DISCUSSION ON THE PROBLEMS OF THE ONLINE OPTIMIZATION OF THE LUMINOSITY OF BEPCII WITH THE ROBUST CONJUGATE DIRECTION SEARCH METHOD

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Abstract

The robust conjugate direction search (RCDS) has high tolerance to noise in beam experiments, and it is an efficient experimental technology for online optimization with multi-dimensional variables. This method has been used to optimize the machine performance of the SPEAR3 storage ring online. In this paper, we discuss the problems and developments of the online optimization of the luminosity of BEPCII with this method. To apply the method in BEPCII, the objective function, optimization time and experimental applications require careful consideration based on the analysis of the real machine situation.

INTRODUCTION

A particle accelerator is a complex system that is made up of many components, e.g., beam transport, control, diagnostic, acceleration systems. There are many variables to be tuned, which are typically coupled. So we have to optimize the performance of an accelerator in a multi-dimensional variable space. To meet the design requirements of the machine, we need to optimize parameters to meet the demands in different phases: design, commissioning, and operation.

Generally, in an accelerator that is built already, optimization algorithms are rarely used. There inevitably exist effects of error which make some differences between the fact and the theoretical model. The optimized parameters from theoretical analysis and numerical calculation may not work very well in real operation. Therefore more efforts are needed in beam tuning and operation to achieve better performance. In most cases, physicists can only repeatedly tune and scan parameters according to the actual situation of the accelerator observed directly, starting from theoretic design values. Although this method usually works, it is time-consuming and the effectiveness decreases as the number of parameters increases.

Along with the unceasing development of computer technology and optimization algorithms, applications of online optimization algorithms of multi-dimensional variables on accelerators have become imperative. Several optimization algorithms have been proposed for different purposes in different accelerator labs, the downhill simplex method [1-3], Rotation rate tuning [4], Random walk optimization [5], Robust conjugate direction search (RCDS) [6] and so on. Among these methods, the algorithm RCDS has high tolerance to noise in beam experiments and high convergence speed, which can reduce effects of noise and lead to optimal solution. RCDS method can be used as an online optimization algorithm to optimize the performance of an accelerator and it is effective in optimizing a single-objective function of several variables with a certain level of noise. This method has been successfully applied to the SPEAR3 storage ring for realistic accelerator optimization problems, including the minimization of the vertical emittance with skew quadrupoles and the optimization of the injection kicker bump match. But it has not been applied to colliders.

The most important measure of performance of colliders is the luminosity. The peak luminosity of BEPCII [7] at IHEP now is 8.0×10^{32} $cm^{-2}s^{-1}$. It is an essential subject for physics study of BEPCII to ensure the stability operation and to achieve a higher luminosity by further optimization of parameters. Luminosity is considered as a multivariable function with more than 20 variables to be tuned, such as the transverse offset in displacement and angular deviation (x, x', y, y') at the interaction point (IP), the x-y coupling parameters (R_1, R_2, R_3, R_4), working point, RF parameters, and optical parameters at the IP. At present, operators mainly tune and scan parameters manually. That is, they manually scan one parameter to get a value which corresponds to a higher luminosity, and then scan the next with the first parameter fixed. All parameters can be manually optimized in a similar fashion. Because the actual situation of the collider changes as beam current decreases, operators always have to repeat the process. Moreover, because of the complexity of the collider, optimization results vary with each person and time.

So it makes sense to set up an online optimization process based on the RCDS method and establish a standard operation system for optimization of luminosity of BEPCII by scanning parameters in a standardized and routine way. It is expected to reduce operators' work and contribute to increasing the peak luminosity using the online algorithm. A flowchart of RCDS for online luminosity tuning in BEPCII is shown in Fig. 1.

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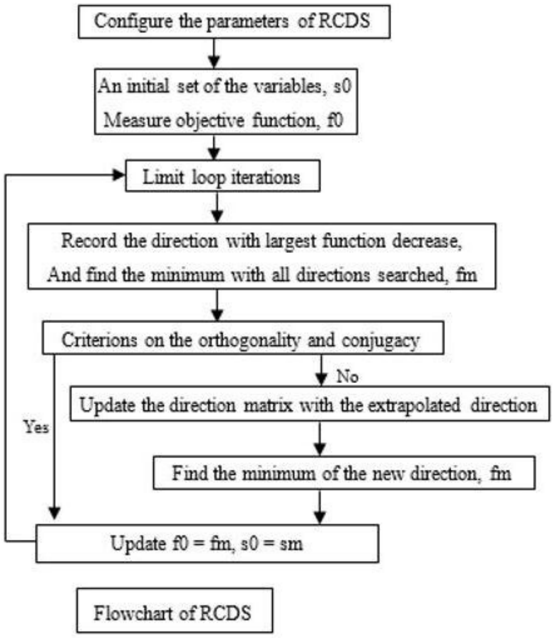

Figure 1: flowchart of RCDS for online luminosity tuning in BEPCII.

