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ORBIT CORRECTION WITH MACHINE LEARNING

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Abstract

A good closed orbit is the basis of high performance of accelerator. A method of orbit correction based on machine learning was studied. The research process includes two parts: study based on simulated data from MADX and study based on actual machine data [1]. Through simulated experiment data and actual machine data, this method can complete automatic correction of closed orbit and meet requirements.

INTRODUCTION

In the operation of accelerator, because of the alignment error and filed error of magnets, and so on, the beam orbit could be deviated of ideal one, where the deviation is changed gradually [2]. In actual accelerators, it is necessary to correct the orbit over time. As the machine learning technology becoming more and more matured, accelerator control based on machine learning may provide a alternative way for beam turning.

In this paper, the study with using simulated data and using actual accelerator data will be introduced.

ORBIT CORRECTION WITH DATA SIMULATED BY MADX WITH BEPCII STORAGE RING LATTICE

In order to validate the machine learning orbit correction, the lattice of BEPCII storage ring is selected to run with MADX which produce data for training. BEPCII is a collider running at 2.2 GEV in Beijing, China. Magnet errors, BPM errors, corrector strengths and other parameters are included in MADX simulation.

Data cleaning and collation:s The output data format from MADX run is complicated and difficult to use directly in machine learning package. Via a recently developed machine learning platform, the data is transformed into a usable format [3].

Selected orbits as features to do regression analysis for the strengths of correctors. Enter a desired orbit and the strengths of correctors calculated.

Set the strengths of correctors with predicted values. Run MADX again with the new lattice and compare the results.

The above process can be shown in Figure 1.

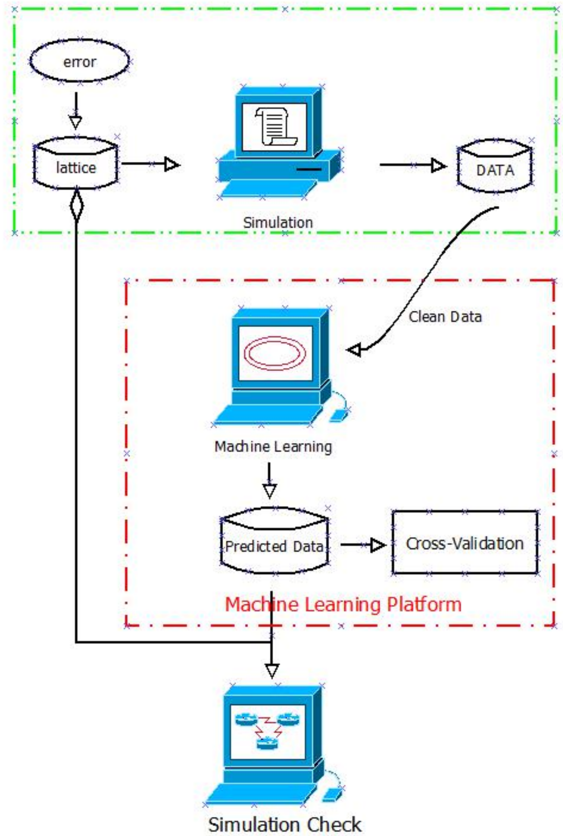

Figure 1: Machine learning orbit correction with simulated data.

In our test and analysis, we choose the lattice of BEPCII storage ring. This lattice has a total of 40 correctors, including 35 vertical correctors and 5 horizontal correctors [4]. An initial random magnets error is added to the lattice. Without considering vertical and horizontal coupling, the strengths of horizontal correctors are set to 0. Different initial values of vertical correctors are assigned to lattice in order to obtain the required data. The predicted results are compared with the result of MICADO, which is an orbit correction program of MADX [1]. The data sets are divided into two parts, 3500 training sets and 1500 test sets. The algorithm of regression analysis is used. Loss function is the variance between predicted corrector strengths and actual corrector strengths.

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$$J(\theta) = \frac{1}{2}\sum_{i=1}^{m}\left(h_\theta\left(x^{(i)}\right) - y^{(i)}\right)^2$$

Cross-validation was used in the training process. The results show that the predicted correctors strengths are in agreement with the actual strengths, and the model performs well.

