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BUNCHING SYSTEM OPTIMIZATION BASED ON MOGA*

S. P. Zhang[1], C. Meng†, J. Y. Li, Key Laboratory of Particle Acceleration Physics and Technology, Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China
[1]also at University of Chinese Academy of Sciences, Beijing, China

Abstract

Multiobjective Genetic Algorithms (MOGA) is effective in dealing with optimization problems with multiple objectives. The bunching system of the High Energy Photon Source (HEPS) linac adopts a traditional bunching system for compressing electron beams with a pulse charge of 4 nC. The bunching system is optimized using MOGA. The optimization include minimizing the normalized emittance and maximizing transmission efficiency. The optimization results have reached the design target, and are presented in this paper.

INTRODUCTION

The preliminary design of the HEPS linac is finished [1]. The linac consists of an electron gun, a bunching system and a main accelerating section. Table 1 lists some main parameters of the linac [1,2]. The linac adopts a traditional bunching system, which is used to compress electron beams with a pulse charge of 4 nC into a number of microbunches. The beam is accelerated to about 54 MeV at the exit of the bunching system. The HEPS booster needs the linac provide beams with low emittance and high transmission efficiency. The main linac adopts constant-gradient structure with constant peak electric field in the center of the tubes. From Liouville's theorem, the normalized emittance remains constant during acceleration [3]. In order to get a better beam quility and high transmission efficiency, the bunching system needs to be optimized.

There are multiple objectives need to be optimized. The optimization includes minimizing normalized emittance and maximizing transmission efficiency. Many parameters are adjusted. Since the traditional optimization methods are inefficient [4], modern optimization methods based on random number generation are needed. In this work, we use Multiobjective Genetic Algorithms (MOGA) to optimize parameters of bunching system. In fact, MOGA has been successfully used for optimization in many fields of particle accelerators [5–11].

This paper first describes the application of MOGA in optimizing the bunching system, introduces the preliminary results of thye optimization, and gives a brief summary.

MULTIOBJECTIVE GENETIC ALGORITHMS

Figure. 1 shows the layout of the bunching system. The system includes a prebuncher, a buncher, an accelerating

Table 1: Main Parameters of the Linac

Parameter	Value
Microwave Frequency	2998.8 MHz
Max Repetition Rate	50 Hz
Max. Beam energy at the Linac Exit	500 MeV
Max Pulse Charge at the Linac Exit	4 nC
Bunch Number Per Pulse	5
RMS Energy Spread	0.5 %
Bunch Length	5 ps
Width of Macro-Pulse (FWHM)	1.1 ns
Normalized Emittance	40 mm·mrad

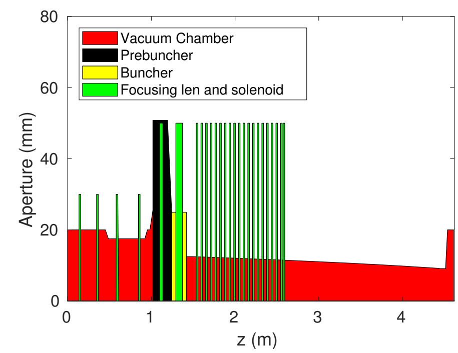

Figure 1: Layout of the bunching system of the HEPS linac.

tube, 4 solenoid focusing lens, 22 solenoids. The position, length, and aperture of each element of the bunching system have been fixed. Only the strength of electromagnetic field along the beam line is tuned in the optimization to obtain better beam quality. This is a multiple objectives and multiple constrains optimization problem. Based on nondominated sorting genetic algorithm II (NSGA-II) [4], MOGA is effective in solving such problems. NSGA-II imitated by the ideas of natural evolution. The multiobjective optimization is realized by populations classification. Details of the MOGA can found in Ref. [9, 11].

In this work, the beam dynamics simulation in the bunching system were optimised using MOGA and PAREMLA [12]. A total of 31 decision variables are used. The parameters used in the optimization include the strengths of 22 solenoids and 4 solenoid focusing lens, the peak voltage of prebuncher and buncher, the phase of prebuncher, buncher and first accelerating tube. The parameters and their ranges are listed in Table 2.

The best solution provided by MOGA with minimum normalized emittance in both x and y directions and maximum transmission efficiency. There are four steps in the optimization. First, random parent populations are created.

* Work supported by the National Natural Science Foundation of China (No. 11675174)
† mengc@ihep.ac.cn

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Table 2: Bunching System Simulation Parameters

Parameter	Range
Solenoid Peak Field(s)	[100, 1000] Gauss
Solenoid Focusing Lens Peak Field(s)	[100, 1000] Gauss
Peak Prebuncher Voltage	[50, 200] kV
Peak Buncher Voltage	[50, 1200] kV
Prebuncher Phase	[0, 360] deg
Buncher Phase	[0, 360] deg
First Accelerating Tube Phase	[0, 360] deg

The population is sorted based on the nondomination level. Each solution is assigned a rank equal to it's nondomination level [4]. Second, it simulates natural evolution process such as inheritance, mutation, selection, and crossover with determined random probabilities. Then a rank is asigned to every offspring population, like step 1. As many as twice parent populations are produced in this step. Third, the offspring populations and parent populations are also sorted based on the nondomination level. Fourth, only half of the best populations are selected based on the nondomination level, and the program then gose to step 2 and cycles until maximum generation evolution is completed.

