Jacob Pachikara participated in the Science Undergraduate Laboratory Internship (SULI) program during the summer of 2006, completing an internship in the Engineering Division of Lawrence Berkeley National Laboratory, where he contributed to the development of a Graphical User Interface for the particle accelerator control room. He presented this work in February 2007 at the AAAS conference in San Francisco. He is currently pursuing an undergraduate degree in electrical engineering at The University of Texas at Arlington. In addition to his academic pursuits, he is active in numerous honor societies including Tau Beta Pi, Eta Kappa Nu, and National Society of Collegiate Scholars.

Greg Portmann has worked in particle physics for the past 15 years at Lawrence Berkeley National Laboratory (LBNL) and Stanford Linear Accelerator Center (SLAC). In general, he works on algorithms to optimize the performance of electron accelerators. Before that he worked at the Johns Hopkins University Applied Physics Laboratory, designing algorithms for radar target tracking and flight control applications. He also had a brief career in the bio-device sector, developing signal processing algorithms to analyze the electrical and mechanical activity of the stomach to determine optimal gastric pacing strategies. Greg has a B.S. in mathematics and M.S. in electrical engineering from Penn State University.

A NEW GUI FOR GLOBAL ORBIT CORRECTION AT THE ALS USING MATLAB

Jacob Pachikara and Gregory Portmann

ABSTRACT

Orbit correction is a vital procedure at particle accelerators around the world. The orbit correction routine currently used at the Advanced Light Source (ALS) is a bit cumbersome and a new Graphical User Interface (GUI) has been developed using MATLAB. The correction algorithm uses a singular value decomposition method for calculating the required corrector magnet changes for correcting the orbit. The application has been successfully tested at the ALS. The GUI display provided important information regarding the orbit including the orbit errors before and after correction, the amount of corrector magnet strength change, and the standard deviation of the orbit error with respect to the number of singular values used. The use of more singular values resulted in better correction of the orbit error but at the expense of enormous corrector magnet strength changes. The results showed an inverse relationship between the peak-to-peak values of the orbit error and the number of singular values used. The GUI interface helps the ALS physicists and operators understand the specific behavior of the orbit. The application is convenient to use and is a substantial improvement over the previous orbit correction routine in terms of user friendliness and compactness.

INTRODUCTION

The Advanced Light Source (ALS) is one of the world's brightest ultraviolet and soft x-ray producing facilities. These powerful beams of light are used for various scientific experiments including the investigation of the structure of atoms, molecules, polymers and chemical reaction dynamics. The ALS is a third generation synchrotron light source which produces light using bend magnets, undulators, and wigglers. Bend magnets are electromagnets used to bend the electron beam and make it travel in a circular ring. As the electron beam bends, light is emitted in the ultraviolet to x-ray region of the spectrum. Undulators and wigglers are composed of numerous magnetic poles. By combining the light created from each pole, they can create particularly bright sources of light.

The electron beams ideally travel through a predetermined orbit, but many times the electron beams are subject to orbital shifts in the transverse direction due to ground settlement, thermal drift in the magnets and vacuum chamber, ground vibrations, and power supply instability [1]. If left uncorrected, this will lead to degradation of the light produced, and will compromise the experiments at the ALS. A global orbit correction system developed in MATLAB, a high-level data manipulation software language, has been implemented to solve this problem. This system uses Beam Position Monitors (BPMs) to measure the current position of the electron beam orbit and electron dipole magnets for orbit steering. The orbit correction algorithm uses a Singular Value Decomposition (SVD), a method of solving singular matrix equations, to analyze these data and to correct the orbit. The current orbit correction routine is cumbersome due to its menu driven system. It asks several questions one by one and based on the answers selected for each of them it narrows down to the type of correction. This report presents a new, user friendly, GUI for SVD global orbit correction developed using MATLAB.

