A FLIGHT SIMULATOR BASED BEAM BASED ALIGNMENT PACKAGE FOR ATF2 *

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Abstract

The Flight Simulator is a Matlab middleware layer which uses the Lucretia beam tracking engine and a lower level EPICS control system to allow the development of beam control and monitoring algorithms in a simulation environment that appears identical to the that of the control room.

The goal of ATF2 is to test a novel compact final final focus optics design intended for use in future linear colliders. The newly designed extraction line and final focus system will be used to produce a 37 nm vertical waist from the extracted beam. Alignment of the magnetic elements is of vital importance for this goal and it is expected that beam-based alignment (BBA) techniques will be necessary to achieve the necessary tolerances.

This paper describes a package for the beam-based alignment of quadrupole and sextupole magnets in the ATF2 damping ring, extraction line, and final focus system. It brings together several common techniques for the alignment of magnetic elements, and has been implemented as a GUI-based tool that may be used on its own, or integrated with other routines. The design of this package is described, and simulation and beam results are shown.

INTRODUCTION

The purpose of the ATF2 project is to demonstrate the concept of "local chromaticity correction", which is a final focus optics scheme intended for use in future linear colliders. Success of the planned tuning techniques (for example [1],[2],[3]) depends strongly on good quality beam diagnostics, and the ability to determine information on the evolution of the beam parameters along the length of the beamline.

Of particular interest is knowledge of the beam orbit with respect to the magnetic elements that define the lattice, and, to this end, a high resolution, stable, system of beam position monitors (BPMs) has been installed along the full length of the ATF2 extraction line[4][5]. BPMs measure the distance of the beam from their electrical centre, so further work is needed to determine this location with respect to the centre of their adjacent magnetic elements.

BEAM BASED ALIGNMENT

The alignment techniques discussed here are commonly known as Beam Based Alignment (BBA) since the location of beamline components is determined using beam position measurements.

Typically, each of the magnets have been installed with a co-located BPM, and, to a good approximation, most of these BPMs can be considered to be at the same longitudinal location as the magnets. This implies that angle effects don't need to be considered, and the offset of the beam in the BPM is identical to that in the magnet.

QUADRUPOLE ALIGNMENT

A beam that travels offset through a quadrupole will receive a transverse kick off the design orbit, thus requiring correction by steering magnets. Such kicks are dispersive, and will cause dispersive emittance growth of the beam, so knowledge of the position of the centre of the quadrupole would allow these negative effects to be mitigated.

The alignment algorithm employed here involves a so-called 'quadrupole shunting' technique. First, the beam is scanned with respect to the quadrupole, and the position at several downstream BPMs is measured. The scan can be accomplished using an upstream steering magnet, or, if available, by physically moving the quadrupole with a , 4) mover system.

The strength of the quadrupole is then changed, or 'shunted', to a new value, which has the effect of modifying the phase advance between the quad and the downstream BPMs, and, therefore, changing the $R(1,2)$ and $R(3$ between the source of the position change and the BPMs.

The original position scan is then repeated, however, due to the R-matrix alteration caused by the quad-shunting, the positions recorded on the downstream BPMs will be different to the initial scan.

Straight-line fits are then performed on the two sets of data, and the crossing point of these lines is calculated. The crossing point is the beam position at which the orbit is unaffected by the strength of the quad, and is therefore the magnetic centre.

The accuracy of the measurement is increased by using multiple downstread BPMs, and combining their results by averaging the error-weighted crossing points found at each one.

This method is repeated for each plane.

SEXTUPOLE ALIGNMENT

Beam offsets in sextupoles will degrade beam quality through the same processes as described for quadrupoles.

The horizontal kick, x', given to the beam by an offset in x and y is as follows,

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$$\Delta x' \propto x^2 - y^2 \tag{1}$$

Therefore, the horizontal kick received by the beam is quadratic with the offset in both x and y, and so the effect of offsets in either plane may be measured by observing only the x kick.

