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Optimal Design for Electromagnetic Machinery by using 3D Finite Element Method with Parallel GA

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***Abstract* – In this paper, the 3-dimensional finite element method were connected by using the Shell script for automation pre-process such as the modeling and mesh generation, and the genetic algorithm was embedded. Moreover, the main-process was programmed to assign the analytical model of each generated gene to several computers for parallel processing, and the computing time was shortened.**

Introduction

The advantages of 3-dimensional finite element method are to obtain a highly accurate solution and to model the complex shapes. However, the calculation time is longer because the mesh number becomes huge, and the nonlinear calculation is necessary. Therefore, it is difficult to embedded genetic algorithm [1]-[3] to 3-dimensional finite element method. In this paper, analysis flow is modified to automate pre-process that is the modeling and mesh generation of the 3-dimensional finite element method, and genetic algorithm is embedded to this program by using Shell script.

Algorithm

The method of distributing the gene in the range of the search is shown in Fig. 1. It is divided into 0-9 because the gene code is processed by the decimal number in this time. When the part of division into 9 is combined and optimized by 4 places, the chromosome structure becomes the chromosome of 4 digits such as 1425, and 5346 and so on. Moreover, the flow chart of this algorithm is shown in Fig. 2. First of all, the numbers of individuals, the intersection rate, and the mutation rate, etc. are set by setting the GA parameter.

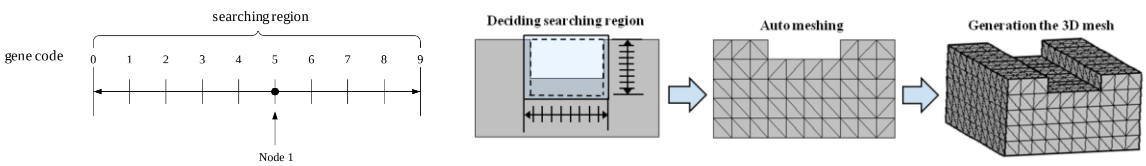


Fig.1 Gene Coding

Parallel GA and Computer Environment

Linux is used for OS, and bash (Bourne-Again Shell) used for the Shell script that is to connect the application. Shortening at the computing time can be expected by distributing each gene against two or more PC so that GA has to evaluate, and to compare two or more genes. Fig. 3 shows the flow chart of making the parallel processing.

Fig. 3 shows consistent of two scripts; one is Controller script that calculates the fitness. Other one is Server script that calculates the electromagnetic field. And it is an instruction set that executes the evaluation block in the flow chart in Fig. 2 at the same time in two or more independent Server scripts.

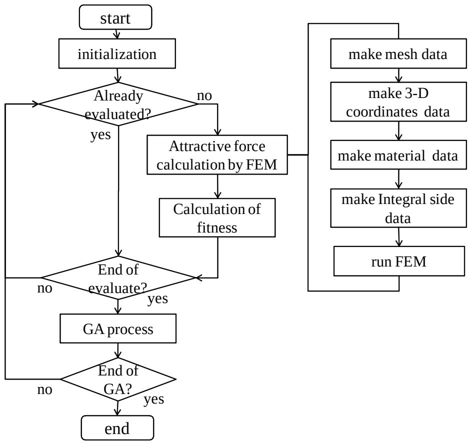


Fig.2 Flowchart of the Shell Script

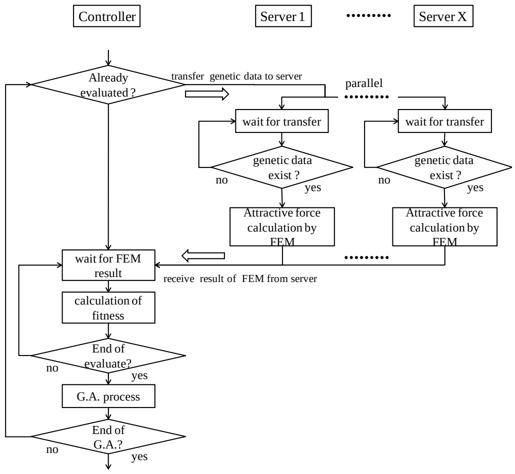


Fig.3 Flowchart of Parallel GA with 3D-FEM

Analysis Model

Fig.4 shows the analysis model for the SPMSM. This SPMSM is 3 phase - 4 pole and 1/8 model (Direction of surrounding 1/4 and direction of axial 1/2). The fitness for GA is to decrease the cogging torque. Shape parameter is around the stator core which has big influence to cogging torque. Fig.5 shows the mesh for FEM analysis. Number of elements is 133680.