SVD Orbit Correction

For orbit correction in accelerators it is usually enough to assume a linear relationship between the electron beam position and the corrector magnet strength. This can be expressed as:

$$\Delta X = A \times \Delta Y \qquad (1)$$

where ΔX is a vector that contains all the desired changes to the BPM values, ΔY is a vector that contains all the necessary changes in corrector magnet strength to achieve that change and A is the corrector-to-BPM response matrix. A contains the ratios between the various corrector strengths and their associated BPM values. Each corrector is represented by a single column in the response matrix [2]. Figure 1 shows a response matrix measured at the ALS. The response matrix can be calculated either by using beta function theory or measuring directly on the accelerator. The response matrix can be measured by varying the strength of a corrector magnet and recording all the BPM measurements and repeating the process for all the corrector magnets individually. For global orbit correction, the next step is to find the desired corrector magnet strength change; this can be done by inverting Eq. (1) as:

$$\Delta Y = A^{-1} \times \Delta X. \tag{1}$$

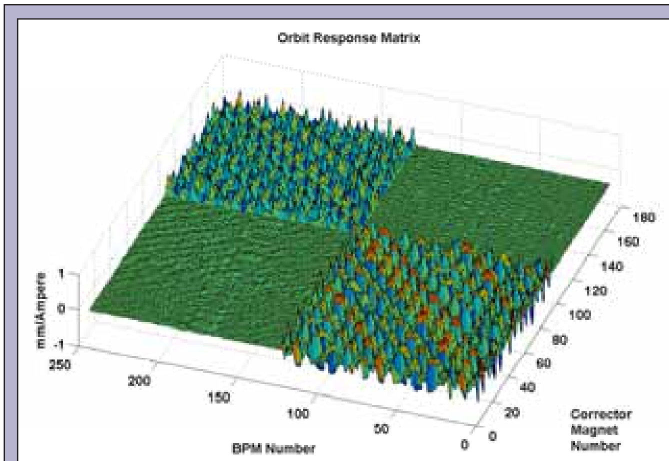

Figure 1. BPM-to-corrector response matrix. The response matrix is measured by varying the strength of a single corrector magnet and recording all the BPM measurements, and repeating the process for each of the corrector magnets.

To find the inverse of the response matrix, it has to be a square matrix and nonsingular. Most of the time, however, response matrices are non-square and are often close to singular and therefore do not have a well-defined inverse. One of the ways to tackle this problem is SVD. The SVD method is based on factorization of the matrix. Using SVD, any $M \times N$ response matrix A can be written as $A = U \bullet S \bullet V^T$, where U is an $M \times M$ orthogonal matrix, S is an $M \times N$ diagonal matrix and V is an $N \times N$ orthogonal matrix. Therefore, the pseudo-inverse of the response matrix can be expressed as:

$$A^{-1} = V \bullet S^{-1} \bullet U^T \tag{3}$$

where V is a set of orthonormal vectors with each axis corresponding to a corrector magnet, U is a set of orthonormal vectors with each axis corresponding to a BPM, and S is a set of vectors that contain singular values of the matrix A. This leads to a solution for Eq. 1 where the corrector magnet strength change, ΔY, is given by:

$$\Delta Y = V \bullet S^{-1} \bullet U^T \bullet \Delta X. \tag{4}$$

A typical orbit correction algorithm is as follows. The first step is to measure the response matrix. After acquiring the response matrix, calculate its pseudo-inverse. Next, measure the current orbit error. This is used to calculate the required corrector strength changes to correct the orbit. Once the corrector strength change is calculated and applied to the orbit, the orbit error is measured again to see how well the orbit was corrected. If the desired orbit is not obtained, the corrector strength change is calculated again. This procedure will be repeated until the user stops the process [3].

It is convenient to use a GUI to correct the electron beam orbit. Figure 2 shows the orbit correction GUI. All the primary features of the GUI are divided into five different panels. These are plane, goal orbit, miscellaneous tasks, correct orbit, and scale down correctors.

