ONLINE OPTIMISATION APPLICATIONS AT SPS

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Abstract

Optimisation of a particle accelerator with very limited diagnostic system is proved to be very challenging and complicated. Theoretical calculation and perfect machine model never guarantee the best solution in the actual machine. In this work, optimisation of injection system from Low energy Beam Transport line (LBT) to Siam Photon Source (SPS) storage ring and reduction of beam coupling employing Robust Conjugate Direction Search (RCDS) algorithm [1] are demonstrated. New record improvement on injection efficiency and better coupling control will be presented.

INTRODUCTION

Generally, an accelerator system can be optimised using mathematical model describing the complex system of magnets interacting with charged particle beam. Known and unknown imperfections lead to discrepancy between the accelerator model and the actual machine. An optimisation technique using Linear Optics from Closed Orbits (LOCO) [2] allows us to converge the two to some extent, but does not guarantee the best solution when diagnostic system is limited. As the real machine is not ideal, it is impossible to perfectly model the machine. Online optimisation, on the other hand, directly targets a set of measured objectives with a given set of variables.

RCDS algorithm was proposed to be an efficient and robust algorithm for online optimisation. The robustness against noise of the RCDS is the result of bracketing the measured data and line search which respond to the noise based on the measured rms noise level using parabolic fit. Conjugate direction search (Powell's method) allows RCDS to find the best solution quickly. The algorithm uses normalised variables instead of raw variables to allow proper distribution of the values when the scales of the variables are different. Practically, the algorithm can target important objectives such as injection efficiency, lifetime, etc. obtained from direct measurements. The RCDS has been widely tested and used at several synchrotron facilities [3-4]. For machines with insufficient diagnostic system, this method could be very useful.

INJECTION OPTIMISATION

Since the first commissioning of the SPS machine, injection efficiency was optimised using accelerator model together with manual adjustment. Lack of BPMs in the transport lines (Low and High energy Beam Transport line: LBT and HBT) introduces complexity to the machine optimisation. Optimisation of the beam transport starts from the expected model, then manual adjustment of the magnets in transfer line was required. Quick and robust online optimiser would be very helpful for improving the injection efficiency.

LBT to Booster Injection Optimisation

LBT receives 40 MeV electron beam from the linac and transfers to the booster where the beam energy is ramped up to 1.0 GeV. In the optimisation, there are 10 variables: 6 quadrupoles, 3 correctors and 1 septum. There is no BPMs and only few fluorescent screens are available. The objective function was calculated from the charge in the booster with respect to that at the end of the LBT. As the algorithm is a minimiser, Figure 1 shows the reduction of the objective function (better injection). Though large noise level could be observed, the algorithm managed to converge toward better solution. This proves the robustness of the RCDS algorithm. Figure 2 summarises the variable values used during the optimisation. For each magnet, bands of good solutions (blue lines) indicate the flexibility of the system. Noticeably, some variables have narrow good solution band, indicating that they have larger influence to the injection efficiency.

HBT to Storage Ring Injection Optimisation

Once the best injection efficiency in the LBT has been found, the HBT was also optimised in a separate process. Similar to the LBT, there is no BPM in the HBT. There are 12 variables that can be used in this optimisation: 5 correctors, 6 quadrupoles and 1 septum.

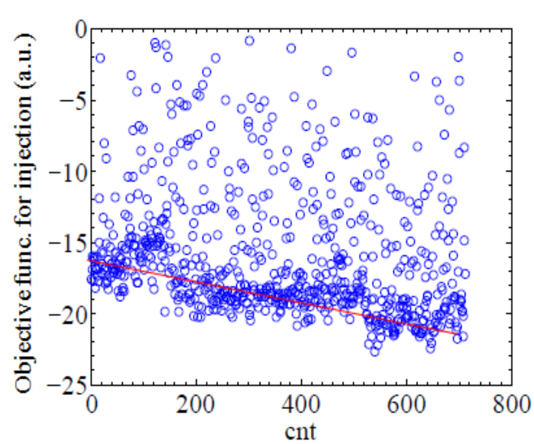

Figure 1: Objective function during injection optimisation from the LBT to the booster.

