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# THE SYNCHRONIZATION BETWEEN BPMS AND CORRECTOR POWER SUPPLIES IN AC MODE OF RCS OF CSNS

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## *Abstract*

This paper introduces our effort for synchronizing BPMs and Corrector Power Supplies in AC mode of RCS of CSNS. This work helps to increase the accuracy of the response matrix measurement, the obit correction, and other commissioning task.

## INTRODUCTION

The diagram of Chinese Spallation of Neutron Source (CSNS) is shown in Figure 1. The accelerator is mainly composed of a 80Mev Linac and a Rapid Cycling Synchrotron (RCS) [1] which accelerates the proton beam from 80 MeV to 1.6GeV in 20 Ms. In this boosting process, the proton beam transfers over the RCS about 20000 turns.

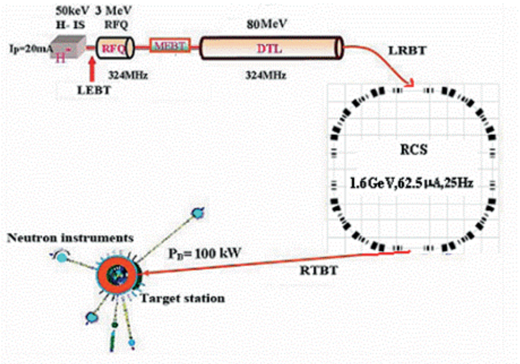

Figure 1: Layout of Chinese Spallation of neutron Source (CSNS).

Because of the hardware designing, there is an asynchronization problem between BPMs and Corrector Supplies in RCS. This problem was unanticipated in the physics design stage. In the beam instruments designing, the 32 BPMs in RCS can only make COD measurement in every $2^N$ (N=7, 8, 9, 10) turns. Otherwise, each one of the 34 corrector power supplies in RCS have a 21 bit Register, which results in an unfortunate fact that each power supply has 21 setpoints during the boosting process in one period. Based on the design, these setpoints are set into the corrector with 1ms interval. In the injection time, the 80 MeV protons transfer over the RCS with a 1.95ms period. In the boosting process, this cycling period asymptotically decrease to0.818ms at the extraction time. This fact naturally leads to that the intervals between the timestamps of the BPM's COD data are all different. In the AC mode of RCS, the BPMs COD data and corrector supplies setting values are not synchronized. This would ruin the obit-correction, response matrix measurement, and so on.

Because of lack of room for hardware improvement of beam diagnostics system and power supply system to eliminate the asynchronization problem, the improvement of beam commissioning software would be the only feasible solution.

In our former works [1, 2], two different methods have been adopted or proposed to solve the asynchronization problem. During the beam commissioning process of increasing the beam power from 20kW to 50 kW in last year, these two methods seemed not as satisfying as expected. The first one performed poor in the horizontal orbit correction that reached ±7 mm level at last. Then the second one was tested. The indefinite variable in the anti-interpolation process can be chosen arbitrarily, which induces non-convergent corrector power supplies' setting value. This divergence is unaccepted for the power supply system. Another solution is then proposed.

## SOLUTION FOR SYNCHRONIZING BPMS AND CORRECTOR POWER SUPPLIES

The motivation of developing the so-called anti-interpolation method is to increase the accuracy of response matrix measurement and to promote the orbit correction of RCS. The anti-interpolation process is actually solving Diophantine equations. The redundant variables result in infinite solutions of the equations. In this case, the gradient of the anti-interpolation is the only redundant variable. As expected in our study, this gradient could be chosen arbitrarily, but in fact, the arbitrarily chosen gradient in the beginning leads to terrible increasing divergence of setting values of the corrector power supplies from beginning to end of the lattice. This divergence would exceed the strict thresholds of the power supply system. In principle，exhaustive method could be adopted to select the gradient. Finally, a group of solutions would satisfy the restrictions of power supply system, but this process is tedious and could not be implanted into EPICS or the orbit correction software in XAL. This method is inconvenient.

The key-point of the pick-up method is to find the nearest BPM COD data to integer ms. Thus, there are large or small err between the timestamp of the COD data and the integer ms.

Based on the pick-up method, at any time, the bunch position can be calculated as the interpolation of the BPM COD datas with timestamps before/after the time. First the timestamps of all the 39 BPM COD data are deduced out from theoretical calculation.