Plane

This panel provides the user with the ability to correct the electron orbit in either the horizontal direction, the vertical direction, or both. The ability to choose different predefined BPM sets as well as corrector sets is provided in the GUI. The user is also able to edit the list of BPM and corrector magnet sets to omit a possibly malfunctioning BPM or to disable a weak corrector magnet from strength changes so that the measurements will be more accurate. It is also useful for test and maintenance purposes.

Goal Orbit

An integral part of the GUI is a panel called the goal orbit which enables the user to correct the current orbit to the ideal or goal orbit. It also allows the user to save the current orbit or load a previously saved orbit. It can then be used as the goal orbit for orbit correction.

Miscellaneous Tasks

The GUI also allows the users to set the number of singular values to be used in calculating the corrector magnet strength change. Using more singular values results in higher corrector magnet strength changes and smaller orbit errors. This panel also allows the user to include the RF frequency. RF changes the energy of the electron beam, and changing the energy of a beam changes the electron orbit. Therefore, varying RF frequency provides another means of correcting the electron orbit.

Correct Orbit

After selecting the BPMs, corrector magnets, and number of singular values to be used, the GUI display shows information on how the orbit will behave if those settings were to be applied. If those settings predict a reasonable correction to the current orbit, then the user can apply those settings to the actual orbit. The GUI display includes the magnitude of each of the singular values used in correction, the change in corrector magnet strength that will be applied, the predicted orbit residual (which is the difference between the goal orbit and the predicted orbit after correction), and the current orbit error before correction. The GUI also has an option to display the sum of the corrector magnet strengths relative to the number of singular values and the standard deviation of the current orbit error relative to the number of singular values. The user will be able to choose between displaying just the four plots or all the plots.

Scale Down Correctors

It is often desirable to scale down the correctors before orbit correction. Some accelerators are able to zero all correctors. If the corrector magnets are never scaled down before starting orbit correction, then over time the total corrector strength may grow quite large. Therefore, users are inclined to turn the correctors down before orbit correction. One of the features of the GUI allows the users to scale the correctors down by percentages of the present corrector value.

