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APPLICATION PROGRAM FOR AUTOMATICALLY GETTING THE FIRST TURN AND CLOSED ORBIT IN TPS COMMISSIONING

M.S. Chiu#, F.H. Tseng, H.P. Chang and P.J. Chou
National Synchrotron Radiation Research Center,
101 Hsin-Ann Road, Hsinchu Science Park, Hsinchu 30076, Taiwan, R.O.C.

Abstract

Taiwan Photon Source (TPS) is a 3 GeV third generation electron synchrotron light source, consist of 5 major modules: LINAC, LTB transfer line, booster ring, BTS transfer line and storage ring. Its beam commissioning is scheduled in 2014. Getting the first turn and approaching the closed orbit is a crucial step for achieving stored beam in ring-based accelerator commissioning. In order to make first turn beam commissioning efficient, we develop a MATLAB-based application program based on AT and MML for automatic beam steering and closed orbit search. The algorithm and simulation results are presented.

INTRODUCTION

It seems that the third generation synchrotron facilities worldwide, such as DIAMOND [1], SOLEIL [2, 3], ALBA and so on, have not yet encountered tremendous difficulties happened in their first turn commissioning. They are even quicker to get few turns only bending and quadrupole magnets were powered on. There is no guarantee TPS will be also quick to get its first turn even few turns in the beginning of commissioning. Unknown error sources may be introduced to cause large orbit distortion even beam loss when magnet manufacture and installation. For the sake of safety and well preparation, it is necessary to develop an automatic procedure for beam steering and closed orbit search to facilitate the first turn commissioning.

The beam steering algorithm implemented in this application program adopts simple bound constraint most effective (SBCME) method, i.e. the MICADO [4] modified with the current limit constraint of corrector magnets. It will select most effective correctors from those correctors located at the upstream of BPMs to reduce the distortion of beam trajectory to steer the electron beam through transport line or the first turn of booster and storage ring quickly. To achieve automatic beam steering, a while loop is employed in program to iterate the steering procedures, i.e. selecting a certain number of BPMs to be corrected and those correctors located at the upstream of selected BPMs, then calling SBCME method to reduce the trajectory distortion of those selected BPMs.

The closed orbit search is to use the last two correctors in the lattice to minimize the trajectory difference indicated by the first 10 BPMs in the lattice between the first and second turns. The closed orbit search will be executed automatically at the end of beam steering through the whole ring. We have tested the beam steering AP in the BTS transfer line in Taiwan Light Source (TLS) and it does work. Surveying relative research in automatic beam steering and closed orbit search worldwide [5-7], our methods are more flexible. The mathematical algorithm, simulation results and the procedures of beam steering and closed orbit search will be described later.

#chiu.ms@nsrrc.org.tw

FIRST TURN BEAM STEERING

To simulate the situation of the first turn beam steering, the machine type of booster and storage ring should be treated as a transport line. In MML, one may change or assign the field “MachineType” of the Accelerator Data (AD) structure to be “Transport” in the file named as “setoperationalmode.m”. Figure 1a and 1b show code fragments of the files for the transport setting for TPS storage ring and booster.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Accelerator Data Structure
%%%%%%%%%%%%%%%%%%%%%%%%%%%%
AD = getad;
AD.Machine = 'TPS';
AD.MachineType = 'Transport';
AD.SubMachine = 'StorageRing';
AD.OperationalMode = '';
AD.Energy = 3.0;
AD.InjectionEnergy = 3.0;
AD.HarmonicNumber = 864;
```

Figure 1a: Assign the “Transport” to the Accelerator Data “AD.MachineType” of TPS storage ring.

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Accelerator Data Structure
%%%%%%%%%%%%%%%%%%%%%%%%%%%%
AD = getad;
AD.Machine = 'TPS';
AD.MachineType = 'Transport';
AD.SubMachine = ‘Booster’;
AD.OperationalMode = '';
%AD.Energy = 3.0;
AD.InjectionEnergy = 0.15;
AD.HarmonicNumber = 828;
```

Figure 1b: Assign the “Transport” to the Accelerator Data “AD.MachineType” of TPS booster.

In order to demonstrate the automatic beam steering, let’s consider the beam is injected on-axis into the ring.

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With some kinds of misalignment in quadrupoles and the non-zeros launching conditions (x_0, x'_0, y_0, y'_0, dp/p_0), the beam trajectory can be detected by some BPMs and the beam gets loss somewhere caused by the aperture limitation. Figure 2 shows the situation before beam steering is applied.

