the changed quadrupole an analytical formula: eq. 1a is used, which can be derived from eq. 1, [4].

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

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

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

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

Where:

β is the beta function at the detector and the changed quadrupole respectively,

K_{quad} is the strength of the undisturbed quadrupole in m^{-2} ($K_{quad}= B_0/rB\rho$),

k_{shunt} is the size of the disturbance applied to the quadrupole,

L_{quad} is the length of the quadrupole,

Q is the betatron tune of the machine,

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 (a bigger k_{shunt}) will result in a larger beam position change when a shunt is activated. The value of k_{shunt} also influences the lattice of the machine changing the β function and the tune. Here are some of the parameters for the MAX I storage ring: k_{shunt} is about 4%. This makes the tune change by about 1 %. Horizontally from 3.16 to 3.14 and vertically from 1.31 to 1.32. 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 in a horizontally focusing quad.

3.2 Expected sensitivity

The sensitivity is on an ideal storage ring equal to the detector sensitivity times *Cj* calculated in eq. 1a.

4. QUADRUPOLE SHUNTS

The easiest way to change a quadrupole magnets strength a few percent is to reduce the current to the coils a few percent. This is done by connecting a resistor in parallel to the windings via a switch transistor to shunt off some of the current.

5. FINDING THE ALIGNMENT ERRORS

To say that a quadrupole magnet is misaligned we have to define a reference point first. In the MAX I machine we decided that when the closed orbit had been corrected as good as possible in the H-focusing quads the remaining orbit error came from misalignments of the V-quads that is all part of doublets. The doublets are at marks number 1-2,4-5,...and so on in figure 3 that shows the measured orbit in MAX I. the amplitude of the large peaks show the misalignments in the doublets directly.

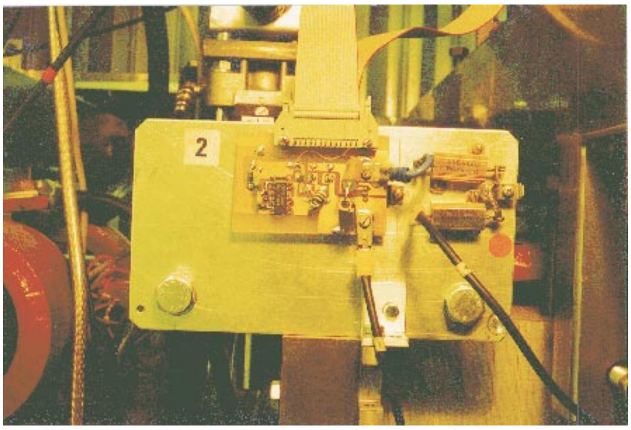

Fig.2. One of the 20 switchable shunts in MAX-I.

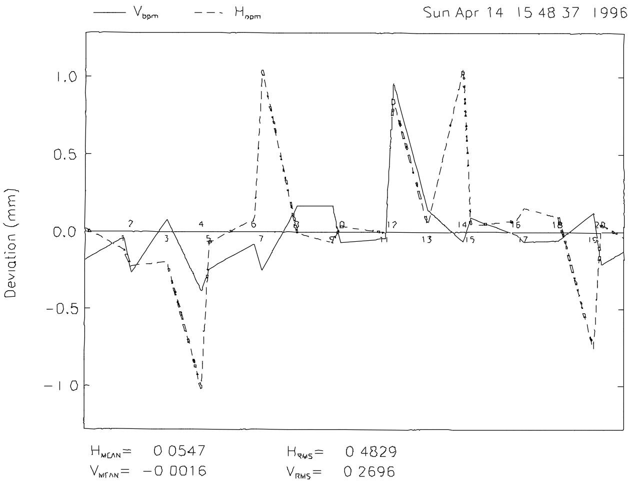

Fig. 3. Plot showing misalignment in the doublets in MAX-I

5.1 Computer simulations

The QSBPM program used to measure the beam position was modified to communicate with a accelerator design program instead of the MAX I machine thus creating a QSBPM simulation program. By offsetting one quadrupole with 1mm the orbit in fig. 4. was created. By letting the QSBPM program correct the orbit the remaining errors show the misalignment. In this case V-quad at mark number 2 in fig. 5.

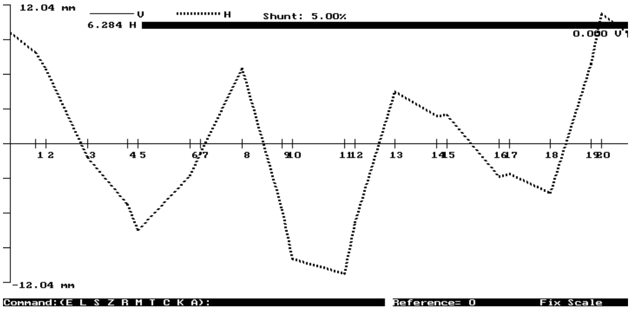

Fig. 4. Orbit in MAX I with the V-quad at mark number 2 offset 1 mm.

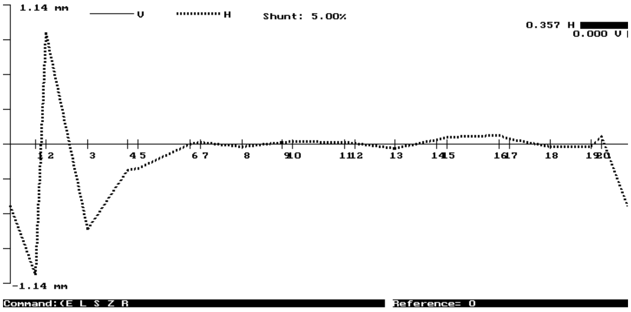

Fig. 5. Orbit after orbit correction showing the misalignment in the doublet at mark 1-2.

5.2 Response matrix method

By letting the QSBPM simulation program create a response matrix that uses magnet positions instead of corrector strengths, the correction output from the program is a list of magnet position changes. It has however to be taken into account that a movement of a quadrupole a distance *l* will move the beam a distance *kl*. In MAX I *k* is about 5.

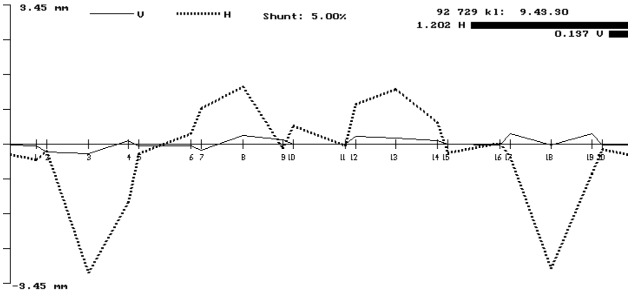

Fig. 6. The orbit change created by length tolerances of the dipole magnets in MAX I.

We found that there was an orbit deviation in the horizontal plane that had a very clear fourier component of 1 in MAX I which can be seen in fig. 6. We then let the QSBPM simulation output the dipole strengths and found that if the strengths of four dipoles on one side of the ring was reduced by 0.15% which is about the effect of removing one lamination thickness. By adding resistors across the four dipoles the orbit deviation was removed.

6. REFERENCES

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