MOGA optimization depends on the selection of initial populations. The more number of initial populations the better results are. In the evolution of the nth generation, each population is independent, and parallel computing is used to speed up the optimization. the total time used for the optimization depends on the computing power.

The parameters of a population are used as input parameters of parmela. The 6-D electron distribution and transmission efficiency are then calculated. The normalized transverse rms emittance is calculated using eq. (1) given in Ref. [13].

$$\epsilon_n = \frac{1}{mc}\sqrt{< q^2 >< p_q^2 > - < qp_q >^2}, q = x, y. \quad (1)$$
$$= \sqrt{< q^2 >< \gamma\beta_q^2 > - < q\gamma\beta_q >^2},$$

where γ and β_q are the normalized energy and transverse velocity of each electron, 'n' denotes the normalized emittance.

PRELIMINARY RESULTS

A total number of 200 populations are used in the optimization. The genetic algorithm is modified so that the program can restart using previously optimized parameters after interrupted by exceptions.

Figure 2 shows the results of 120 generations, which indicates the objectives tend to evolve in the direction to lower normalized emittance and higher transmission efficiency. Each point in Fig. 2 represents the solution of a population. Two good solutions are marker using red stars in the figure. One of them with a lower emittance, 36.3 mm·mrad, is selected. The transmission rate of this solution is about 80%. Table 3 shows some main parameters of this solution.

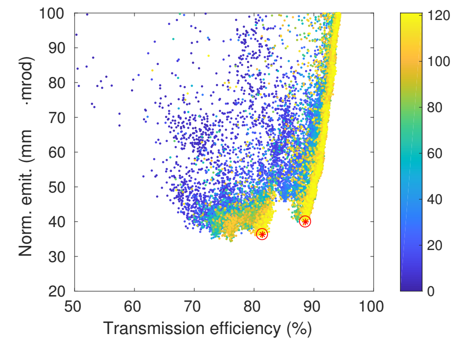

Figure 2: The results of 120 generations. The red points (80.7%, 36.3 mm·mrad) and (88.9%, 41.0 mm·mrad) represent two good solutions.

Table 3: Main Parameters of Selected Solution

Parameter	Solutiom
Prebuncher Peak Voltage	175 kV
Buncher Peak Voltage	233 kV
Prebuncher Phase	112 deg
Buncher Phase	91 deg
First Accelerating Tube Phase	281 deg

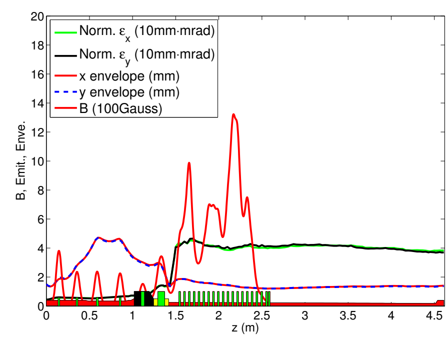

Figure 3: The distribution of magnetic field, normalized emittance and envelope of the selected solution along the beam line.

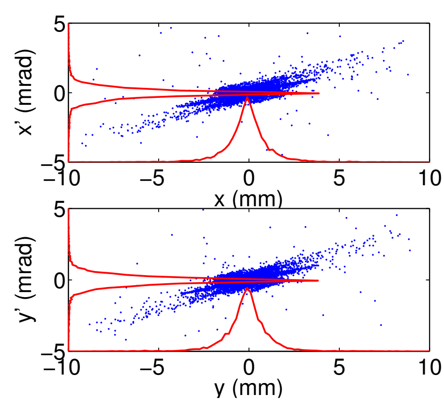

Figure 4: The electron distribution at the exit of the bunching system. (left)x-x'phase space; (rigth)y-y'phase space.

Figure 3 shows the normalized emittance, envelope and magnetic field of this solution along the beam line. The red

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curve in the figure shows the magnetic field. The black and green curves represent the normalized emittance, which is less than 40 mm·mrad at the exit of the bunching system, and meets the design requirements of HEPS linac. Figure 4 shows the electron distribution at the exit of the bunching system of the selected solution in x-x' and y-y' pase space. The red curve in this figure is the electron distribution curve. Table 4 shows the rms distribution of the electrons.

Table 4: RMS Distribution of Electrons at the Exit of the Bunching System

Parameter	σ
x	1.4 *mm*
x'	1.2 *mrad*
y	1.37 *mm*
y'	0.9 *mrad*

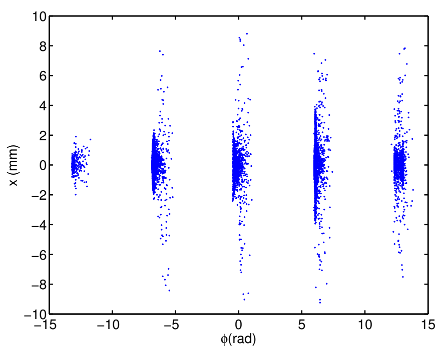

Figure 5: Micro-bunches at the exit of the bunching system.

Figure 5 Shows the main five micro-bunches in a macro-pulse at the exit of the bunching system.

SUMMARY

The bunching system of the HEPS linac is optimized using a MOGA based program. Preliminary results are achieved. Some results meet the requirement of the HEPS booster. Further studies are under-going.

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