Application of the Inverse Estimation Method of Current Distribution from Magnetic Fields using Genetic Algorithm to Beam Profile Measurement

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ABSTRACT

In this paper, the new type of non-invasive beam profile monitor for intense ion accelerator using high-temperature superconductor. We regard the inverse estimation problem of beam profile as the optimum allocation problem of the currents into the cross-section of the beam vacuum pipe and applied genetic algorithm to solve this optimization problem. And we carried out the computer simulation to verify the effectiveness of this inverse estimation method of beam profile.

1. BEAM PROFILE MONITOR FOR INTENSE ION ACCELERATORS

In the Japan Atomic Energy Research Institute, the development of the intense proton accelerator (1.5GeV, 10mA) for the OMEGA project (Options Making Extra Gains of Actinides and Fission Products) has been continued. But, for intense proton beam, a conventional invasive measuring instrument can not be adopted because of its destruction and new beam measuring instrument need to be developed.

The authors have been studying about the selective magnetic field detection with high-temperature superconductor [1] and applied it to the new type of non-invasive beam profile monitor. Therefore, we measure the magnetic field induced from beam current and estimate the beam profile from the measured data on the magnetic field. The schematic diagram of the beam profile monitor is shown in Fig.1. This beam profile monitor consists of two high-temperature superconductor disks, which are separated with a gap of very short distance and cooled with liquid nitrogen. The magnetic sensors are settled in that gap so as to surround the beam vacuum pipe. By the magnetic shield effect of these disks due to perfect diamagnetism of superconductor, the only magnetic field induced from proton beam in the vicinity of the superconductor disks can be detected selectively and in high sensitivity. But, the distribution of magnetic field near the monitor is influenced by the perfect diamagnetic substance. So, it is very difficult to estimate the beam profile by means of analytical technique. Then, to solve this inverse problem in electromagnetism, we use the inverse estimation method of current distribution from magnetic fields using Genetic Algorithm [2].

2. GENETIC ALGORITHM AND INVERSE ESTIMATION OF CURRENT DISTRIBUTION AS A SOURCE OF MAGNETIC FIELD

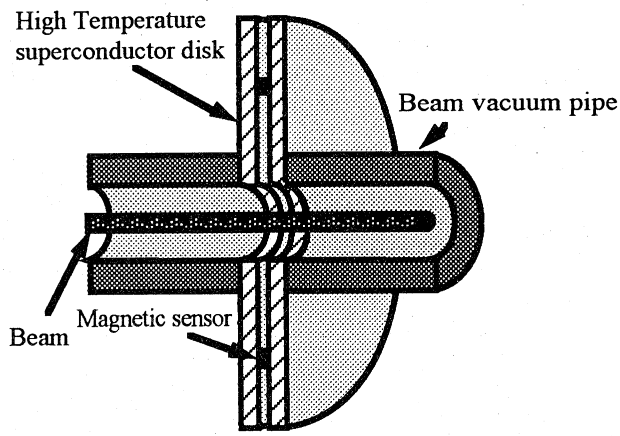


Fig.1. Schematic structure of beam profile monitor

Genetic algorithm is a new type of algorithm on the basis of the mechanism of evolution of living organisms [3]. Normally, most organisms adjust themselves to the environment through the process of selection, reproduction and mutation in the process of evolution. Genetic algorithm is search and optimization algorithm that utilizes these mechanisms of organisms and has wider application than do the conventional ones. The feature of Genetic algorithm is easy to avoid local minimum problem because Genetic algorithm searches from a population of points in the solution space simultaneously. And besides, genetic algorithm uses probabilistic transition rules, not deterministic rules.

We regard the inverse estimation problem of current distribution as a source of magnetic field as the optimum allocation problem of the currents in the cross-section of beam vacuum pipe and applied Genetic algorithm to the means of solving this optimization problem.