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Table 1: Timestamp of the 39 BPM COD Data

| **index** | **Time** | **index** | **Time** |
|---|---|---|---|
| | **ms** | | **ms** |
| 1 | 0.4971 | 21 | 12.4022 |
| 2 | 1.4712 | 22 | 12.8427 |
| 3 | 2.3851 | 23 | 13.2801 |
| 4 | 3.2252 | 24 | 13.7147 |
| 5 | 3.9948 | 25 | 14.1469 |
| 6 | 4.7036 | 26 | 14.577 |
| 7 | 5.3623 | 27 | 15.0051 |
| 8 | 5.9805 | 28 | 15.4317 |
| 9 | 6.566 | 29 | 15.8568 |
| 10 | 7.1249 | 30 | 16.2806 |
| 11 | 7.6621 | 31 | 16.7034 |
| 12 | 8.1814 | 32 | 17.1253 |
| 13 | 8.6859 | 33 | 17.5464 |
| 14 | 9.1779 | 34 | 17.9668 |
| 15 | 9.6596 | 35 | 18.3868 |
| 16 | 10.1324 | 36 | 18.8063 |
| 17 | 10.5976 | 37 | 19.2255 |
| 18 | 11.0564 | 38 | 19.6445 |
| 19 | 11.5096 | 39 | 19.9276 |
| 20 | 11.958 | | |

Unlike the methods mentioned in our former works, we developed a new method to increase the accuracy. The two nearest BPM COD data to integer ms are chosen. One data has a timestamp before integer ms, another one has a timestamp after integer ms. These information is listed in Table 2.

Table 2: Interpolation Between BPM COD Data at Every Integer ms

| **Time** | **BPM COD data** | | | |
|---|---|---|---|---|
| | **before** | | **after** | |
| | **index** | **time** | **index** | **time** |
| **ms** | | **ms** | | **ms** |
| 1 | 1 | 0.4971 | 2 | 1.4712 |
| 2 | 2 | 1.4712 | 3 | 2.3851 |
| 3 | 3 | 2.3851 | 4 | 3.2252 |
| 4 | 5 | 3.9948 | 6 | 4.7036 |
| 5 | 6 | 4.7036 | 7 | 5.3623 |
| 6 | 8 | 5.9805 | 9 | 6.566 |
| 7 | 9 | 6.566 | 10 | 7.1249 |
| 8 | 11 | 7.6621 | 12 | 8.1814 |
| 9 | 13 | 8.6859 | 14 | 9.1779 |
| 10 | 15 | 9.6596 | 16 | 10.1324 |
| 11 | 17 | 10.5976 | 18 | 11.0564 |
| 12 | 20 | 11.958 | 21 | 12.4022 |
| 13 | 22 | 12.8457 | 23 | 13.2801 |
| 14 | 24 | 13.7147 | 25 | 14.1469 |
| 15 | 26 | 14.577 | 27 | 15.0051 |
| 16 | 29 | 15.8568 | 30 | 16.2806 |
| 17 | 31 | 16.7034 | 32 | 17.1253 |
| 18 | 34 | 17.9668 | 35 | 18.3868 |
| 19 | 36 | 18.8063 | 37 | 19.2255 |
| 20 | 38 | 19.6445 | 39 | 19.9276 |

After the nearest BPM COD data to every integer ms have been chosen, then the simple linear interpolation algorithm is adopted:

$$y = y_{0+}\frac{y_1-y_0}{t_1-t_0}(t-t_0) \tag{1}$$

here, $t_1/t_0$ indicate the timestamp before/after integer ms; $t$ indicates integer ms; $y_1/y_0$ indicate the raw BPM COD data; y is the wanted interpolated value.

This interpolation process is realized in EPICS. Beam Diagnostics provides the BPM COD data as 50-elements waveform records. The first 39 elements are filled with the real BPM COD data, while the rest 11 elements are kept as zero. A new set of 20-elements waveform records are created in EPICS whose names follow the pattern in the XAL lattice file. A new set of aSub records are also created. Using the above equation, these aSub records would transform the 50-elements waveform records to the 20-elements waveform records.

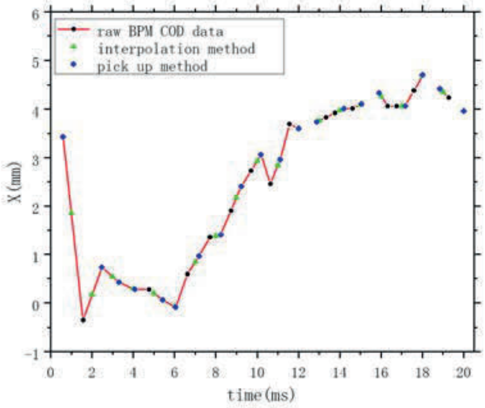

Figure 2: BPM COD data transformed for orbit correction. The red broken line and the black dots indicate the raw BPM COD data from beam diagnostics. The green dots indicate the result of the "pick up" method, while the blue dots indicate the result of the new interpolation method in this work.

During beam commissioning in last year, it was discovered that the timing of corrector power supplies and that of the main dipole/ quadrupole magnet power supplies was not synchronized. At worst, there is a more than 15 ms err between the timing of corrector power supplies and that of the main dipole/ quadrupole magnet power supplies. In this situation, it is impossible to correct the orbit and to measure the response matrix. Fortunately, this problem was easily discovered and solved by shifting the timing of the corrector power supplies. But the timing of different corrector power supply was not strictly synchronized. This was a serious problem, because this kind of asynchronization problem would counteract all the efforts to synchronize the BPMs and correctors.