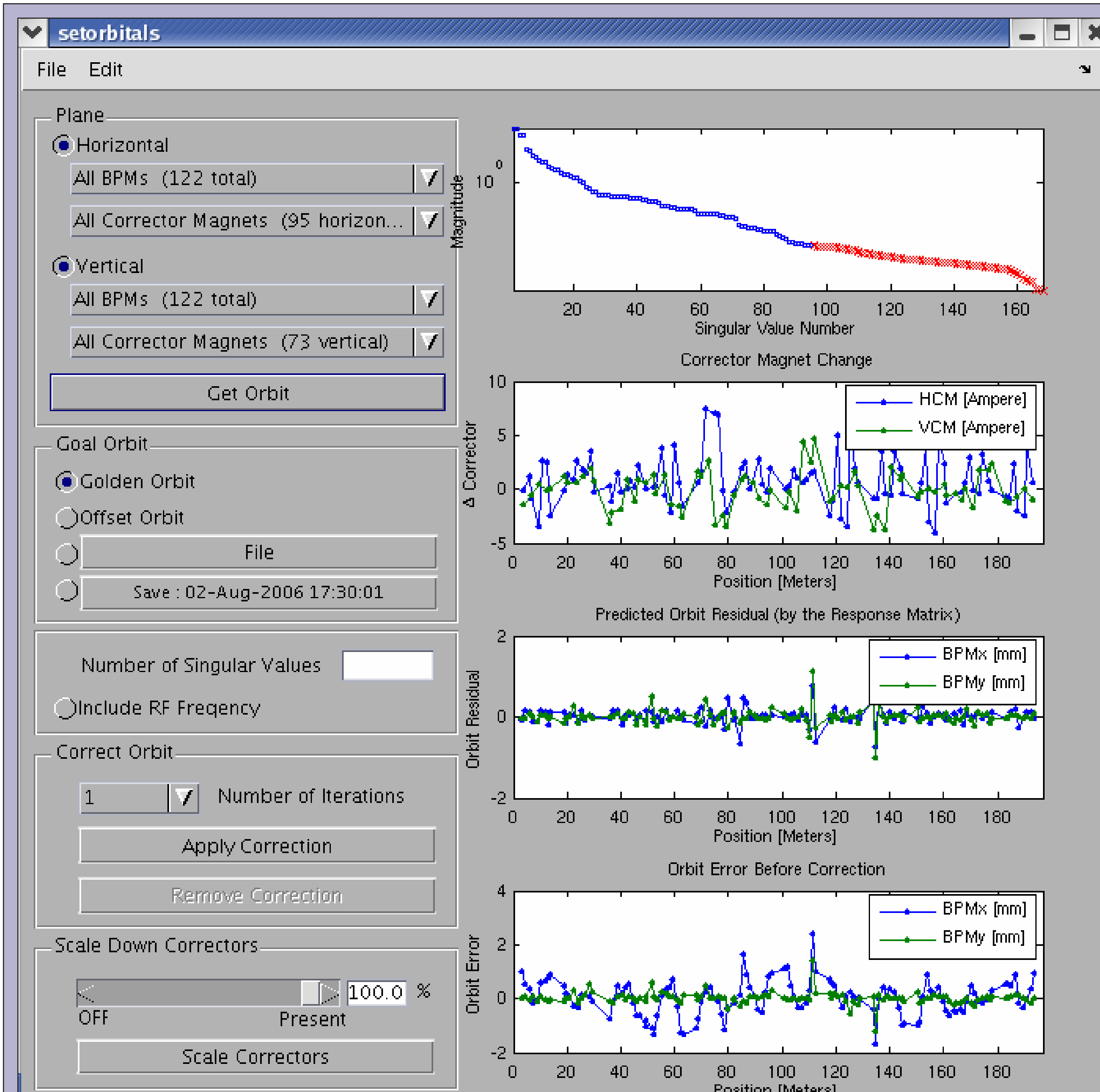

Figure 2. The new application provides a convenient way of performing global orbit correction at the ALS.

RESULTS

The orbit correction GUI was tested in the ALS and data was collected regarding the orbit error before and after correction using three different singular values (1 to 47, 1 to 50 and 1 to 92). The application worked effectively. Results for the horizontal plane will be shown. All 122 BPMs and 95 horizontal corrector magnets in the ALS were used in the testing. The orbit correction was tested by saving an orbit, then scaling down the correctors to introduce a large horizontal error. After scaling, the orbit error was observed to be around 2mm. This is a large orbit distortion compared to the few micrometer level of error during normal ALS operations. The perturbed orbit was then corrected using the GUI. Figure 3(a) shows the orbit error before and after the correction. After the correction, the error was only about 5.6µm, showing that the algorithm worked quite well. The corrector magnet change and the number of singular values used are shown in figures 3(b) and 3(c) respectively.

DISCUSSION AND CONCLUSIONS

As discussed earlier, the use of more singular values results in better correction of the orbit. This can be seen in figure 4. The three lines in the plot represent the orbit after correction when different numbers of singular values were used. The plot shows an inverse relationship between the peak-to-peak values of the orbit error and the number of singular values used. For the set of singular values of