3. APPLICATION OF GENETIC ALGORITHM TO BEAM PROFILE MEASUREMENT

We consider the cross-section of beam vacuum pipe and that the currents flow in the direction orthogonal to it. The cross-section is divided into small segments and then, the magnetic field at a measuring point is represented by the sum of the magnetic fields induced from the current of each segment. The inverse estimation problem of beam profile can be regarded as the optimum allocation problem of the currents in the cross-section so that the magnetic field calculated from them can be equal to the measured at each measuring point.

A. Design of Gene

We divide the current distribution area - the cross-section of beam vacuum pipe - into $M \times N$ segments and define the coordinate system as shown in Fig.2. The current Iij which flows through the segment (i, j) (i=1~M, j=1~N) is represented as :

$$I_{ij} = n_{ij} J_u dxdy \quad \cdots\cdots \quad (1)$$

where, Ju is unit current density and nij is an integer from 0 to 255, which represents the strength of the current flowing through the segment (i, j). Then, the state of the current distribution area is represented by the $M \times N$ state matrix which element is the current strength. We use this state matrix as the gene of genetic algorithm and make the population of the genes. In Fig.3, we show the examples of current distribution, its state matrix and the population.

B. Evaluation of Gene

As the fitness, which is index of evaluation of gene in genetic algorithm, we use the error evaluation function. In Fig.2, the magnetic field $\mathbf{B}^{\alpha}$ that the currents induce at the measuring points α is given by

$$\mathbf{B}^{\alpha} = \frac{\mu_0 dxdy}{4\pi} \sum_{i=1}^{M} \sum_{j=1}^{N} \frac{\mathbf{I}_{ij} \times (\mathbf{r}_{ij} - \mathbf{r}_{\alpha})}{|\mathbf{r}_{ij} - \mathbf{r}_{\alpha}|^3} \quad \cdots \quad (2)$$

where Iij is the current which is represented by eq. (1). $\mathbf{r}_{ij}$ and $\mathbf{r}_{\alpha}$ are position vectors of segment (i , j) and the measuring point α respectively.

When the magnetic field measured at measuring point α is $\mathbf{B}^{\alpha}{}_{m}$, we define the error evaluation function to evaluate the fitness of the gene as :

$$\frac{1}{2} \sum_{\alpha} |\mathbf{B}^{\alpha}{}_{m} - \mathbf{B}^{\alpha}|^2 \quad \cdots\cdots \quad (3)$$

And, we try to find out the current distribution of proton beam to make this error evaluation function equal to zero by means of Genetic algorithm.

