Accelerator Modeling at SPEAR*

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Abstract

The response matrix, consisting of the closed orbit change at each beam position monitor (BPM) due to corrector magnet excitations, was measured and analyzed in order to calibrate a linear optics model of SPEAR. The model calibration was accomplished by varying model parameters to minimize the chi-square difference between the measured and the model response matrices. The singular value decomposition (SVD) matrix inversion method was used to solve the simultaneous equations. The calibrated model was then used to calculate corrections to the operational lattice. The results of the calibration and correction procedures are presented.

1 INTRODUCTION

The modeling program is based on using a measured response matrix to calibrate a model of the accelerator system. The measured response matrix as a tool for determining the linear optics of storage rings has proven valuable in the past [1-4]. The practical aspects of measuring the matrices at SPEAR and their use as a diagnostic tool are discussed.

1.1 Objectives

The objectives of the SPEAR modeling program are to:

- calibrate models for different configurations of the ring parameters to create an accurate on-line model,
- identify hardware errors and predict and correct beam parameters such as beta functions,
- fine-tune the ring and improve the overall performance of the accelerator,
- isolate the effects of insertion devices on the electron beam and calibrate models for them.

2 MEASUREMENT PROCEDURE

The measurement procedure is time consuming and therefore automated. There are three types of measurements for each attempt at model calibration:

- The response matrix.
- The rms noise level of the BPMs.
- A dispersion orbit.

2.1 The Response Matrix Measurement

The measurements are initially made with a bare lattice. This means shutting off octupoles and skew quadrupoles as well as removing the insertion devices. Once a model is calibrated for the bare lattice, the other elements can be added and modeled.

The measurements are made using a procedure which systematically changes the excitation current of each corrector magnet. For each corrector, the change in the closed orbit is recorded. In the case of SPEAR, there are 31 correctors and 29 BPMs in each plane, which results in a 62 x 58 matrix.

2.2 The BPM noise

The rms noise levels for each of the BPMs is measured by simply taking many orbit measurements with a stable beam. This defines the limit to how well the model matrix can be made to match the measured one.

2.3 The Dispersion Orbit

The dispersion measurement is used to calculate the energy shift associated with each of the horizontal correctors.

3 CALIBRATED PARAMETERS

The calibration of the various model parameters depends upon the effect they have on the response matrix. If the effect is larger than the BPM noise level, it can be calibrated. At present, the following parameters have been calibrated for SPEAR:

- The corrector strengths.
- The BPM gain factors.
- The energy shifts associated with horizontal correctors.
- The quadrupole strengths.

3.1 Corrector strengths

Initially, the corrector strengths are all set to the same value. This provides a means of checking the calibration procedure since there are different types of correctors, which should have different values. The calibrated values can then be compared to the predicted values.

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3.2 BPM Gain Factors

The BPM gains are initially set to unity. Once they are allowed to vary, a measure of the spread in gains and a direct indication of whether or not all BPMs are functioning is obtained.

3.3 Quadrupole Strengths

The initial model quadrupole strengths need not be very accurate. In the case of SPEAR, there are numerous "fudge" factors which have been introduced in order to obtain a better correlation between model and machine. The calibration procedure described here eleminates these factors.

4 THE CALIBRATION PROCEDURE

The calibration procedure is as follows:

- Measure the response matrix.
- Create a model response matrix.
- Calculate the changes in the model response matrix for the parameters that are to be calibrated.
- Compare the measured and model matrices.
- Calculate the parameter changes that minimize the difference.
- Iterate until the solution converges.

When starting with an un-calibrated model, the number of iterations necessary for convergance can be reduced by calibrating the corrector strengths, energy shifts with horizontal correctors and quadrupole family strengths first. Once this is done, the BPM gains can be added and the individual quadrupole strengths can be calibrated seperately. Experience has shown that five or six iterations usually suffice for convergance of the solution. With several thousand (62 x 58 = 3596) measured data points, it is possible to include many parameters. At present there are 2 x 31 correctors, 2 x 29 BPM gains 50 quadrupole strengths, and 31 energy shifts for a total of 201 calibrated parameters for the bare lattice.