The online control program at the BEPCII is SAD, which is a computer program complex for accelerator design and operation. So we developed the algorithm code of the RCDS method in SAD program, and the optimization algorithm is combined with the operating system as needed. The luminosity is considered as an objective function with multi-dimensional variables to be tuned. The set of parameter values produced by the RCDS method is used to set up the collider. Then we get the luminosity from the database of BESIII. As needed, the value of objective function is calculated from the luminosity and introduced into the RCDS method to continue the iterator.

CHOICE OF THE OBJECTIVE FUNCTION

It is very critical to choose an appropriate objective function in order to achieve high optimization efficiency and effectiveness. The luminosity of BEPCII determined by the BESIII End-cap Electro-Magnetic Calorimeter is actually an integral average luminosity value of luminosity values in 30 seconds. So it has a long response time. Moreover, the decrease of beam current has a significant effect on the luminosity both in theory and in practice such that the same parameter set may lead to different luminosity values over time, which will directly affect the efficiency of optimization. Theoretically, luminosity can be expressed as

$$L\left[cm^{-2}s^{-1}\right] = L_0 R$$
$$= 2.17\times 10^{34}(1+r)\xi \frac{E\left[GeV\right]k_b I_b[A]}{\beta_y^*[cm]} R \quad , \qquad (1)$$

where L_0, r, ξ, E, k_b, I_b, β^*_y represent the nominal luminosity, the aspect factor, the beam-beam parameter, the energy, the number of bunches, the bunch current, and the value of the vertical beta function at IP, respectively. R is a reduction factor which may come from a non-zero horizontal crossing angle, coupling, tune and so on. It is expected that the optimization algorithm can find an optimized set of parameter values, which can lead to a higher luminosity value with the factor R closer to 1.

So we have to choose another objective function which can well represent the collision luminosity, has a short response time and would be less affected by the decrease of beam current. To this end, the objective function (with a minus sign) is chosen to be the so-called specific small-angle luminosity (SSAL),

$$L_{SpeLumP} = \frac{L_{ZeroLumP} / N_{bCollide}}{(I_{BER}/N_{bBER})*(I_{BPR}/N_{bBPR})} \quad , \qquad (2)$$

where $L_{ZeroLumP}$ is the small-angle luminosity given by a zero-degree detector [8], $N_{bCollide}$ is the number of collision bunches, I_{BER} and I_{BPR} are the electron and positron beam current respectively, and N_{bBER} and N_{bBPR} are the number of electron bunches and positron bunches respectively. As a result, the decay of the beam current during the RCDS scan has a very weak effect on the SSAL.

SHORTENING OPTIMIZATION TIME OF THE APPLICATION

Electron beam current and positron beam current both decay in time due to the limited beam lifetime in BEPCII. So the state of the machine also changes with time. Time between two injections is limited, which means time for optimization is also limited. Thus shortening optimization time becomes very important.

The optimization time depends primarily on the response speed for setting parameters and the data acquisition speed from the database, which in fact determines the time needed to get an evaluation. Because the luminosity of BEPCII is sensitive to the vertical displacement, we estimate the response time requirement by setting the y offset to a fixed value. The results of a series of measurements show that the state of the machine becomes stable again 7 seconds after a deviation. Thus, to obtain a trust worthy response for the luminosity for a changed variable, it is best to take more than 7 s to complete an evaluation.

FOUR VARIABLES WERE USED AS KNOBS IN THE EXPERIMENTS

As a preliminary test of the effectiveness of this method in a collider, only the 4 offset variables were considered, i.e., (*x*, *x'*, *y*, *y'*) at the IP. We set an optical model of BEPCII, which was already found by manual tuning, as the reference state, with SSAL of about 51 mA^{-2}. The variables were deliberately set to deviate from the

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reference and then the RCDS scan was performed to observe the increase in luminosity.

Right from the reference, we deliberately set the offset with a deviation. The SSAL decreased to be only 4.3 mA^{-2}. The corresponding state of the machine was used as the initial state to run the RCDS algorithm. During the run, the objective was calculated from an individual reading of the luminosity. Finally, the objective is tuned to about −50 mA^{-2}, with a total of 138 evaluations taking about 24 minutes. The evolution of the luminosity recorded by BESIII is shown in Fig. 2, and further verifies the experimental effectiveness.

