ORBIT RESPONSE MEASUREMENTS IN THE COMMISSIONING OF THE BESSY II BOOSTER SYNCHROTRON AND STORAGE RING*

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Abstract

Already in the early commissioning stages of the BESSY II booster synchrotron and the 1.7 GeV electron storage ring for synchrotron radiation, orbit response measurements to corrector magnet variations have been performed to verify the functioning of the hardware and the properties of the linear lattices. The extracted sensitivity matrices were used to detect malfunctioning BPMs, to adjust the calibration factors of the quadrupole and steerer power supplies and the BPM gains. They were used for orbit correction and tune adjustment. The paper summarizes the essential findings for the booster synchrotron as well as for the storage ring.

1 INTRODUCTION

The BESSY II complex consists of a 50 MeV racetrack microtron, a 1.7 GeV booster synchrotron and a 1.7 GeV electron storage ring. While the commissioning of the injection system started in summer 1997, the commissioning of the storage ring will continue throughout autumn 1998.

The booster synchrotron consists of a 16 fold missing magnet FODO-structure [1]. Electrons are injected at 50 MeV and accelerated in a 10 Hz cycle up to 1.7 GeV (1.9 GeV are feasible). The 32 Beam Position Monitors (BPM) measure up to 256 orbits during one cycle. In each plane there are 7 steering magnets (ST-H, ST-V) and 8 steering coils inside the sextupoles (SX-H, SX-V). The steering concept was layed out for orbit correction at low energy.

The storage ring lattice is a double bend structure with alternating high and low beta sections. There are 58 horizontal and 64 vertical correctors, included in the sextupole magnets, 32 horizontal coils in the dipoles and 112 beam position monitors (BPM). [2].

2 RELATED FEATURES IN THE BESSY CONTROL SYSTEM

The Bessy II control system offers online modelling of all the linear parameters of the two transfer lines, the booster synchrotron and the storage ring. The modelling is based on the GOEMON C++ library [3]. Sensitivity matrices are calculated by GOEMON and are available for the orbit correction. For the modelling, the actual settings of the magnets are read directly from the power supplies. The geometrical data of the lattice and the conversion factors (current to field) are taken from the ORACLE database [4]. The initial conversion factors were extracted from the magnetic field measurements taken prior to the installation of the hardware. Orbit response measurements have been given high priority in the control software. The measurement itself can be started via 'mouse clicks' from the orbit-control program and takes $40min$ in the synchrotron and about $2h$ in the storage ring. The extraction of the sensitivity matrices from the measured data is accessible in a similar way. The experimentally determined matrices can be used directly in the correction features. After fitting, the corrected conversion factors can be fed into the model via (preliminary) files or via ORACLE.

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3 SYNCHROTRON SPECIFICS

Orbit response measurements have been performed at many storage rings [5]. Compared to a storage ring where the noise level of the BPM system can reach the micron level, the accuracy of the BPM system in a booster synchrotron usually is reduced:

- the changing energy usually causes orbit changes, at the BESSY II synchrotron $\Delta y = \pm 1.5mm$ and $\Delta x = \pm 10mm$, with the maximum changes occurring between 50 and 400 MeV [6]
- the measuring time for each orbit is reduced to $6.4\mu sec * 32BPMs$ compromising between the amount of data taken during one cycle and the accuracy of each measurement. Thus a relative accuracy of $\pm 0.3mm$, and an energy variation of up to $7MeV$ can be associated with each orbit
- the low energy steering concept confines the measurement to the first couple of turns, where in addition to the above mentioned jitters of the microtron and the injection process are still visible especially in the horizontal plane

Typical noise levels of the BPM, i.e. rms deviation of successive orbit measurements, were around $0.3mm$ in the horizontal and $0.16mm$ in the vertical plane. At higher energy, the rms noise is strongly reduced (up to 40% in the horizontal plane).

4 MEASUREMENT AND FITTING PROCEDURE

By measuring the orbit as a function of different corrector settings, one can determine the gradient of the orbit change at each BPM, for every corrector. Following the GOEMON convention, two sensitivity matrices for the horizontal and the vertical plane are extracted. Their analysis directly yields information on malfunctioning hardware and the asymmetry in the ring. In a second step corresponding matrices are set up by the computer model, and by varying quadrupole fields, steering strength and BPM gains in the model, the theoretical matrices are fitted to the measured ones, thus yielding information about the linear optics in the ring. The underlying theory of the measurement and fitting procedure can be found in [7] and [8].