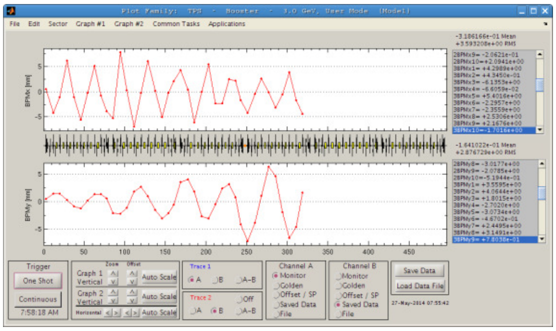

Figure 2: Before using the automatic beam steering application program, the situation of the beam trajectory caused by some misalignment of quadrupoles and non-zero launching conditions. The beam gets loss somewhere due to the aperture limitation.

Before starting beam steering, model orbit response matrix must be calculated and saved as Golden File firstly. In real situation only bending and quadrupole magnets were powered on, RF and sextupole magnets off for first turn commissioning. The beam steering application uses a certain number of corrector magnets located at the upstream of the last BPM where the beam is available or can be detected, then applies the SBCME method to minimize the trajectory. Such that the beam can be steering further more. After some iteration of beam steering procedures between the horizontal and vertical planes, one can achieve the first turn beam.

The Figure 3 shows the result after the first beam steering in the horizontal plane. Using a certain number of most effective correctors calculated with the SBCME method, the beam trajectory was reduced. However, the beam does not pass through the whole ring yet caused by the beam lost in the vertical plane. When we apply the automatic beam steering in the vertical plane, we can steer the beam passing through the whole ring as shown in Fig. 4 and 5.

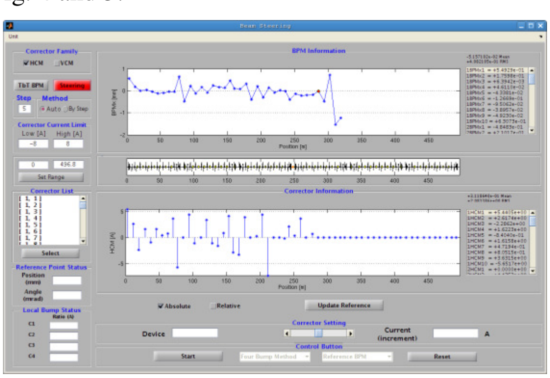

Figure 3: The situation of the beam trajectory after applying the automatic beam steering application in the horizontal plane.

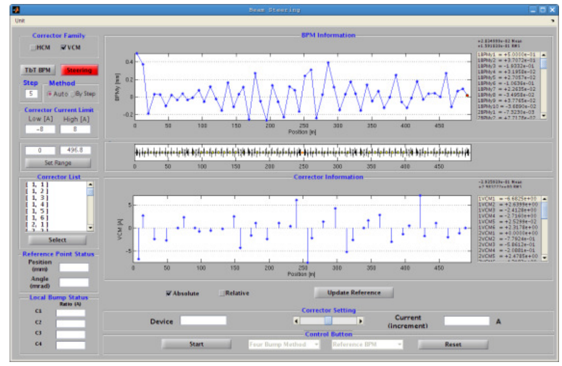

Figure 4: The beam passes through the whole ring after applying the automatic beam steering application program in the vertical plane.

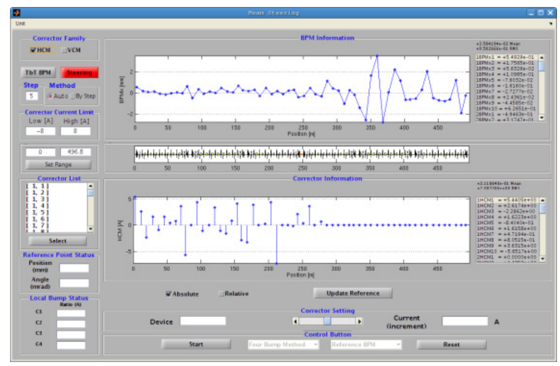

Figure 5: It shows the horizontal beam trajectory when the beam can pass through the whole ring after automatic beam steering in the vertical plane.

More detailed procedures about automatic beam steering are described in the following. In the control panel of the graphic user interface (GUI), one may input 5 BPMs per each correction step (see Fig. 3-5). Any positive integer, which can divide the total number of BPMs without remainder, is allowed but must less than the last BPM where the beam arrives at. Then one may launch the beam steering by click the "Steering" button in the GUI. Since we input 5 BPMs for each steering step, the program will automatically select those number of BPMs is a multiple of 5, i.e. 5, 10, 15… to reduce the trajectory distortion in selected BPMs for each steering step by a while loop. For the first step of beam steering, the program will select those correctors located at the upstream of the 5th BPM in the order of lattice, and call SBCME subroutine to select most effective correctors from those correctors located at the upstream of the 5th BPM in the lattice. When the corrector strengths are calculated, they are applied to reduce the trajectory distortion in selected BPMs, i.e. $BPM_1 \sim BPM_5$. An orbit response between the first 5 BPMs and those correctors at the upstream of the 5th BPM must also be an input argument when calling SBCME subroutine as Figure 6 shown.