For the lattice with a set of errors, the vertical correctors strengths for desired orbit calculated by this method are put back into MADX to calculate its orbit. The orbits before and after correction are shown in Figure 2.

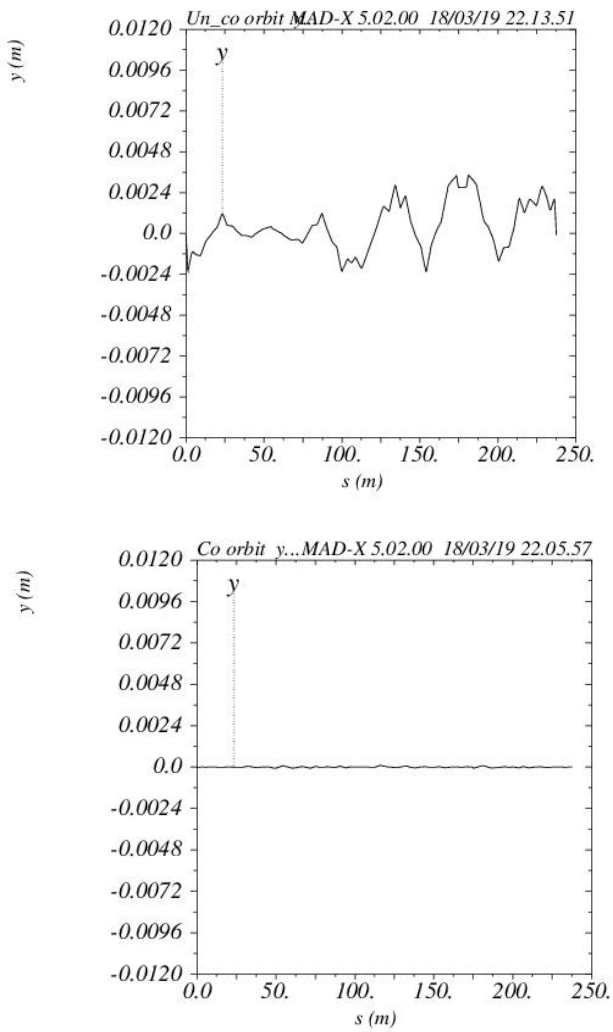

Figure 2: Uncorrected orbit (top) and corrected orbit (bottom).

Figure 3 shows the result of orbit correction with 10% random error to BPM. The results show that calculated vertical correctors strengths for corrected orbit perform quite well.

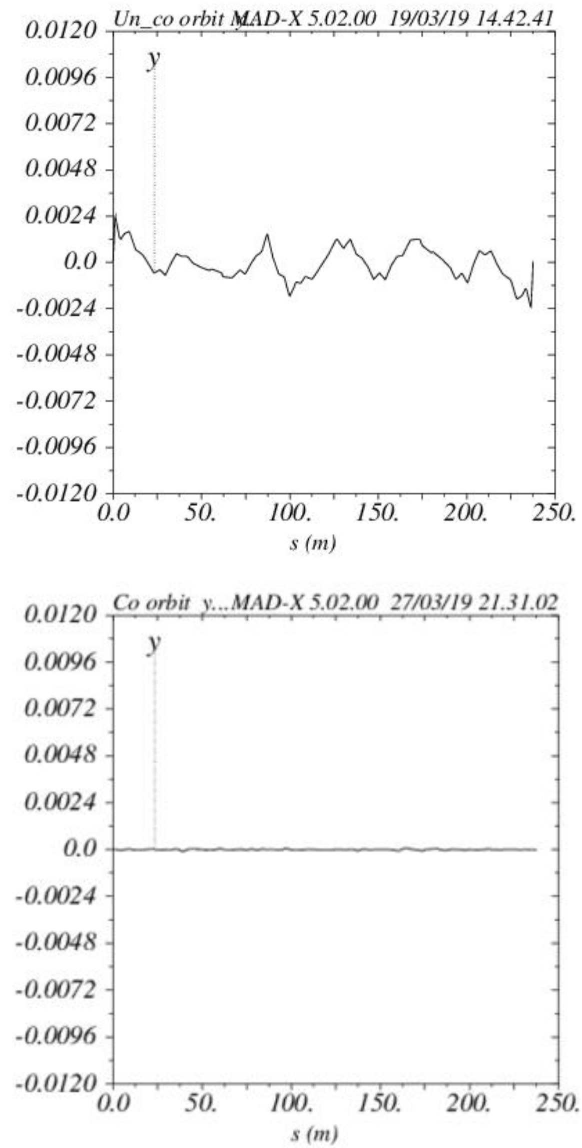

Figure 3: Uncorrected orbit (top) and corrected orbit with BPM errors (bottom).