Once a calibrated model is acquired, changes in the parameters can be calibrated. All of the parameters can be left to vary and the measured response matrix from the bare lattice replaced with one measured after the change is made.

5 OBSERVATIONS AND RESULTS

The initial calibrations of SPEAR illuminated the need for a more precise model. The calibration of the bare lattice is now routine.

The results of the very first iterations of the calibration procedure showed that there were two BPMs with gains that differed considerably from the rest. These happen to be older monitors that were known to be problematic. After calibration it is possible to use the information obtained from them scaled with the gain. While the coupling terms of the matrix are not presently being used in the calibration routine, they have shown that there is a BPM that gives an erroneous vertical signal when the horizontal correctors are changed. The cause is still under investigation.

The corrector gains obtained from the first calibrations showed that there was a new corrector that had little or no effect on the beam. This was discovered to be due to the fact that one of the corrector coils was wired wrong and has since been corrected.

5.1 Quadrupole Families

There are seven families of quadrupoles in SPEAR. Each family is powered in series by a single power supply. The calibration of the quadrupole family strength gives a current/quadrupole-strength value which is independent of magnetic measurements made prior to installation of the magnets on the ring. This can then be used to calculate new current settings in order to make any changes. The tunes are not directly used in the calibration routine and are used to confirm that the calibrated values are correct. The individual quadrupole strength calibrations show the spread within families that, while it is not possible to individually set the current, offer a way to simulate beam parameters which are difficult or impossible to measure on the machine.

5.2 Quadrupole Shunt Calibrations

Quadrupole shunts are used on SPEAR for finding the center of quadrupoles and measuring the beta functions [5,6]. A response matrix was measured for a bare lattice and a model was calibrated, and then the shunt was activated and a new response matrix was measured. This matrix was put into the calibration routine and all the parameters were left to vary. The first iteration showed that the calibrated strength of the shunted quadrupole was reduced by a couple percent while the others remained virtually unchanged. This test will be repeated for every quadrupole and the calibrated change in strength with shunts used to refine shunt-based measurements. It also shows that the calibrated differences in quadrupole strengths within a family of the order of a few percent can be trusted. The calibrations done so far have shown that the quadrupoles within a family keep their ordering from strongest to weakest with different current settings as well.

5.3 Beta Function Corrections

The beta functions calculated using the initial calibrated model were not very uniform compared to the design values. A measurement of the beta functions was then made and compared to the calibrated model values. The calibrated current/quadrupole-strength values were then used to calculate new current settings in order to correct the discrepancy. The beta functions were measured and a new model was calibrated. Figures 1 and 2 show the vertical beta functions before and after correction. The stars are measured values and the solid lines are calculated from the calibrated models. Some of the difference between the measurements and the model values is due to the fact that the quadrupole shunts are not all calibrated as yet and the measured values are an average over the length of the quadrupoles.

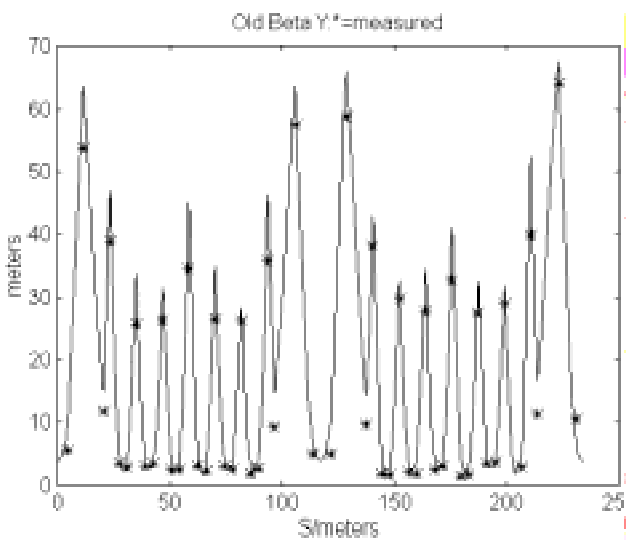

Figure 1: Vertical beta function before correction.