Additionally, since the dependence is quadratic, the received kick will always be in the same direction, and the centre of the magnet can be defined as the point at which the relationship between the offset and kick changes sign; i.e. the turning point of the parabola. This feature enables the alignment measurement to be performed without shunting the sextupole.

The measurement procedure involves moving the position of the beam with respect to the sextupole, and recording the position change on downstream BPMs. Each of these datasets are fit to a 2nd order polynomial, from which the turning point of this parabola is calculated.

As with the quadrupoles, data can be collected at each of several downstream BPMs, in order to improve accuracy by performing an error-weighted average of the result.

FLIGHT SIMULATOR GUI PACKAGE

The Flight Simulator (FS)[6] is a Matlab middleware package that uses Channel Access commands to communicate with ATF2 power supplies, BPMs, etc., via its EPICS database. It is part of the Lucretia software package[7], and one of its most interesting features is its ability to run in 'simulation mode', which uses the Lucretia physics and tracking engine to produce simulated beam measurements. Since this process is completely transparent to the user, it is possible to design and implement beam control software entirely in simulation mode, which may then be transferred to operation on the physical machine with no changes needed to the code.

A Graphical User Interfacce (GUI) tool was developed to align the ATF2 quadrupoles and sextupoles using the algorithms presented in the previous sections. A screenshot of this GUI is shown in figure 1 after simulating the alignment measurement of a quadrupole.

Controls on this panel allow the user to select the type of magnet (quadrupoles or sextupoles) on which to perform the alignment, and then to choose a specific magnet from a drop down list. Once the magnet is selected, the various parameters of the scan need to be input:

1. The number of positions to scan through ('*Points per scan*').
2. The number of BPM readings to record at each beam position ('*Averages per point*').
3. The value to which the quad should be shunted as a percentage of its original strength ('*Shunt value*').
4. The range over which to scan the position in the magnet ('*Scan range*').

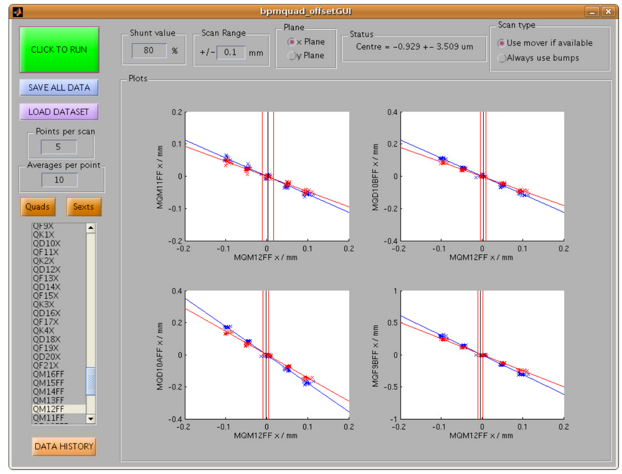

Figure 1: BBA implemented as a FS GUI.

5. The measurement plane ('*Plane*').
6. The beam position movement method ('*Scan type*').

Once each of these parameters has been set the scan can then be started, and the results will be displayed in the figure window (one axis for each of the four BPMs used). The error-weighted average of the four results is displayed in the '*Status*' panel at the top of the window.

RESULTS

While this tool has been under development for quite some time, it has only recently been moved from the simulation environment to operation on the machine, so, while it has been demonstrated to be quite stable and accurate in simulation, its robustness under real-life conditions has yet to be fully developed.

Simulation

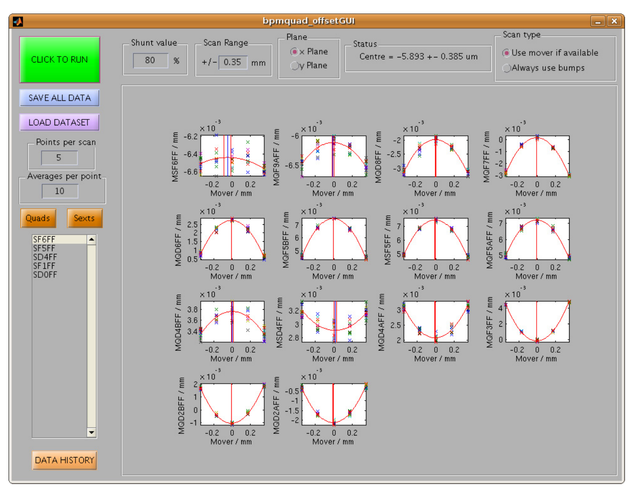

Figure 2: Simulation results for a sextupole.