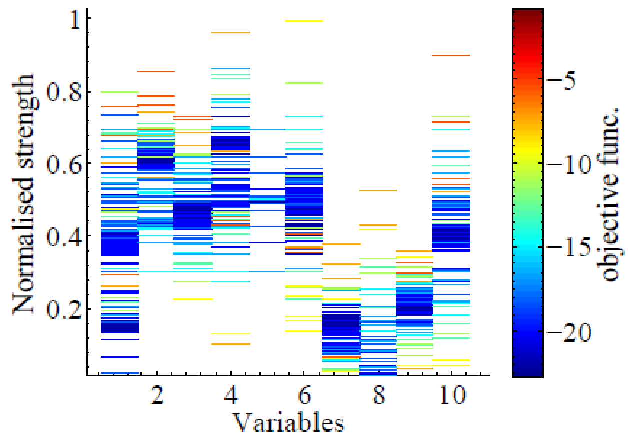

Figure 2: Normalised variable strength used in the LBT to the booster injection optimisation.

Injection efficiency optimisation from the HBT into the storage ring is more complicated than the LBT optimisation due to the fact that when the accumulating current reach the maximum limit (~150 mA), the beam needs to be dumped. This requires the optimisation to be put on hold and then resume after clearing the stored electrons. To lengthen the injection process, the output from the electron gun was reduced.

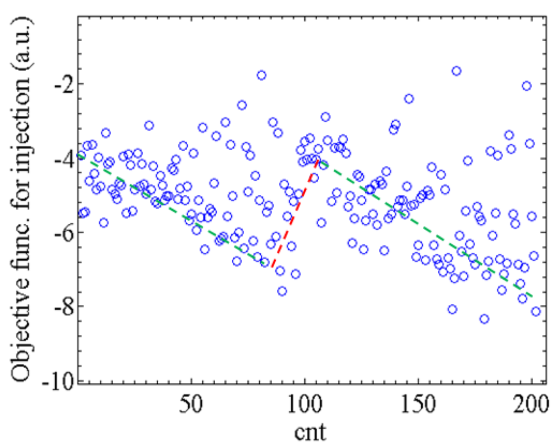

Figure 3: Objective function during injection optimisation from the HBT to the storage ring.

Figure 3 shows the objective function during HBT optimisation. There was time dependent effect that we observed from the degradation of the injection efficiency. After about 100 iterations, the beam was dump and the optimisation was resumed. It is clear that the objective function grew (worse injection efficiency) at the beginning of resuming the optimisation. Then the optimiser tried to improve the situation again. With passing time, even when no change was introduced to the machine, the accumulation rate decreases as shown in Figure 4. In HBT case the magnets will be turned on only during the injection process and thus thermal effect may be the cause of this problem. This limits the allowed optimisation time for HBT. However, from both LBT and HBT optimisation we have made a new record for injection rate of ~110 mA/s which speeds up our injection time by about half an hour. In the future, we plan to monitor the surface temperature of the HBT magnets, which will allow us to understand the thermal effect on the injection efficiency better.

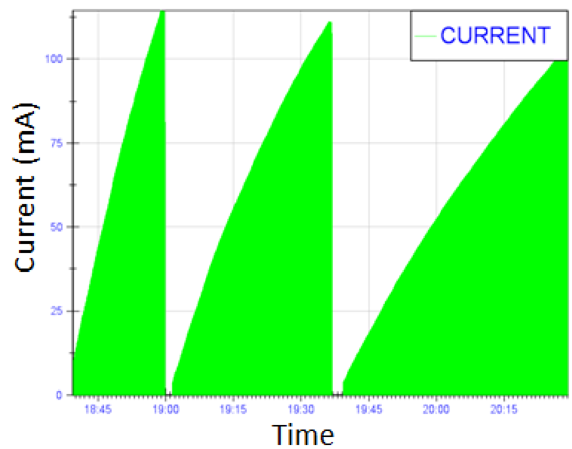

Figure 4: Beam current in the storage ring.

COUPLING OPTIMISATION

The origins of the vertical beam emittance are betatron coupling and dipole rolling which create vertical dispersion. Beam coupling was normally adjusted according to the information given by the orbit response matrix (ORM). We try to reduce the coupling terms in the ORM. However, beam tilt was still observed after the conventional correction when there are insertion devices (IDs) in operation. This may indicate the imperfection of the accelerator model.