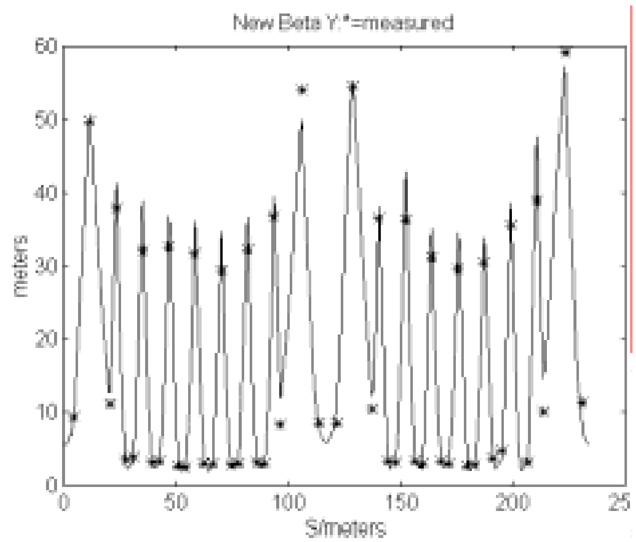

Figure 2: Vertical beta function after correction.

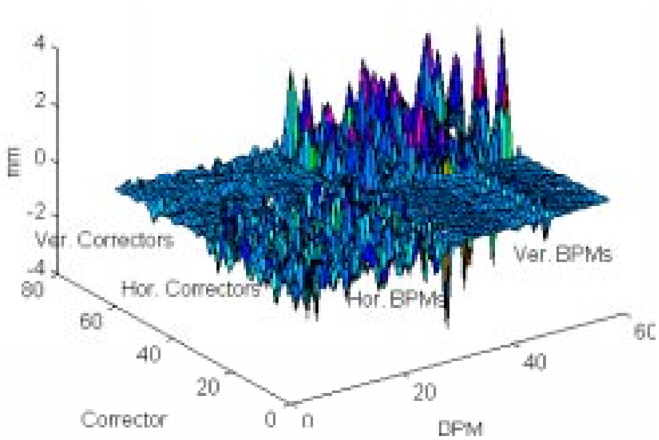

Figure 3: Difference matrix before calibration.

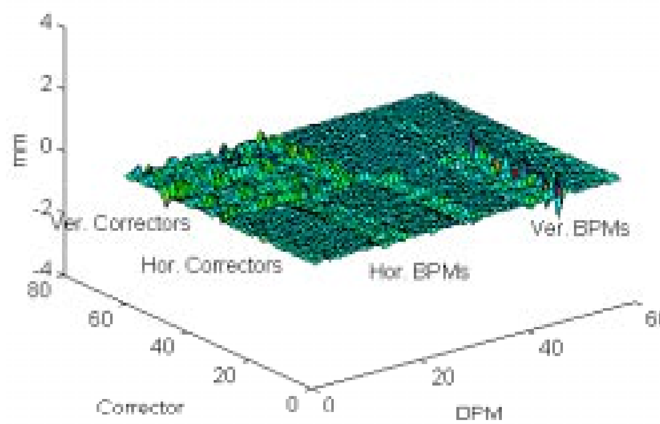

Figure 4: Difference matrix after calibration.

6 CONCLUSIONS

The response matrix calibration method produces a very accurate model of the linear optics of a storage ring. Figures 3 and 4 show the difference between measured and modeled response matrices before and after calibration. Work is in progress to calibrate the effects of insertion devices.Once a calibrated model exists, it is straigthforward to identify and quantify changes to the machine due to installation of new elements or failure of existing ones.

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