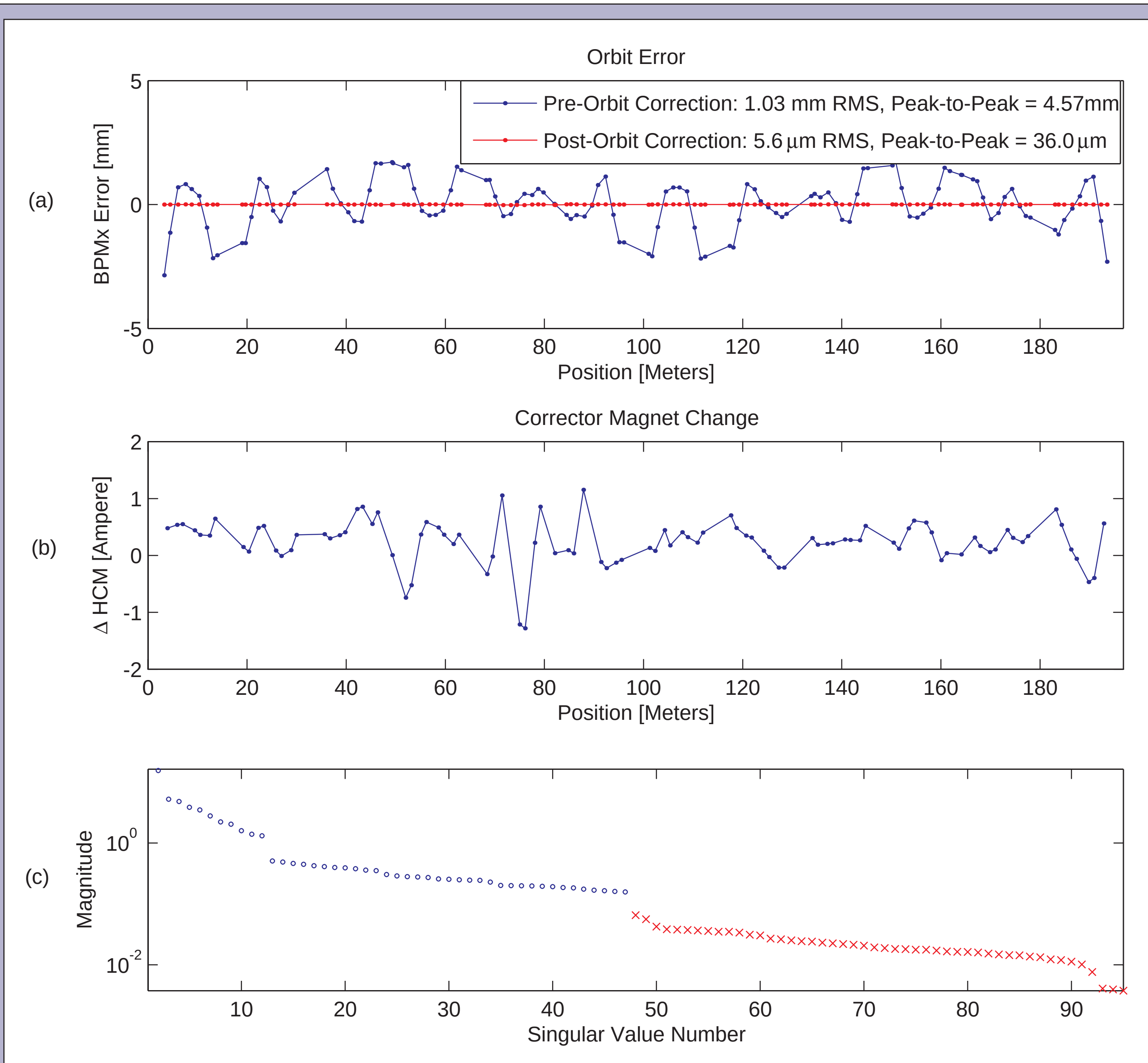

Figure 3: (a) Orbit error before and after correction. The error before correction was about 2mm, whereas after it was only about 5.6µm. (b) Amount of corrector magnet strength used in the correction. (c) Number of singular values used in the correction.

47, 50, and 92, the peak-to-peak values were 36.0μm, 21.8μm and 18.7μm respectively.

Another result obtained from testing the application is the data regarding the standard deviation of the orbit error and the sum of the corrector strength compared to the number of singular values. Standard deviation of the orbit error is illustrated in figure 5(a). It can be seen that the standard deviation of the orbit error is dramatically decreased by using just the first few singular values.