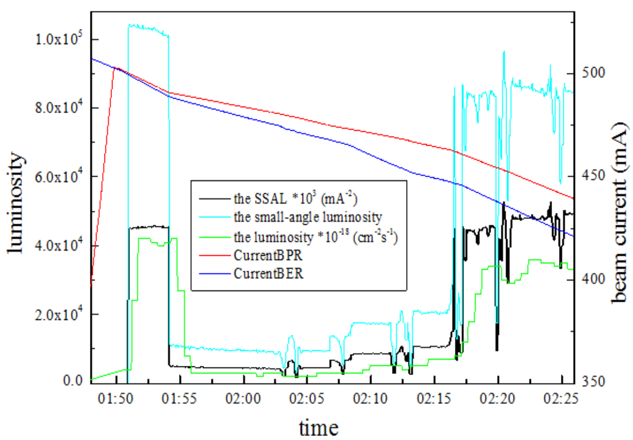

Figure 2: Evolution of the luminosity recorded by BESIII. Unlike the recovery of the SSAL, both the small-angle luminosity and the luminosity recorded by BESIII achieve a partial recovery, which results from the effect of the decay of the beam current.

DISCUSSION

The paper states the major problems of the online optimization of luminosity with RCDS. Taking the SSAL as objective function, we have explored the feasibility of online luminosity tuning using the RCDS method in machine experiments with the BEPCII collider. Four variables of orbital offset were used as knobs in the experiments. They were first deviated from the reference standard, which led to a reduced luminosity. An automatic scan of these knobs was then launched with the RCDS method. Convergence was reached within a few iterations, and a recovery of luminosity was also observed.

Only 4 variables are tuned among the more than 20 variables affecting the luminosity in the experiments. As we know, an actual luminosity optimization requires delicate tuning of all the related variables.

The more variables are tuned, the more evaluations are taken and the longer time is needed. Then it is difficult to tune more variables simultaneously during a collision period. Fortunately, the more than 20 variables scanned for the luminosity tuning are controlled by different machine components (e.g. correctors for orbital offset and skew quadrupoles for coupling factors). So the variables can be divided into several groups (orbital tuning, coupling factors). Then one RCDS scan may be done in turn for each group, or even in different collision periods, until all the optimal values of the variables were found.

Moreover, when some sensitive parameters are tuned online, great care will be required to ensure the stability of the machine. For example, the present working point of the collider is around (6.513, 5.583) (as shown in Fig. 3). The reasonable tuning ranges of the working point for a higher luminosity are extremely limited.

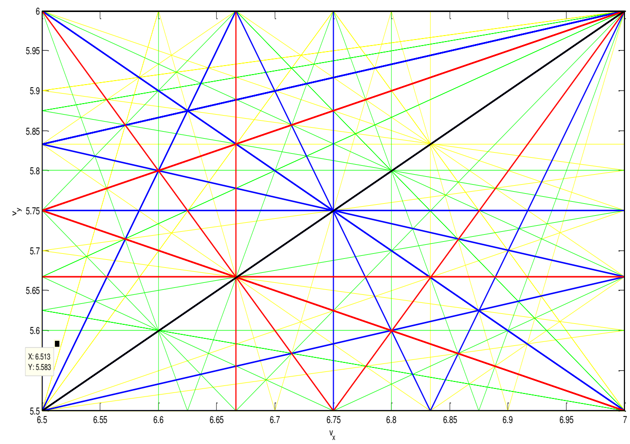

Figure 3: The available tuning ranges of the working point.

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REFERENCES

[1] Emery L et al. PAC03, Portland, Oregon, 2003
[2] Nelder J, Mead R. Computer Journal 7, 1965, 308
[3] Funakoshi Y et al. EPAC2008, Genoa, Italy, 2008, p.1893
[4] Scheinker A et al. Phys. Rev. ST Accel. Beams, 2013, **16**: 102803
[5] Aiba M et al. IPAC2012, New Orleans, Louisiana, USA, TUPPC033
[6] Huang X, Corbett J, Safranek J, Wu J. Nucl. Instrum. Methods Phys. Res., Sect. A, 2013, **726**: 77-83
[7] IHEP-BEPCII-SB-03-3, 2003. (in Chinese)
[8] Xue Zhen et al. Chinese Physics C, 2011, **35**(1): 1-5