THE CLOSED ORBIT MEASURING SYSTEM AT THE DELTA SYNCHROTRON RADIATION FACILITY

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Abstract

This paper presents the closed orbit measuring system of the DELTA SR Facility, concerning the hardware set-up, data processing and the calibration methods. The results of the calibration measurements and the recent operating experiences will be discussed. These results show, that the BPM offsets with respect to the magnetic centre of the quadrupole magnets turn out to be not acceptable. Therefore it was decided to install a beam based BPM calibration system in the near future.

1 INTRODUCTION

At DELTA (**D**ortmund **El**ectron **T**est **A**ccelerator) [1] we installed a total number of 58 identical BPM heads, 44 in the main storage ring and 14 in the synchrotron (**Bo**oster **Do**rtmund). The main design parameters of the BPM electronics are:

resolution:	< 10μm
long-term stability (12h)	< 50μm
absolute accuracy (in relation to quadrupole axis)	< 100μm
measuring frequency	10Hz
dynamic range	-60dbm – 0dbm (0.5mA – 500mA)

2 HARDWARE SET-UP

2.1 BPM Head

The BPM heads (see Fig.1) are made of blocks of stainless steel with an inner geometry identical to the vacuum chamber. 4 capacitive pick-up electrodes (ESRF type) are mounted into the BPM. Due to the minimum wall thickness of 20mm the change of the geometry forced by air pressure is negligible. All BPMs are mounted in quadrupole magnets without mechanical fixing. The pick-ups are connected to the BPM-electronics with double shielded RG223U cables via SMA connectors.

2.2 BPM Electronics

For cost reasons we used a simple design [2] without First Turn capability. One basic unit consist of two electronic boards (16cm×10cm). The measuring frequency is set to the accelerating frequency of 499.790MHz for both machines. On the mixer board all 4 signals of one BPM pass through 600MHz low pass filters. The subsequent multiplexing is performed by a PIN switch using a 400Hz clock signal. The output signal is mixed to the intermediate frequency of 10.7MHz. The local oscillator for down converting the signal is of the PLL type, consisting of a crystal reference oscillator, a VCO, a 1:256 divider and a phase comparator. One local oscillator board supplies four mixer boards. The second board is the IF amplifier board. It consists of two gain controlled video amplifiers followed by a 10.7MHz band pass filter (100KHz bandwidth), a fixed gain amplifier and a fast rectifier. The output signal is demultiplexed to four output channels, each averaged with a time constant of 100ms. The gain control of the two leading amplifiers is done in that way that the average output voltage is equal to a reference voltage U_r (U_r=4V).

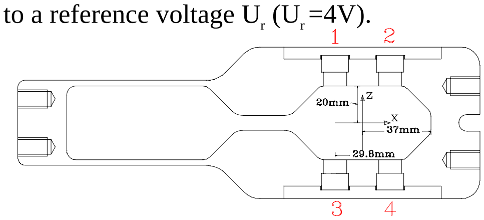

Fig.1 General layout of the DELTA BPM.

Four of these basic units together with one oscillator and two CAN modules with 16 0-10V input channels with 12 bit resolution are housed in one 19″ rack. 12 of these racks are placed around the storage ring and 4 BPMs each are connected to one of these racks.

3 DATA PROCESSING

From the control system we have access to the 4 pick-up signals from each BPM. This gives us flexibility for the calculation of the beam position. The calculation is done in linear approximation by using the BPM calibration factors of the centre of the BPM (c_x=15.9mm/%, c_z=19.6mm/%).

This leads to an absolute position error of 0.5mm for an offset of 5mm in x-direction of the centre of the BPM.

If a more accurate absolute determination of the beam position for greater offsets is necessary we can perform the calculation by an algorithm of iteration and polynomial fit. For this algorithm we are using signal functions of the BPMs calculated by MAFIA resulting in an absolute accuracy of 10μm for offsets of ± 10mm.

4 TEST MEASUREMENTS

The test measurements were done in two steps. First we made basic laboratory measurements using a signal source and a calibrated 4 way power splitter. Subsequent beam tests were done at ELSA (**EL**ectron **S**tretcher **A**ccelerator), University of Bonn.