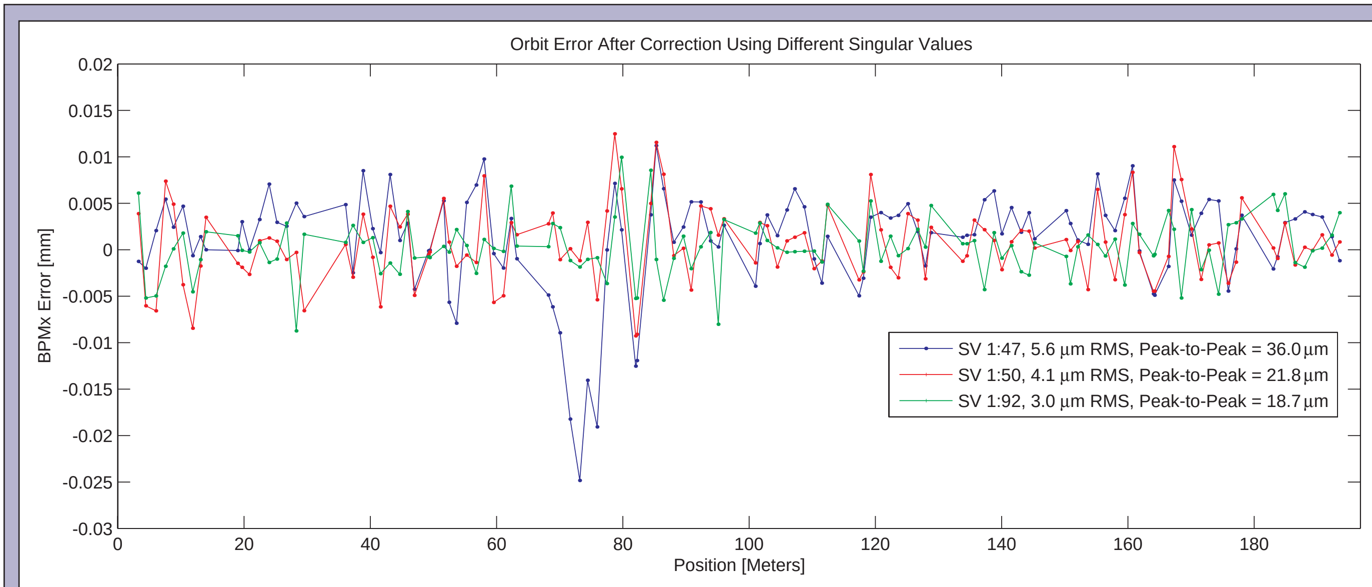

Figure 4. The three different plots represent the orbit after correction with each corresponding to a different set of singular values. The plots show that there is an inverse relationship between the RMS and peak-to-peak value of the orbit error and the number of singular values used.