4.1 HARDWARE IMPLICATIONS

First orbit resonse measurements in the booster where taken in July 1997 in DC mode at $50MeV$ and where mainly used to verify the functionallity of the BPM system. Exchanged labeling of two BPM cabels was detected as well as wrong cabeling in the orientation of two further BPMs. No hints for major optics deviations could be found. In a perfectly symmetric ring steering coils located at identical optical locations have identical effects on the orbit. The deviation between corresponding rows of the sensitivity matrix yields insight in the symmetry of the machine. Figure 1 shows the difference orbits for the 8 vertical steering coils included in the sextupoles. Except for clearly detectable bad measurements the beat is of the order of a few percent, as expected from field and alignment errors.

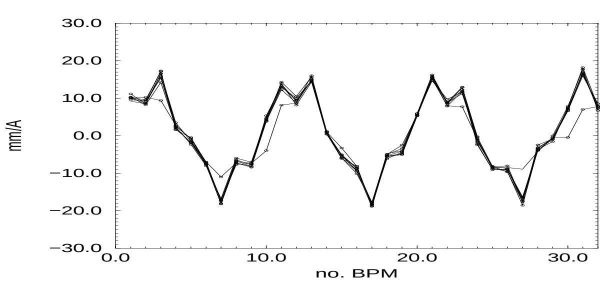

Figure 1: The effects of equivalent correctors differ by a few percents only. Bad measurements are clearly detectable, and usually caused by too low intensity of the beam.

4.2 FITTING OF THE BOOSTER OPTICS

Further orbit resonse measurements where performed in spring 1998. They were separated by shut down periods of the whole complex. The settings of the main power supplies were practically indentical. Up to 40 orbits where taken for each of usually 3 corrector settings differing by typically $0.1A$. All $\approx$ 120 readings have been used to fit the effect of a corrector at each BPM, with an average uncertainty of around $0.7mm/A$ for average orbit deviations of $18mm/A$ in both planes. The mean absolute deviation between the matrix elements of different measurements is around $3mm/A$.

In a first step the K-value of the two quadrupole families and the conversion factors of the four steerer types have been fitted, in an iterative proceedure with either the individual conversion factors of the steering magnets or the BPM gains. Table 2 displays the results for the K-values of the QF and QD families and the conversion factors of the steering coils in the sextupole (SX) and the separate steering magnets (ST). In the fit, the conversion factors depend on the energy, i.e. the measuring time, so they where scaled accordingly. The last two lines show the rms deviation between the measured and the fitted matrices, i.e. the quality of the fit.

Table 1: Global fit parameters

		3.4.98	21.4.98	31.5.98	$\Delta[\%]$
QF	$1/m^2$	1.7598	1.7587	1.7585	0.07
QD	$1/m^2$	-1.3744	-1.3735	-1.3704	0.27
Qx		4.5528	4.5513	4.5497	0.003
Qz		3.3117	3.3092	3.2962	0.234
SXH	Tm/A	0.992e-4	0.992e-4	0.992e-4	-
SXV	Tm/A	0.528e-4	0.565e-4	0.525e-4	0.57
STH	Tm/A	2.306e-4	2.301e-4	2.369e-4	1.84
STV	Tm/A	1.902e-4	(1.587e-4)	2.025e-4	3.13
rmsH	mm/A	2.83	3.39	2.96	-
rmsV	mm/A	1.53	3.31	1.47	-

The quadrupole fields could be determined to better than 0.3%. The conversion factors of the steering coils in the sextupoles show similar consistancy, while the deviation for the separate correctors is much larger. The reduced quality of the fit from April 21st correlates in the vertical plane with an increased rms BPM noise during the measurement of $0.29mm$ compared to $0.16mm$ in the other measurements, due to low intensity.