## SYNCHRONIZING DIFFERENT CORRECTOR POWER SUPPLIES

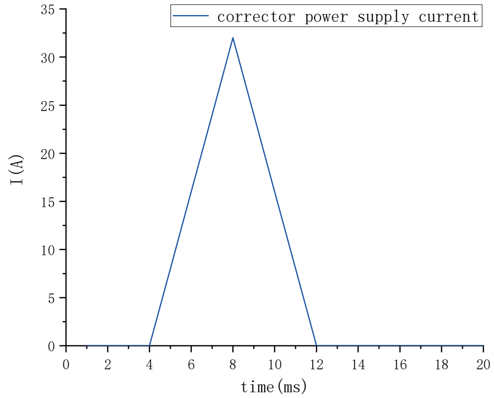

Figure 3: Triangular waveform current signals were set into corrector power supplies.

Experiments were carried out. Triangular waveform signal were set into one corrector power supply, shown in Fig. 3. Then the 32 BPMs would response to the current changing. First the response of R1BPM05 to the horizontal correctors was measured. The result is shown in Fig 3. There is a as large as 1 ms err, unexpected.

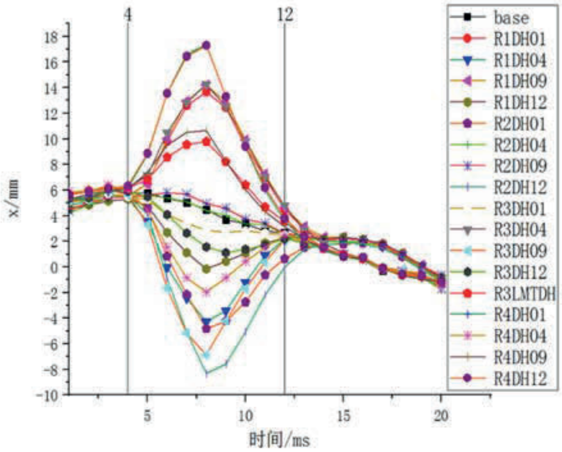

Figure 4: The response of R1BPM05 to the horizontal correctors.

As shown in Fig. 4, there is chaos in the graph. It is clear that the response of R1BPM05 to some horizontal correctors have distinct time delay. Obviously, this time delay ia brought out by the err of timing of these specific corrector power supplies.Under our proposal, the power supply system modified the timing of these correctors several times, and then the response was measured again and again. At last, the response measurement seemed satisfying, as shown in Fig. 5. This result was just what is expected under the stimulation of the triangular waveform signal.

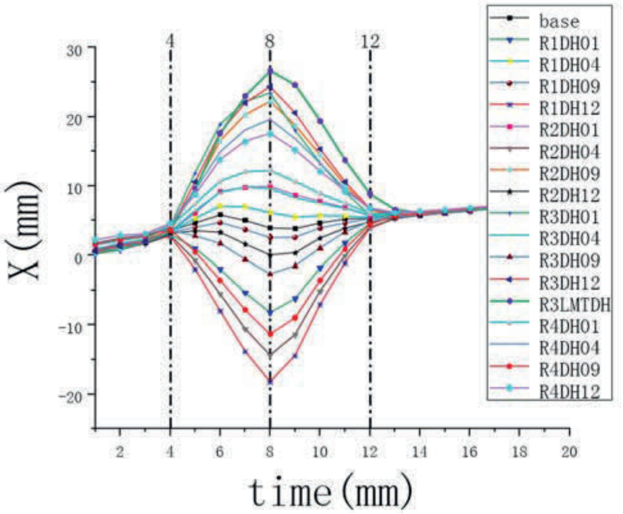

Figure 5: The response of R1BPM05 to the horizontal correctors after timing modifying.

## CONCLUSION

To promote the effect of orbit correction, we have made our best efforts to synchronize BPM and corrector power supplies. Unlike the anti-interpolation method in our former work, we now interpolates the BPM COD data, to make sure that the timestamps of the interpolated beam position values math those of the corrector power supply's setting values. Before synchronizing the BPM and corrector power supplies, we also check the timings of different corrector power supplies.

## REFERENCES

[1] M. T. Li, Y. W. An, and Y. D. Liu, "Solvements of the Asynchronization between the Bpms and Corrector Power Supplies in RCS of CSNS", in Proc. 8th Int. Particle Accelerator Conf. (IPAC'17), Copenhagen, Denmark, May 2017, pp. 2339-2342, `doi:10.18429/JACoW-IPAC2017-TUPVA106`

[2] M. T. Li, Y. W. An, and M. Y. Huang, "Solvement of the Asynchronization Between the BPMs and Corrector Power Supplies During Orbit Correction in RCS of CSNS", in *Proc. 9th Int. Particle Accelerator Conf. (IPAC'18)*, Vancouver, Canada, Apr.-May 2018, pp. 1008-1010, `doi:10.18429/JACoW-IPAC2018-TUPAL001`