ORBIT CORRECTION WITH DATA DOWNLOADED FROM BEPCII

In a real accelerator, the actual states of the machine are often inconsistent with the theoretical model due to the various errors.

This machine learning method that is feasible in theoretical model may not be effective for practical machine. Part of BEPCII storage ring BPMs and correctors data from March 2019 run were downloaded for study. The data are divided into training and testing sets.

A preselected "golden orbit" is chosen as the target orbit with the corresponding corrector strengths recorded; The ML algorithm is then applied to the training data set and the learned model is checked against the golden orbit.

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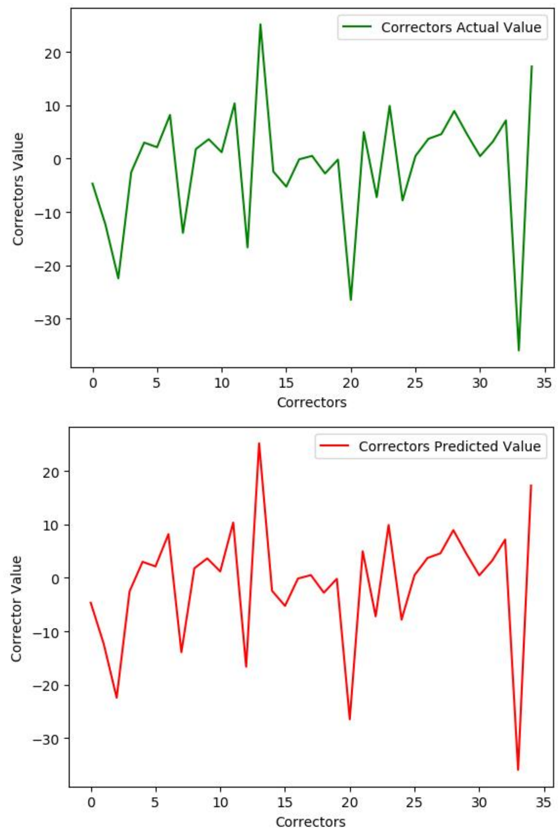

Figure 4: Correctors actual strengths (top) and predicted strengths (bottom).

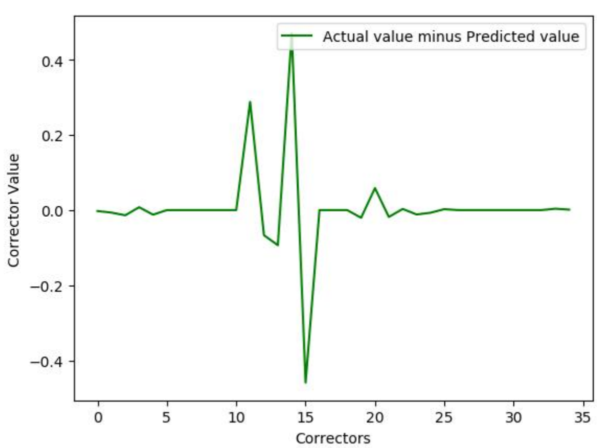

Figure 5: Actual correctors strengths minus predicted correctors strengths.

Figure 4 and Figure 5 show that the predicted results are in agreement with the actual strengths, which validates the possibility of this method for a real machine. In the process of checking the algorithm with different data sets, some results were slightly off due to bad BPM data. The faulty BPM situation will be studied next.

CONCLUSION

A process and method of orbit correction based on machine learning is presented in this paper. This method can quickly correct the orbit if the ML training data amount is enough. Comparing with the traditional orbit correction methods, this method does not need full response matrix calculation and can be extended to solve much more complicated coupling problems. Data generated from BEPCII lattice simulation and real data from BEPCII are used to validate this method, and good results are obtained in both of cases. The theoretical feasibility of this method is verified. This method is hopeful to be applied in real accelerators to improve their performance.

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