The fit of individual quadrupole fields showed that their effect on the matrices was smaller than the insecurity of the measurement. Table 2 shows the rms deviation between the correctors of the same type and the BPM gain. The larger deviation for the horizontal correctors have probably be attributed to the reduced quality of the data.

Table 2: rms deviation within families and BPM gain

SX-H	SX-V	ST-H	ST-V	BPM
7.2%	2.4%	6.1%	2.5%	11.6%

5 PRELIMINARY RESULTS FROM THE STORAGE RING

The first two commisioning blocks for the storage ring took place in April and May/June 1998. The first beam has been stored with the 5 sextupole families set to their design values. The uncorrected orbit reached deviations of more than 10 mm in both planes. The sensitivity matrices where dominated by the orbit offsets in the sextupoles, and difficult to fit. They were primarily used to commission the BPM system, where no severe errors where found, except for two interchanged cabels and wrong polarity for all steering coils in the dipoles.

During the second commissioning block beam could be stored with the sextupoles turned off. Due to the limited accumulation orbit response measurements where taken during continuous injection. The derived sensitivity matrices showed good agreement with the model in the horizontal plane and an integer difference in tune in the vertical plane, which was confirmed by single turn measurements. The sensitivity matrices have been fitted successfully, and the conversion factors for the defocussing quadrupole families Q2 and Q3 located close to the dipoles turned out to be $2-3\%$ lower than originally thought. The remaining families where confirmed on the 1 percent level. This effect has not yet been finally analyzed, but could probably result from shielding effects. Using the improved conversion factors, the machine was set to the design tunes, and orbit corrections were performed using the model sensitivity matrices and an singular value decomposition proceedure. The successively reduced rms orbit during 4 consecutive corrections in the vertical plane is shown in figure 2.

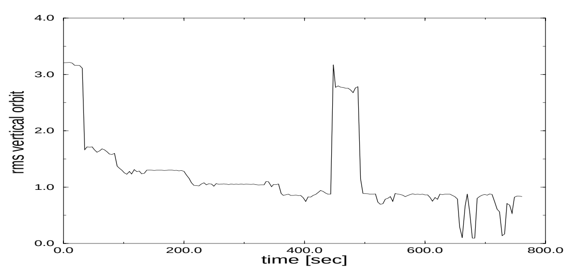

Figure 2: The rms orbit deviation during corrections with the fitted model. At 450 sec the old values have been restored. Around 700 sec the beam was lost.

Additional measurements at the adjusted tune suggested modifications of less than 0.5%, thus confirming the linear model. It should be mentioned, that the fit in the storage ring at that stage did not consider individual parameters. The agreement between theoretical and experimental matrices of less then 10% was reached for a purely symmetric model and all BPM gains set to 1. Further the orbit has not been corrected during the measurement and thus reached the nonlinear region of the BPMs. Figure 3 shows typical difference orbits of the fitted matrix (solid line) and the experimental matrix (circles).

6 SUMMARY

Orbit response measurements and their analysis have been a suitable tool during the early stages of commisioning the BESSY II booster synchrotrons and storage rings. The accuracy of the measurement and the fit can at this early stage of commisioning not yet be compared to those reached in

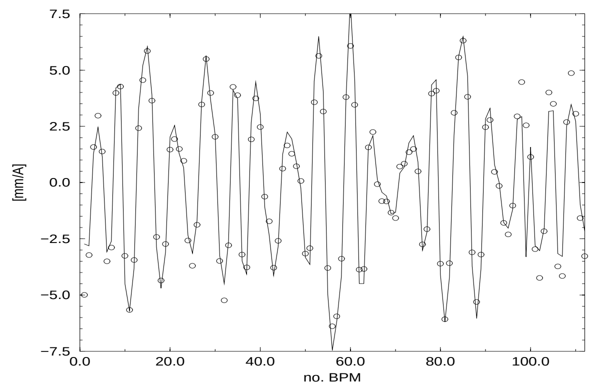

Figure 3: Measured and theortical difference orbits with a malfunctioning BPM no. 99 and larger deviations around the injection

established facilities, but corresponds well to the momentary level of understanding of the machine. Hardware errors could be eliminated, possible sources of deviations where found quickly and the model could be brought to useful agreement with the measurements practically from the very beginning.

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