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For the second step of beam steering, the program will select first 10 BPMs in the lattice by a while loop, i.e. BPM_1 ~ BPM_{10}, and those correctors located at the upstream of the 10th BPM, and then call SBCME subroutine to reduce the trajectory distortion in BPM_1 ~ BPM_{10}. Of course an orbit response between these 10 BPMs and those correctors at the upstream of the 10th BPM must also be an input argument when calling SBCME subroutine as Figure 6 shown.

Code fragments of automatic beam steering are list below for reference:

```
steering_step_BPM=5;
A=getrespmat('BPMx','HCM');
nBPM=0;
while (nBPM <=Total_BPM)
   nBPM = nBPM + steering_step_BPM;
   b=getam('BPMx');
    x=getsp('HCM');
   for k=1:nBPM
        bb(k) = b(k);
        AA(k,:) = A(k,:);
   end
   [b2, A2, c2] = SBCME (bb, AA, x,l,u,nBPM);
   setsp('HCM',c2);
   % Continuously inject beam.
end
```

$$\begin{bmatrix} BPM_1 \\ BPM_2 \\ BPM_3 \\ BPM_4 \\ BPM_5 \\ \vdots \\ \vdots \\ BPM_{M-2} \\ BPM_{M-1} \\ BPM_M \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ & & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\ & & & 0 & 0 & \cdots & 0 & 0 & 0 \\ & & & & 0 & \cdots & 0 & 0 & 0 \\ & & & & & \ddots & 0 & 0 & 0 \\ & & & & & & \vdots & \vdots & \vdots \\ \multicolumn{7}{c}{R_{ij} = \sqrt{\beta_i \beta_j}\,\sin(\mu_i - \mu_j)} & 0 & 0 \\ & & & & & & & & 0 \\ & & & & & & & & \end{bmatrix} \cdot \begin{bmatrix} \Delta\theta_1 \\ \Delta\theta_2 \\ \Delta\theta_3 \\ \Delta\theta_4 \\ \vdots \\ \vdots \\ \vdots \\ \Delta\theta_{N-2} \\ \Delta\theta_{N-1} \\ \Delta\theta_N \end{bmatrix}$$

Figure 6 Orbit responses matrix between M BPMs and N correctors in transport line or ring for first turn. The response of BPM is 0 if the corrector is at the downstream of BPM.

CLOSED ORBIT SEARCH

By definition of the closed orbit condition, we have the beam position satisfies the equation Mx = x, where M is the one-turn transfer matrix. The basic idea for closed orbit search is to use the last two correctors in horizontal and vertical plane respectively in lattice to adjust the position (x, y) and slope (x', y') such that the exiting beam conditions at the end location of the ring can match the launching conditions at the entrance location of the ring.

Since the launching and exiting conditions are unknown, what we can do is to minimize the difference trajectory between the first and the second turns by using the last two correctors in the ring.

Define the objective function:

$$F(\theta_1, \theta_2) \equiv \sum_{i}^{N} (x_{ith\_BPM}^{2nd\_turn} - x_{ith\_BPM}^{1st\_turn})^2, \qquad (1)$$

where θ_1, θ_2 are the corrector strengths of the last two correctors in the ring lattice. This application program adopts a built-in function 'fminsearch' of MATLAB to search corrector strengths to minimize the objective function. Once the difference trajectory is minimized, it means the closed orbit is achieved.

CONCLUSION

The beam steering application is designed to steer the beam through transport line or the whole ring for first turn. It provides two steering modes: "auto mode" and "step mode". These two steering modes shut two different injection modes: continuous injection and shot injection respectively. In "auto mode" the AP will steer the beam till the beam can't be steered further more due to the strength limitation of correctors, beam loss at the other plane, or the beam has arrived at the end of the lattice. If the beam does not pass through the whole lattice, user needs to select another plane to continue beam steering or iterate many times between horizontal and vertical planes till the bam pass through the whole lattice. In "step mode" user can decide continue, back or stop beam steering in each steering step. The closed orbit search will be executed automatically at the end of beam steering through the whole ring.

Although the beam steering AP is easy and quick to steer the beam through the whole lattice in simulator, we expect it will be able to work well in TPS first turn commissioning as in simulator to alleviate the burden on TPS commissioning team.

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