MULTIOBJECTIVE LIGHT SOURCE LATTICE OPTIMIZATION*

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Abstract

Multiobjective optimization has been used in many fields including accelerator related projects. Here we use it as a powerful tool for lattice design and optimization, which includes betatron functions and brightness.

INTRODUCTION

Lattice design and optimization have been a try-and-error process which relies mostly on the experience of the expert. Due to the development and introduction of new algorithms, e.g. MOGA (Multi-Objective Genetic Algorithms) [1, 2] this kind of work can be more and more done automatically by computers while supervised by experts. In this paper, we show some results of lattice optimization with MOGA and the global-view a MOGA approach can have.

GENETIC ALGORITHMS AND MOGA

GA (Genetic Algorithms) mimics the nature, it first generate a population and then according to criteria function and constraints to select the survival candidate, the survival will generate new children according to random or predetermined algorithms. Keep this evolution for tens to hundreds of generations, the remaining population will be an optimal set of solutions.

The structure of MOGA we used is shown in Algo. 1.

Algorithm 1 Multi-Objective Genetic Algorithm [3]

1: Initialize population (first generation, random)
2: **repeat**
3: select parents to generate children (crossover)
4: mutation(children)
5: evaluate(children)
6: merge(parents, children).
7: non-dominated sort(rank) [3]
8: select half of (parents, children)
9: **until** reach a generation with the desired convergence to the PO set

The initial population in our case are uniformly distributed random numbers. Then two solutions are chosen as parents to generate two children and then a mutation (a small perturbation of the value). In our simulation the two children are generated following a polynomial distribution shown in Fig. 1. So are the mutation process.

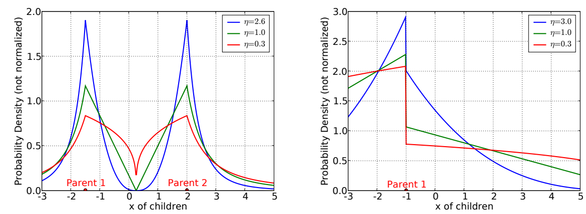

Figure 1: Probability distribution used for generating children from parents, and perturb the children.

MOGA uses GA as the iteration process, and make the "nature select" in a multi-objective way. One way is the Non-Dominated Sorting, where instead of comparing two scalars in a single objective optimization problems, in multiple criteria optimization problems, the candidate is compared as two vectors, and sorted group by group [3, 2]. Without any preference of the objective functions, any candidate is not better than the others in same group. The first group of the sorting is called non-dominated set, and it has the best solutions in searching iterations.

BRIGHTNESS OPTIMIZATION

Brightness is defined as the radiated flux per unit source area, emitted in a relative bandwidth:

$$B = \frac{F}{\sigma_x \sigma'_x \sigma_y \sigma'_y}$$

It is usually quoted in units of (photons per second)/(mrad^2 mm^2 0.1% bandwidth) [6]. It is more convenient to use, as a figure of merit, an average brightness, which for dipole source is defined [4]:

$$B_{d,avg} = \frac{dF/d\theta}{2.36\sigma_x 2.36\sigma_y 2.36\sigma'_\gamma}$$

where $dF/d\theta$ is the vertically integrated flux, $2.36\sigma_x$ is the Full Width Half Magnitude (FWHM) of the horizontal electron beam size, $2.36\sigma_y$ is the FWHM of the vertical electron beam size, and $2.36\sigma'_\gamma$ is the FWHM of the photon emission angle in the vertical plane [6]:

$$\sigma'_\gamma = \sqrt{{\sigma'_z}^2 + 0.41(\frac{\lambda}{\lambda_c})\frac{1}{\gamma^2}}$$

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For average brightness of an undulator, because of the usually very small source size and divergence diffraction effects must be taken into account [5]:

$$B_{u,avg} = \frac{F_n}{2.364^4 \sigma_{\gamma x}\sigma'_{\gamma x}\sigma_{\gamma z}\sigma'_{\gamma z}}$$