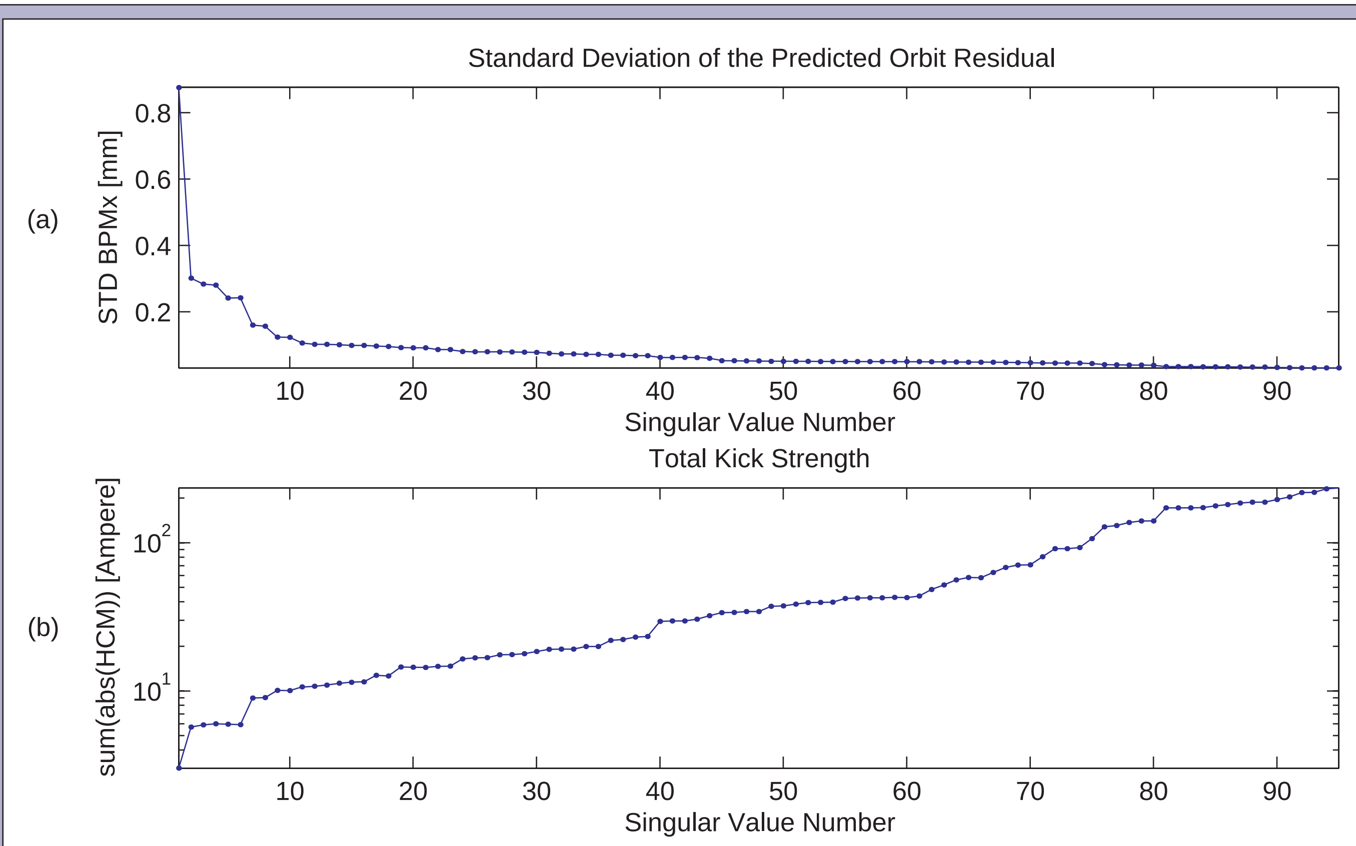

Figure 5: (a) Standard deviation of the orbit error is dramatically reduced by using just the first few singular values. Subsequently more and more singular values will only result in a very small reduction in the standard deviation and thus the orbit error. (b) As more and more singular values are included, it takes a huge amount of corrector strength to reduce the orbit error by a very small number.

Subsequently, more and more singular values will only result in a very small reduction in the standard deviation and thus the orbit error. However, as more and more singular values are included, it takes a huge amount of corrector strength to reduce the orbit error by a very small number. This is illustrated in figure 5(b). The figure shows the sum of all the absolute corrector strength changes for each number of singular values used. Higher strength changes could potentially cause damage to the corrector magnets. These plots are useful in seeing the relationship between the total corrector strength changes and the number of singular values used. SVD is useful because it allows the user to choose the number of singular values to be used for calculations. This would not be possible with a linear least squares method, the method that was used in many accelerators before SVD, because it uses all the singular values for calculation.

In conclusion, the global orbit correction application worked effectively when tested in the ALS. Its features are self-explanatory and are relatively easy to use. The plots displayed on the GUI help the ALS physicists and operators to understand the behavior of the orbit. It is a convenient application to use and is a substantial improvement over the previous orbit correction routine in terms of user friendliness and compactness.

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