Local Orbit Bump in Sextupoles

In SPS storage ring, there is no skew quadrupoles to directly control the beam coupling. The natural coupling in the operation mode with all insertion devices is about 8% which is considered to be large and needs to be reduced to increase the delivered photon flux. The strong effect of the IDs on the beam coupling has to be compensated. Despite the lack of skew quadrupole, the beam coupling can still be manipulated using local vertical orbit bump in sextupoles which introduce skew quadrupole term:

$$a_2 = 2b_3 y_0, \tag{1}$$

where b_3 is the sextupole integrated strength and y_0 is the vertical orbit bump amplitude. There are 4 local orbit bumps in sextupoles that can be employed as the tuning knobs in RCDS optimisation. The objective function was the vertical beam size taken from the visible light beam profile monitor. This optimisation is different from the

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previous optimisation of injection efficiency where the variation of the instrument parameters affects directly the objective function. A separate code was written to generate the requested local orbit bump amplitude in the sextupoles and the RCDS optimiser will use the input bump amplitude as variable. This is similar to the RCDS optimisation carried out at Diamond Light Source which used Resonance Driving Terms (RDTs) as variables to optimise the beam lifetime [3]. This concept could allow us to find a better solution and understand the physics behind. The coupling optimisation started from the normal operation parameters without any vertical orbit bump. Figure 5 show the four vertical orbit bump amplitude in sextupole during the optimisation. Preferable bump amplitude giving small vertical beam is highlighted clearly in blue. The beam tilt was corrected after the optimisation.

Local Orbit Bump in Multipole Wiggler

A multipole wiggler (MPW) which was installed in the injection section just after the septum appears to introduce difficulty to the beam coupling control. After the ID was put in operation (gap closed), the conventional correction was unable to solve the observed beam tilt. We then investigated further the effect of the ID starting from the best parameters found previously. Similar to the previous step, local orbit bump in horizontal plane was created locally in the MPW which reduce the beam coupling further. The tests were carried out by separately adjusting the bump after the previous optimisation and including the bump amplitude in the MPW as one of the variables in the RCDS optimisation. Both methods give similar optimum solution.

For the beam coupling of 2.7%, the bump amplitude in the MPW has to be about 2 mm. The comparison of the beam before and after coupling optimisation is shown in Figure 6. This option, however, requires beamline realignment and thus is not practical. The effect of the ID has to be compensated using other methods.

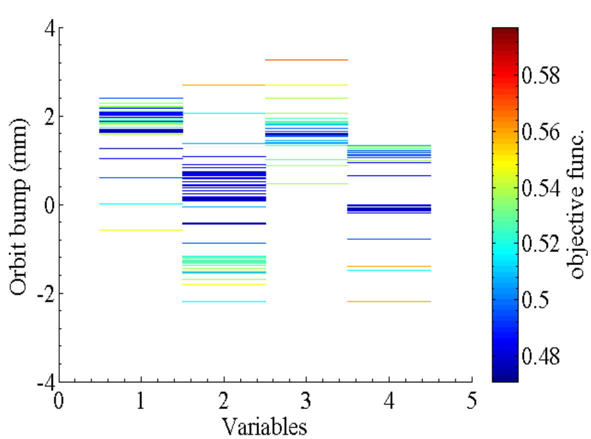

Figure 5: Four local orbit bump amplitude in sextupoles used in coupling correction.

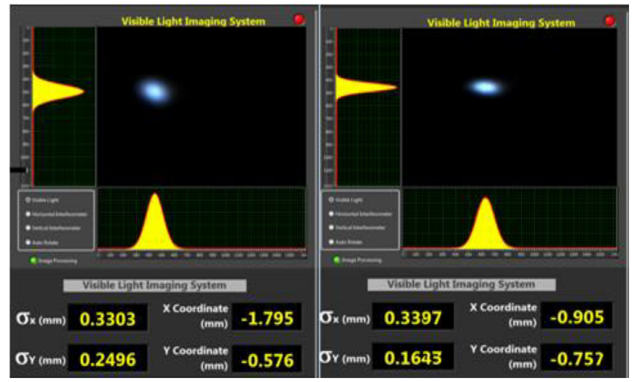

Figure 6: Visible light beam profile before (left) and after (right) RCDS optimization.

CONCLUSION

It is clear that online optimisation is getting more attention in particle accelerator community. The usefulness has been proved in our case where diagnostic system is limited. With RCDS algorithm, we have made a new record for injection rate. Also we could provide a smaller vertical beam size option to the users if needed. However, there are some limitations for the optimisation when some parameters of the system are time-dependent. Machine learning may be included in such situation. Combining the knowledge of accelerator physics with powerful optimisation algorithm could let us find better solution and understand our machine better.

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