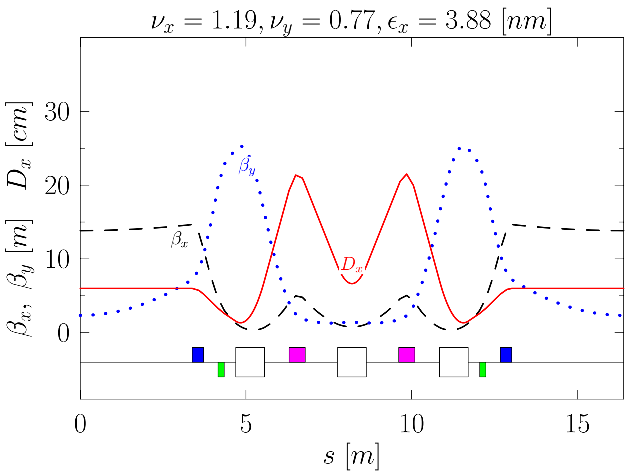

Figure 2: ALS normal bend sector

A desired design would be having optimal brightness at both straight sections for ID (Insertion Device) and Bending magnets. Although weighted sum can achieve this goal in some degree, but the non-convexity and discontinuity could make it not very practical. MOGA is used for this optimization based on a simplified ALS lattice, i.e. only the normal bend sector [2]. The lattice is shown in Fig. 2. Three quadrupoles are used as parameters to optimize the brightness, k_{QF}, k_{QD} and k_{QFA}. The range for these quadrupole strength are chosen $[-10, 10]\ m^{-2}$ and symmetric about the center bend.

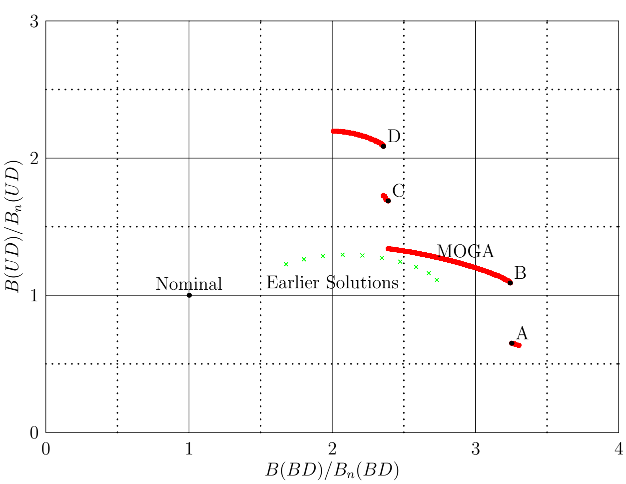

Figure 3: Brightness optimization with MOGA. The previous result with traditional approach are also shown. (1,1) is the the normal sector of ALS as the reference lattice.

Fig. 3 shows the result of optimization of ALS normal sector with MOGA, and compared with other approaches. The optimal solutions are 4 disjoint regions, which corresponding to different combination of low β_x and low β_y at two locations, straight and center bending magnet. This figure can give the lattice designer/optimizer a global view that what is the trade off between brightness in two locations. Since the curve is flat, that means increasing brightness in bending magnet would not compromise the ID brightness too much. Therefore, the solutions near "D" and "B" may be two good candidates.

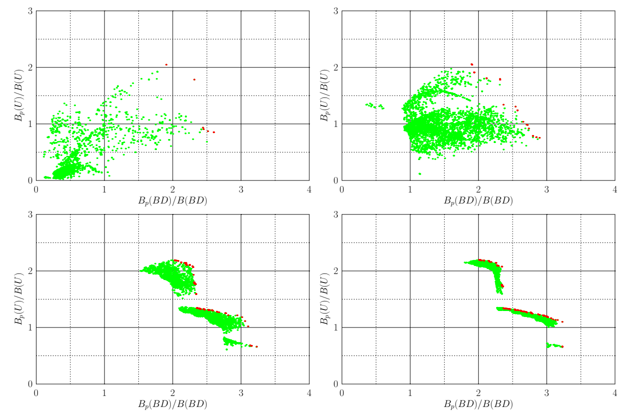

Figure 4: Brightness optimization as the population evolves in MOGA. The four plots are the 30^{th}, 45^{th}, 80^{th}, 100^{th} generation. Red dots represent the non-dominated solutions.

The evolution of objective functions, i.e. the brightness at center of straight section and bending magnet, are shown in Fig. 4. Initially the parameters of the candidate solutions, k_{QF}, k_{QD} and k_{QFA} are random numbers with uniform distribution in $[-10, 10]\ m^{-2}$. As the iteration (evolution) goes, new children candidate are generated following certain probability around the parents. Their lattice properties are evaluated and compared using non-dominated sorting with existing solutions. The better ones are kept. In the later generation (the steps of iteration), solutions move toward the upper right corner where both brightness tend to have optimal values. At the final stage, almost all solutions are non-dominated.

For the optimal solutions, we have compared the parameter space with another optimization of emittance and beta functions. This shows how different the optimization of emittance and brightness can be for the strength of quadrupoles. Fig. 5 and Fig. 6 have same ranges of $_{\mathrm{QF}}$, k_{QD} and k_{QFA}. The parameters for optimizing brightness are in four disjoint groups, same as shown in Fig. 3, while for optimizing emittance ϵ_x, there are only two close sets corresponding to high and low beta solutions [2]. This confirmed the lattice design strategy that not only emittance but also the beta function at source point are important for high brightness.