4.1 BPM test with signal source and power divider

The tests of the dynamic range of several BPM electronics showed that the electronics work as specified in the range of –60dBm to –5dBm input power (this is comparable to a average beam current of 0.5mA to 280mA). The virtual orbit drift in the x-direction is in the order of 20µm, the resolution is smaller than 10µm. The long-term stability test over 16h with constant power level of –40dBm showed an orbit drift of 20µm.

4.2 BPM test with beam at ELSA

The measurements were done during normal synchrotron radiation runs (40 minutes duration, current between 60mA to 12mA). During a single run we saw an orbit drift of about 30µm in x- and 20µm in the z-direction. During 17 runs we could detect an additional drift from 20µm in the x-direction. These drifts are most likely caused by thermal movements of the BPM or influences on the pick-ups and cables. The resolution was tested by making slightly variations of the rf-frequency.

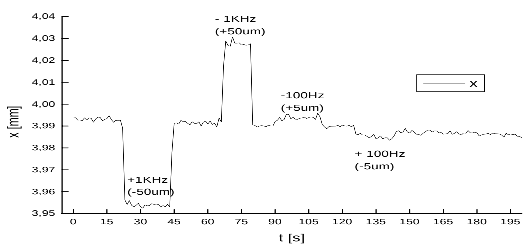

Fig.2. Variation of the rf frequency (500MHz) of ELSA (dispersion=1.63m, momentum compaction = 0.0615).

These measurements showed that the BPM electronics fulfill the requirements listed above.

5 CALIBRATION

The first step of the calibration procedure is to perform a calibration of the system with respect to the centre of the BPM.

5.1 BPM Head

Due to the manufacturing process of the DELTA vacuum chamber it was not possible to calibrate each BPM individually on a test bench with an antenna simulating the beam. Therefore we developed a method (pick-up method) to calibrate the BPMs by applying and measuring signals from the 4 pick-ups. The goal of this method is to determine 4 factors describing the individual attenuation of the pick-ups (coming from the pick-up itself and a displacement of the pick-up in the z-direction). These factors equalise the measured signals for a centred beam

To perform this calibration for one BPM we measure the signal received by three pick-ups if the fourth pick-up is connected to a signal-source. This results in 12 measured signals $S_{i,j}$ (= signal received from pick-up i when pick-up j is transmitting) and allow for the calculation of calibration factors a_i for each pick-up [3]:

$$a_1 = 1\ ;\ a_2 = \sqrt{\frac{S_{1,4}\cdot S_{1,3}}{S_{2,4}\cdot S_{2,3}}}\ ; a_3 = \sqrt{\frac{S_{1,4}\cdot S_{1,2}}{S_{3,4}\cdot S_{3,2}}}\ ; a_4 = \sqrt{\frac{S_{1,2}\cdot S_{1,3}}{S_{4,2}\cdot S_{4,3}}}$$

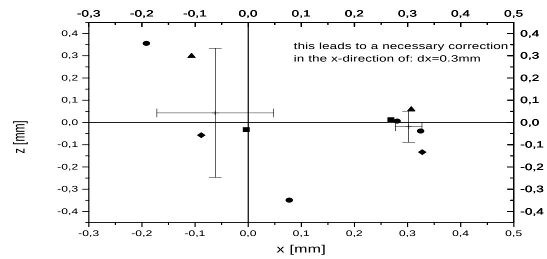

Fig.3 Calculated beam positions of a centred beam before and after pick-up calibration for 5 different BPM.

The offset in the x-direction is caused by the influence of the asymmetry of the vacuum chamber.

Measurements performed with all 14 BoDo BPMs showed an average variation of the relative pick-up sensitivity of ±2%.

5.2 Electronics

The calibration of the electronics (BoDo and DELTA) were done after installation. We used a signal source with calibrated power divider and measured the output signals obtaining a calibration of the whole data acquisition system. The relative deviation between the sensitivity of the 4 input channel is ±3%

5.3 Measuring Cables

The calibration of the cables together with the BPM head by the pick-up method was only possible in a rough manner. The necessary input signal of 40dBm to get output signals of –45dBm led to a not vanishing cross talk between the cables and an uncertainty in the calibration in the order of 0.5mm.