Results of simulated measurements are shown in figures 1 and 2.

Figure 1 shows a simulation the measurement of quad *QM12FF* in the ATF2 Final Focus (FF). For this dataset, the simulated BPM resolution was deliberately degraded in order to demonstrate the error-handling features of this GUI.

The two scans are plotted in different colours, and the calculated crossing points of the lines are indicated with a vertical black line, and the 1σ errors are shown in red. In this case, it can be seen that the centre of the quad lines up very well with that of the BPM.

Figure 2 shows the results from a simulation of a sextupole measurement. In this case, the data is plotted against the position of the mover, and so, instead of showing the difference between the BPM and magnet centres, it shows how far the magnet would have to move to line up with the current beam position.

For this measurement, as explained earlier, only one position scan is needed, and this is fit to a second order polynomial. The turning point of each of these, along with its associated error, is plotted, and then the combined results are shown in the *status* panel.

In this case, the beam was located $\sim$5.5 μm from the centre of the sextupole.

Beam Measurements

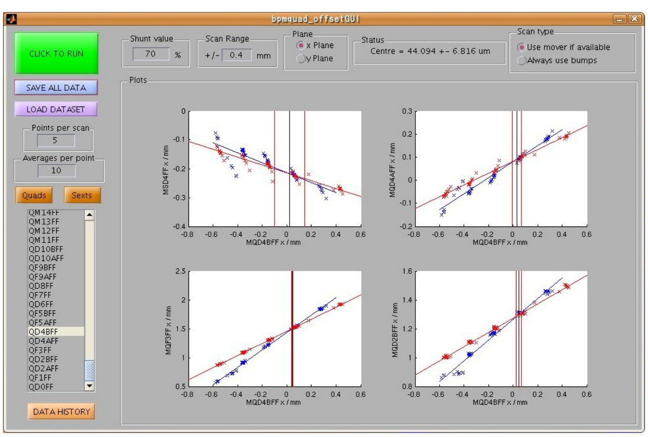

Figure 3: Beam measurement for quadrupole QD4BFF x.

Commissioning work on the ATF2 has recently begun[8], allowing initial tests of this tool. An early result is shown in figure 3, where a measurement was made of the x centre of a FF quadrupole (QD4BFF). It can be seen that the centre of the magnet is offset from that of the BPM by 44$\pm$7 μm.

The cluster of ten points at each position setting can be quite clearly seen in each of the plots, and, in the figure showing MSD4FF vs MQD4BFF (upper left), a large amount of correlated motion can be seen in cluster. This suggests that there is a substantial amount of beam jitter – perhaps due to dispersion – that is degrading the resolution of this result. It is hoped that efforts to minimise the dispersion, and to improve beam conditions, will lead to a considerable improvement in the quality of these results, however it should be noted that this resolution is in no way considered to be poor, and will allow the commencment of initial beam steering studies.

Further Work

Building this tool in the Flight Simulator environment has allowed an almost finished product to be deployed on the ATF2, however it is clear that some further work could lead to large improvements in the operation of this GUI.

It should be possible to choose whether to make the measurement with respect to the mover position or the readout of the co-located BPM, as this would allow the alignment to be done with respect to the current beam position, or to be a measurement of the offset of the BPM with respect to the magnet centre.

The ability to select different downstream BPMs, instead of the four closest, would add to the flexibility of this tool, especially if combined with a prediction of the R matrix between the movement source (the upstream corrector, or the movement of the quad) and the available BPMs.

Also, it would be interesting to extend the data-save feature to build up a time history of results for each magnet.

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