OPTIMIZING THE OPERATIONAL PARAMETERS OF THE SFC BY USING PSO ALGORITHM

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Abstract

HIRFL-SFC is a Sector-Focused Cyclotron which plays an important role in scientific experiments in IMP. The SFC was equipped with four groups of harmonic coils, for orbit correction and single turn extraction. There was not a code to calculate the currents of harmonic coils, thus the Orbit-PSO code was developed. Comparing the orbit of 7 MeV $^{12}C^{4+}$, the current of harmonic coils, injection energy and voltage of Dee were calculated by the Orbit-PSO code which contain of PSO(particle swarm optimization) method and the orbit calculation code.

INTRODUCTION

In HIRFL-CSR, various heavy-ions beam are utilized for research in mass measurement, biotechnology and materials science. HIRFL was equipped with a variable-energy Sector-Focused Cyclotron (K=69) [1] which provides various heavy ions. SFC is a three-spiral sector machine with one 180 degree Dee. The extraction radius is 0.75 m and harmonic number 1 and 3 are used. Dee voltage of up to almost 90 kV. The magnetic field can be adjusted by a group of main coils, 11 groups of trim coils and 4 groups of harmonic coils. The beam is extracted by means of three electrostatic channels. Three differential probes are used to measure the position of beam along radius.

SFC always extracts beam with hardness because the operational parameters of harmonic coils based on empirical observations, so it is of much importance to develop the Orbit-PSO code for calculating the currents of harmonic coils, injection energy and voltage of Dee.

THE PROGRAM (ORBIT-PSO) FOR OPTIMIZING THE PARAMETERS

The Orbit-PSO code mainly includes three parts: the PSO algorithm [2], the orbit calculation and post analysis. The orbit of 7 MeV $^{12}C^{4+}$ is considered as the referential orbit, because the carbon beam was utilized for cancer therapy frequently. Generally, $^{12}C^{4+}$ is extracted from ECR, accelerated to 7 MeV by SFC, stripped to be $^{12}C^{6+}$, injected into the CSRm and accelerated to different energy for cancer therapy. Thus we have experienced parameters of 7MeV $^{12}C^{4+}$ for SFC.

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Particle Swarm Optimization (PSO)

Particle swarm optimization (PSO) is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. The system is initialized with a population of random solutions what dubbed particles. Each particle keeps track of its coordinates in the problem space which are associated with the best solution (fitness) it has achieved so far. And it is also guided toward the best known positions in the problem space, which are updated as better positions are found by other particles. this is expected to move the swarm toward the best solutions.

Magnetic Field

The isochronous magnetic field for different beam, which was calculated by the codes of EQUIL and OPTCC, was provided by a group of main coil, eleven groups of trim coils and four groups of harmonic coils. Figure 1 shows the magnetic field distribution along the radius of SFC. The maximum deviation between isochronous magnetic field and real magnetic field can reach 20 Gauss.

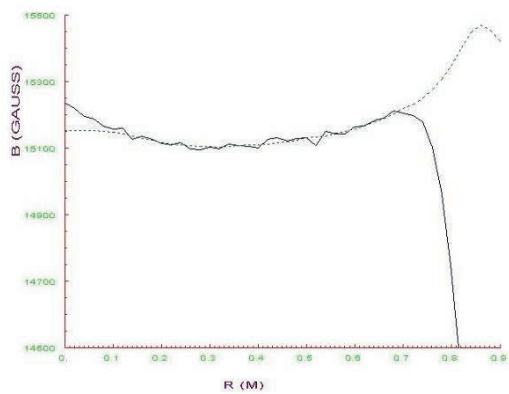

Figure 1: Magnetic field distribution along the radius.

Figure 2 shows the layout of the harmonic coils and Figure 3 shows the magnetic field produced by all coils for 7MeV $^{12}C^{4+}$. For each group of harmonic coils, the currents can be calculated by the equation of:

$$I_A = I * cos(\theta) \quad (1)$$
$$I_B = I * cos(\theta + 120) \quad (2)$$
$$I_C = I * cos(\theta + 240) \quad (3)$$

where I is the current and θ is the phase of each group of harmonic coils. The Eqs. (1-3) distribute the currents to the

groups of harmonic coils, aiming to keep the isochronism of magnetic field.