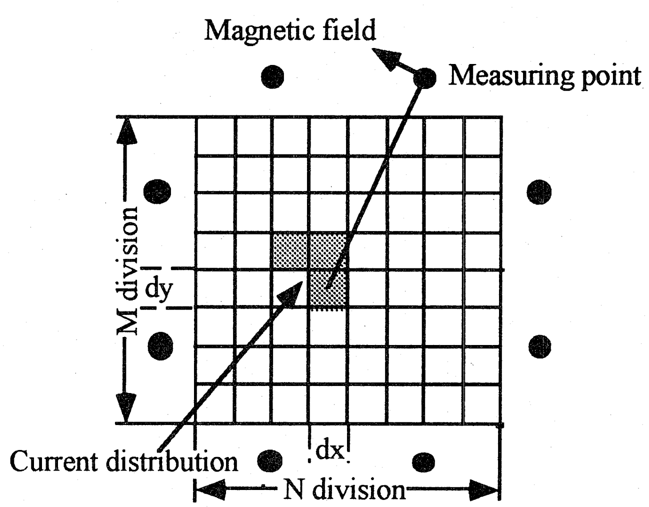


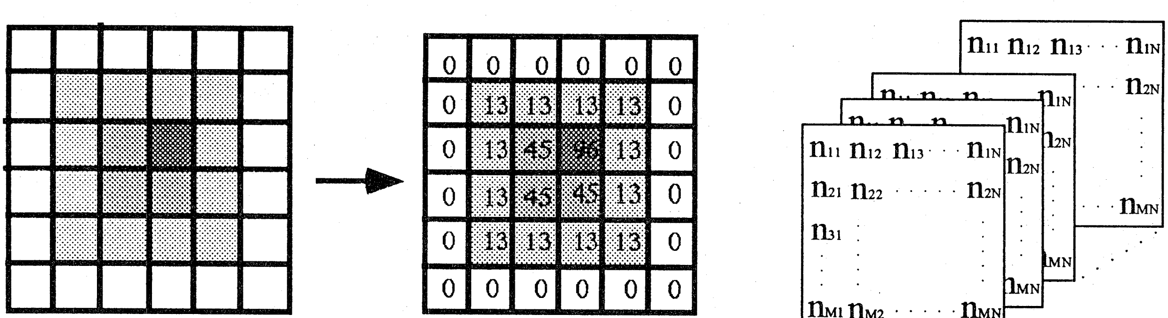
Fig.2. System of Measurement

4. COMPUTER SIMULATION

To verify the effectiveness of inverse estimation method of beam profile by means of Genetic algorithm, the computer simulations were carried out. The parameters of simulation are shown in Table.1 and the simulation result shows in Fig.4 . Fig.4. (a) is the real current distribution and (b) is the inverse estimation result, which the number of measuring points is 24 . The height of the figures represents the current strength. From simulation result, the effectiveness of the inverse estimation method of beam current distribution by means of Genetic algorithm was proved.

5. CONCLUSIONS

The non-invasive beam profile monitor for intense ion accelerator using the high-temperature superconductor was proposed. And we regard the inverse estimation problem of beam profile from the data on magnetic field as the optimum allocation problem in the cross-section of beam vacuum pipe and used genetic algorithm for the solution method of this optimization problem. And the effectiveness of this inverse estimation method of beam profile was proved by the computer simulation.



(a) Current Distribution

(b) State Matrix

(c) Population

Fig.3. State Matrix and Gene

6. REFERENCES

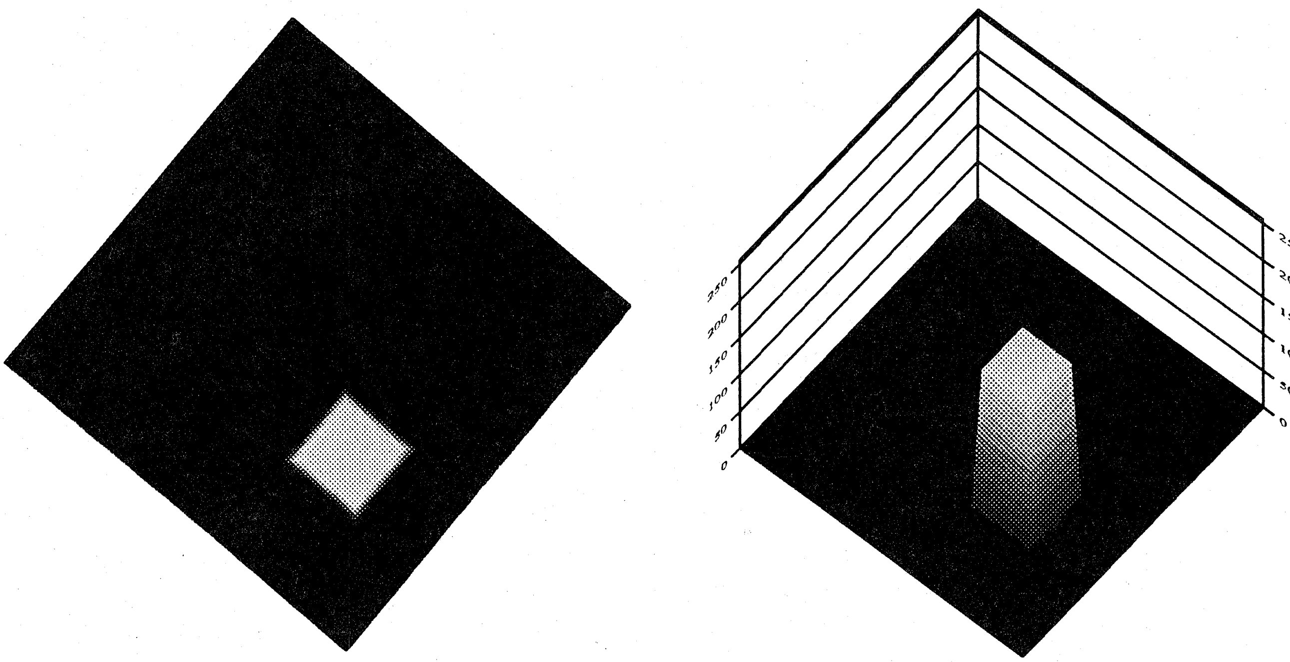
[1] K.Ara, K.Sakasai and M.Kishimoto, Nonlinear Phenimena in Electromagnetic Fields, Elsevier Science Publishers B.V., 1992, 193-196