5.4 Overall Calibration

Performing the whole calibration procedure of pick-ups, cables and electronics it is possible to guarantee an absolute accuracy of the determination of beam position with respect to the BPMs of better than 100µm. Up to now this has been done for BoDo only. So for DELTA just a rough test of cables and pick-ups were made. Interpolating the calibration results from BoDo this leads to an uncertainty in the beam position of ±0.3mm.

On the other hand it is quite clear that we need a calibration with respect to the magnetic centre of the quadrupoles. The BPMs are mounted into the quadrupoles in two different ways. 50% of the BPMs fit to the aperture of the quadrupole magnets with an accuracy of 100µm. The other has no mechanical connection to the quadrupole and can move to avoid any stress on the quadrupole due to thermal movements. The resulting uncertainty of the position of the BPM centre in relation to the quadrupole is in the order of 1mm. A system for beam based BPM calibration is therefore absolutely necessary to reach the desired accuracy.

6 EXPERIENCES DURING COMMISSIONING

During the first period of operating BoDo the commissioning of the BPM system suffered from low beam current (< 0.5mA) and high noise level from the accelerating RF. The installation of an additional amplifier on the mixer board and the change of the measuring frequency to the next harmonic of the revolution frequency have solved these problems and allow sufficient orbit measurements in single bunch train mode (5-8 buckets filled). For DELTA operation with different filling patterns however the frequency change is not acceptable and the RF noise problem must be solved.

During the commissioning of DELTA we detect a very strong dependence of the measured orbit from the stored beam current. Some BPMs showed a virtual orbit drift of 9mm. The problem was solved for most of the electronics by removing the additional amplifier. Some BPMs shows furthermore a small but not negligible dependence of the orbit measurement from the beam current.

First measurements with 24 BPM electronics installed allow for a reduction of the average absolute orbit deviation in the x-direction from 3.9mm to 1.4mm and an increase of the average stored beam current from 20mA to 50mA.

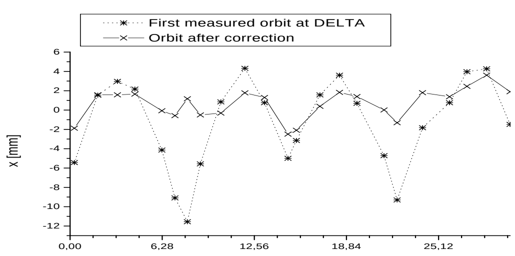

Fig.3 Measured orbit (horizontal plane) before and after first correction.

7 FUTURE PLANS

As described in section 4 DELTA needs a beam based BPM calibration system. The basic idea is to change slightly the k-value (quadrupole strength) of a quadrupole magnet and to detect the resulting orbit deviation. By steering the beam in the selected quadrupole and minimising the orbit deviation the magnetic centre of the quadrupole can be determined.

Because no DELTA quadrupole has a separate power supply we will install additional cables for all quadrupoles and a relay cascade to select each quadrupole individually. The k-value of the selected quadrupole will be changeable in a static way by shunting the quadrupole with a variable resistor or in a dynamic way with a dedicated power supply and frequencies between 1Hz and 40Hz.

To measure the dynamic orbit deviation at 2 BPMs (approximately 90° spaced in betatron phase), we will install a dedicated electronic to detect the amplitude modulation of the stored beam. This electronic consists of a AM demodulator followed by an FFT analyser.

With this system it is possible to determine at any time the offset between the BPM centre and the magnetic axis of the quadrupoles. Also a determination of the offset between any given orbit and the magnetic centres of all quadrupoles is possible. This allows a beam based alignment of the quadrupoles.

Furthermore we want to answer all questions concerning possible thermal movements of the BPMs. Additional it is possible to perform measurements concerning the optic of the machine. The beta functions of each quadrupole can be measured individually by measuring the tune shift caused by the variation of the k-value of the quadrupole.

A important step in the near future is to equip the remaining 20 DELTA BPMs with electronics to allow orbit corrections for the low emittance optics with higher tune values.

8 ACKNOWLEDGEMENTS

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