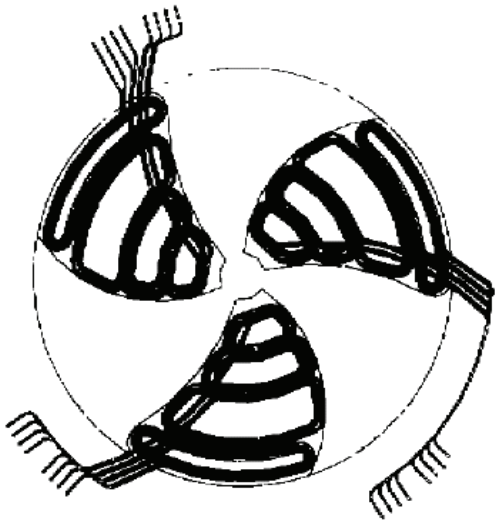

Figure 2: The layout of the harmonic coils.

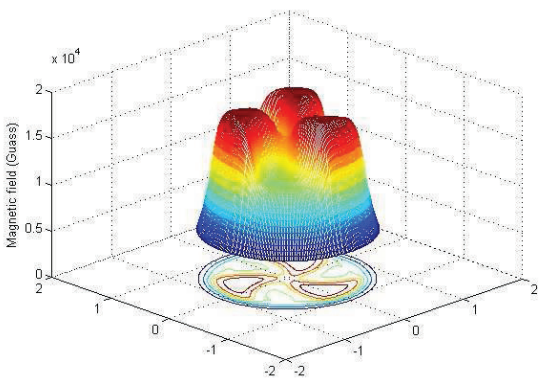

Figure 3: The distribution of magnetic field superimposed by all coils.

Orbit Calculation

The AGORA-SCE [3] is a code, including three parts: initialization, orbit calculation and result output, to calculate beam radial and longitudinal movement on the cyclotron center plane. In the initialization part, the magnetic field, equipotential line and other parameters of SFC was input and transmitted to next step. The orbit calculation part mainly include the subroutines of ACCGAP and ESPACE. The former calculates the orbit inside the accelerating gap, and the latter calculates the orbit between two accelerating gap. So the accelerated equilibrium orbit based on the input data can be calculated.

Flow Chart of Orbit-PSO

As stated above, Orbit-PSO code mainly includes three parts. The flow chart of Orbit-PSO is shown in Figure 4. Firstly, a number of seeds in a certain scale was generated in PSO part. The information of these seeds consists of 10 variables: the currents of four harmonic coils, injection energy and the voltage of Dee. Secondly, delivering the information of each seed to the subroutine of HARM, the magnetic field generated by the harmonic coils can be calculated. And this field is superimposed to the magnetic field generated by main coil and trim coils. Thirdly, AGORA-SCE code calculates the beam orbit under the given input data. Finally, comparing the calculation orbit with the referential orbit, the fitness of this orbit was calculated by the subroutine of Compare. Through the iteration step by step, we finally get the results which meet our requirements.

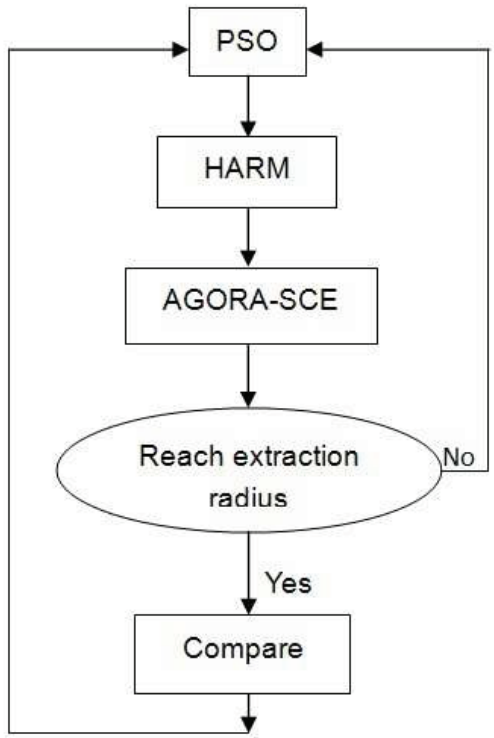

Figure 4: The flow chart of Orbit-PSO.