[2] M.Kishimoto, K.Sakasai, K.Ara, "Application of Genetic Algorithm to Inverse Estimation of Current Distribution from Magnetic Fields", W-42, ISEM-Sapporo,1993

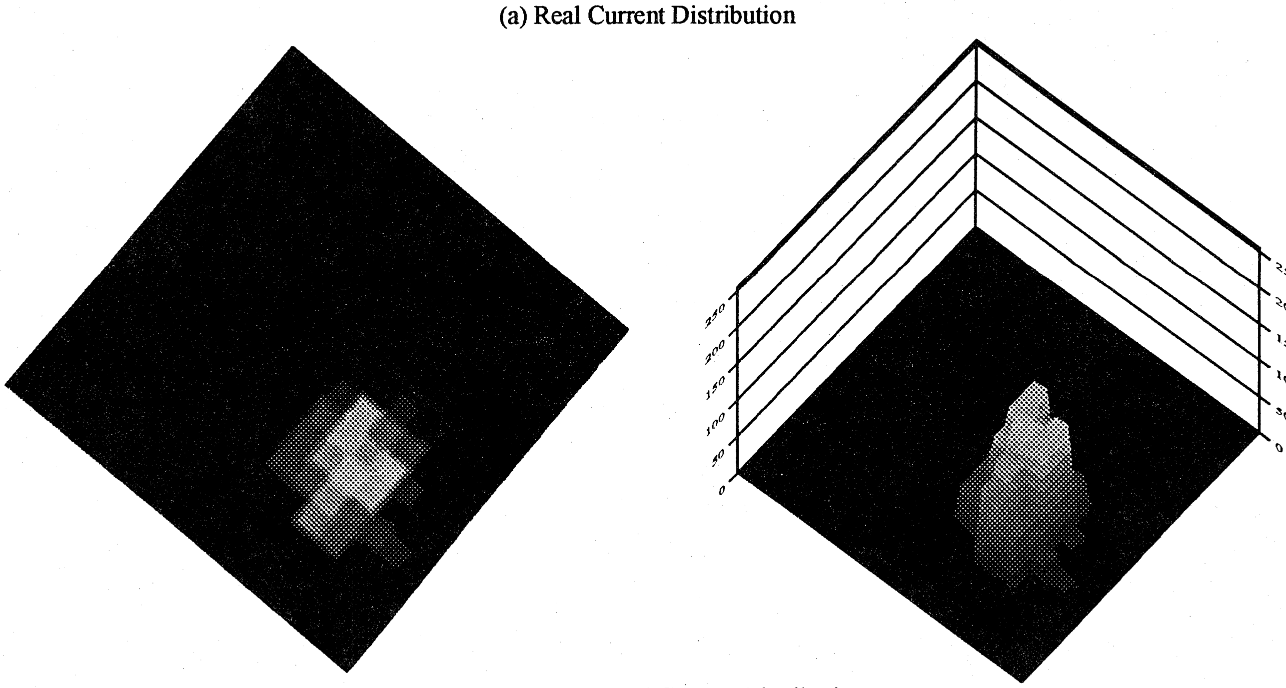
[3] John.H.Holland, Scientific American, July 1992, 44-55

Table.1
Simulation Parameters

Segments	256 (16 × 16)
Measuring points	24 points
Current area	9 segments
Population	100



(a) Real Current Distribution



(b) Inverse Estimated Current Distribution
Fig.4 Simulation Result