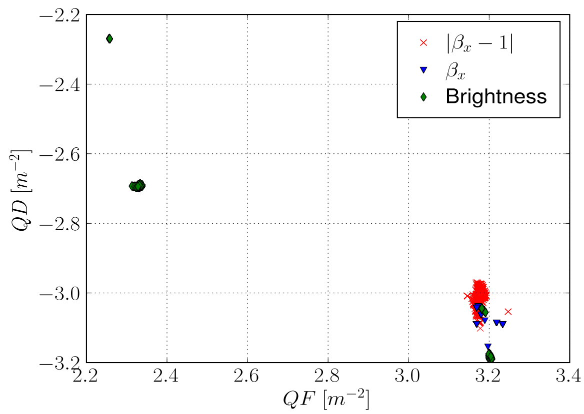

Figure 5: Parameters for optimizing ϵ_x vs. β_x, ϵ_x vs.$|\beta_x - 1|$ and $B(UD)$ vs. $B(BD)$. Projected at $k_{\mathrm{qf}} - k_{\mathrm{qd}}$ plane.

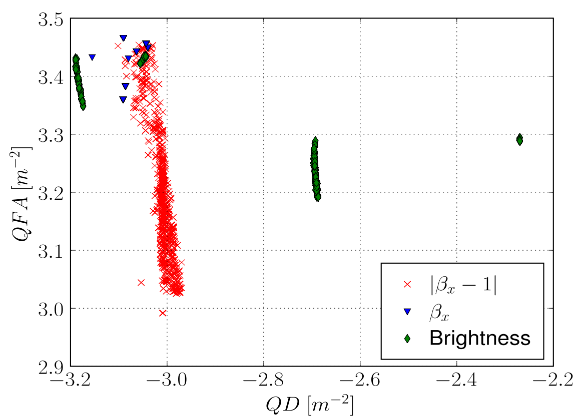

Figure 6: Parameters for optimizing ϵ_x vs. β_x, ϵ_x vs.$|\beta_x - 1|$ and $B(UD)$ vs. $B(BD)$. Projected at $k_{\mathrm{qd}} - k_{\mathrm{qfa}}$ plane.

HIGH-LOW BETA AND LOW EMITTANCE

The conflicting lattice functions can also be optimized by MOGA. A practical example would be that the injection requires high beta at straight, while the high brightness of ID may require low beta. Both cases should keep the emittance low. MOGA can find the optimal set of solutions, and give a global picture about this kind of trade offs.

The optimization was done for two normal sectors of the ALS, with low and high beta functions at the straights. One for the injection and the other for optimal ID brightness. The targeting β_x is $\beta_L \approx 1\ m$ and $\beta_H \approx 10\ m$. The emittance is the third objective function to optimize. Part of the optimal solutions are shown in Fig. 7, where certain range of high beta β_H is chosen to project onto emittance-β_L plane.

We noted that the $|\beta_H - 10|$ is actually equivalent to $10 - \beta_H$. This means the trade-off of solutions are that in this high-low beta lattice, low emittance may tend to have low β_x at both locations. Based on the tolerance of

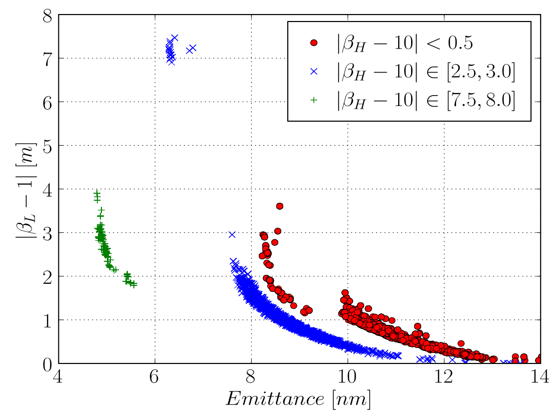

Figure 7: Optimal solutions of optimizing $|\beta_x - 10|$, $|\beta_x - 1|$ and ϵ_x. Projected in $\epsilon_x - |\beta_x - 1|$ plane.

emittance and one of the β_x, the β_H of an optimal solution is determined, and therefore the lattice. Further dynamics may also be carried on.

CONCLUSION

MOGA was used for optimizing brightness for ID and bending magnets of the normal bend sector of ALS. It showed the distinct regions where different β_x and β_y and the trade off between them in the center of straights and bending magnets can affect the brightness choice. This brings the possibility of low-beta high brightness lattice.

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