RESULTS

The calculation results of $^{12}C^{4+}$ and proton are shown in the Table 1. Comparing the calculation results of $^{12}C^{4+}$ with the parameters which used for referential orbit of 7 MeV $^{12}C^{4+}$, we find that the code basically reaches the demand of design. The orbit patterns based on the calculation results of $^{12}C^{4+}$ and proton were shown in Figure 5 and Figure 6, from which it can be seen obviously that the two orbit patterns are similar to each other.

Most of the losses of particles in isochronous cyclotron usually occur at the deflector septum during extraction. The

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radius gain between turns should be increases as much as possible to decrease these losses. The radius gain per turn on the extraction radius and angle mainly due to the magnetic field produced by harmonic coils. As can be seen from Figure 5 and Figure 6, the turn separation on the extraction radius is enough to decrease the particles losses and achieve single turn extraction.

Table 1: The Calculation Results

Name	$^{12}C^{4+}$ **(reference)**	$^{12}C^{4+}$	**proton**
Current of harmonic coils No.1(A)	33	20	61
Phase of harmonic coils No.1 (degree)	136	158	57
Current of harmonic coils No.2(A)	66	34	50
Phase of harmonic coils No.2 (degree)	84	117	81
Current of harmonic coils No.3(A)	41	35	51
Phase of harmonic coils No.3 (degree)	108	103	171
Current of harmonic coils No.4(A)	72	61	25
Phase of harmonic coils No.4 (degree)	343	286	301
Injection energy (kV)	23.07	22.75	21.5
Voltage of Dee (kV)	82.02	83.9	80.8

SUMMARY

In order to calculate the operational parameters of SFC, a code of PSO algorithm and orbit calculation was developed. The $^{12}C^{4+}$ was used to do the feasibility study and the result almost reached the demand of design. Meanwhile, the operational parameters of SFC for proton was calculated by the code and the single turn extraction is achieved in simulation. The correctness of the calculation parameters will be check when the proton acceleration comes true.

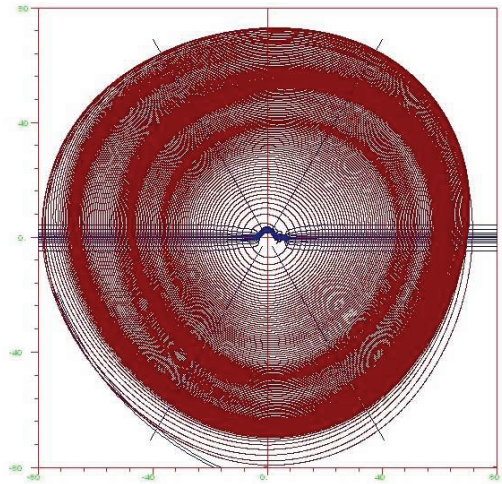

Figure 5: The orbit of $^{12}C^{4+}$ drew by calculation results.

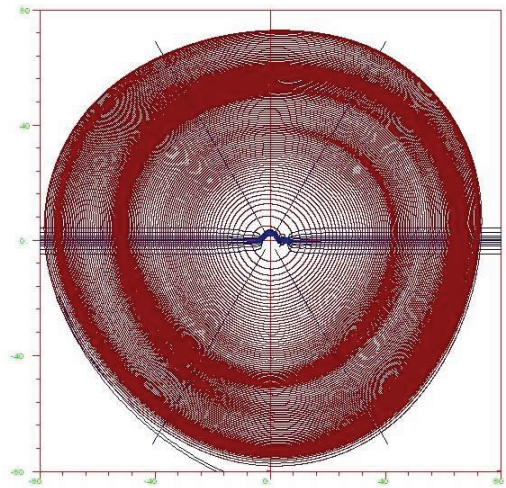

Figure 6: The orbit of proton drew by calculation results.

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