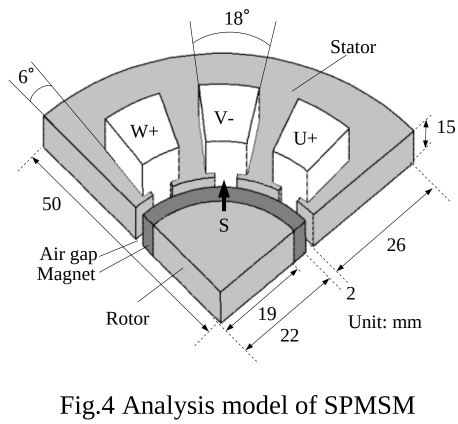


Fig.4 Analysis model of SPMSM

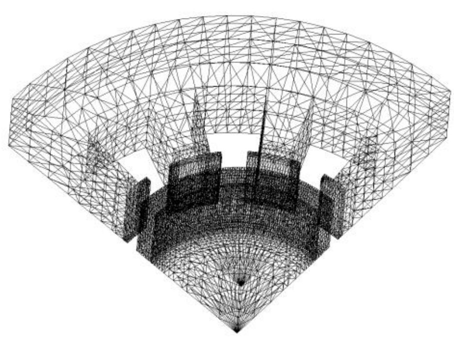
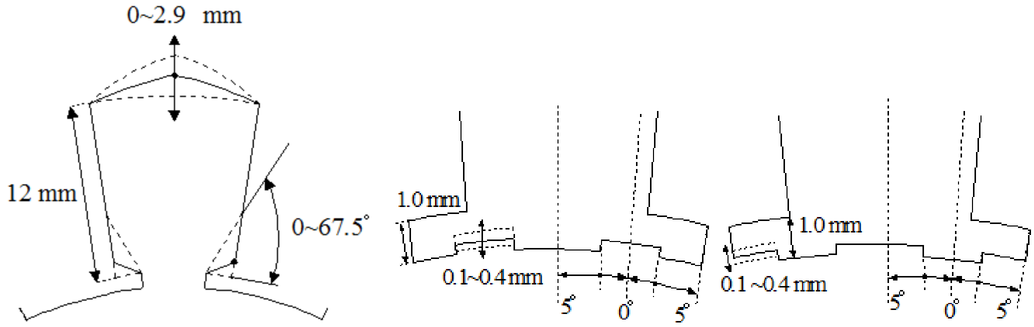


Fig.5 Mesh of analysis model for FEM

Fig.6 shows the searching region for GA. 1st chromosome is about the shape of coil portion by the Fig.6 (a), it is changed degree of rotor side between 0 deg. and 67.5 deg. 2nd chromosome is about the edge shape of teeth by the Fig.6 (b), it is changed 2 ruggedness pattern between 1 deg. and 5 deg. 3rd chromosome is about depth of the ditch by the Fig.6 (b), it is changed between 0.1 mm and 0.4 mm. The fitness equation is below.

$$f = \frac{1}{\sum_{i=1}^{ns} \left| 2T_{Ci} \right|} \quad (1)$$

T_{Ci} : Cogging torque value of i steps, ns : Analysis steps



(a) coil shape cording (1st chromosome)　　(b) teeth shape cording (2nd and 3rd chromosome)

Fig.6 Searching region

Fig.7 shows the analysis model of the 2 degree of freedoms actuator. The fitness for GA is to increase detent force. It is composed of a fixed part where 2 "C" type yoke for the rotation direction drives and 2 "E" type yoke for linear direction drives. Moreover it surroundings of the moving part that establishes 2 magnets of the ring in a different pole as an annex and inserts it in a magnetic shaft at the angle of 180° axially and the direction that vertically intersects with it. The magnet has been magnetized in parallel by rare earths (Br=1.3T). The gap length is 0.3mm. Fig.8 shows the mesh for FEM analysis. Number of elements is 542700.

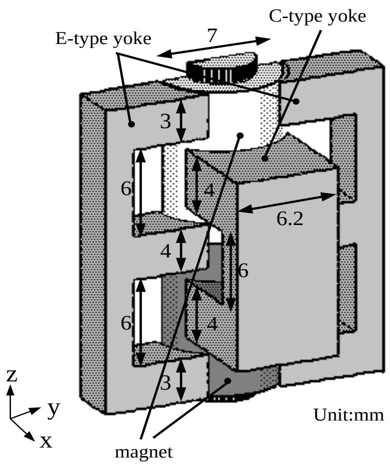


Fig.7 Analysis model of 2-DoF Actuator

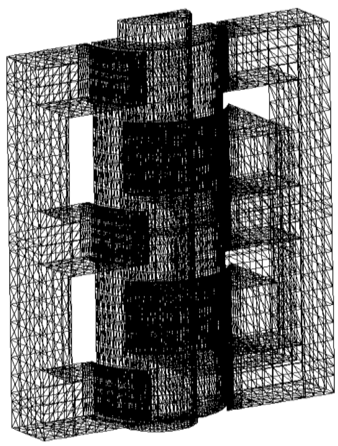
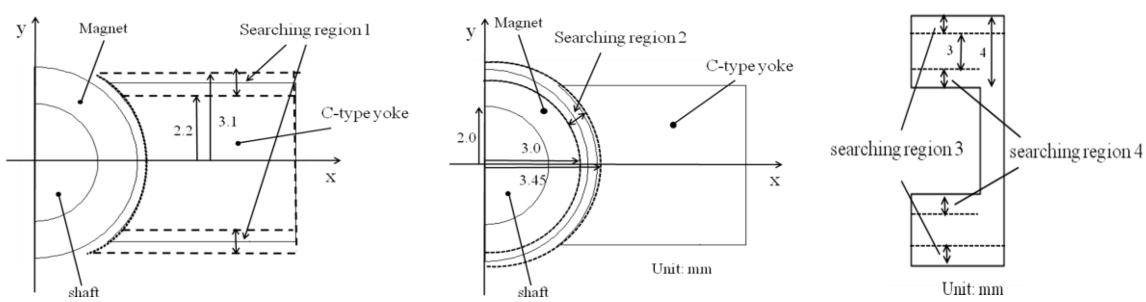


Fig.8 Mesh of analysis model for FEM

Fig.9 shows the searching region for GA. 1st chromosome is about y direction of C-type yoke by the Fig.9 (a), it is changed between 2.2 mm and 3.1 mm. 2nd chromosome is about the thickness of permanent magnet by the Fig.9 (b), it is changed between 3.0 mm and 3.45 mm. 3rd chromosome is about z direction of C-type yoke by the Fig.9 (c), it is changed between 3.0mm and 4 mm. The fitness equation is below.

$$f = \sum_{i=1}^{n_s} \left| T_{Ci} \right| \tag{2}$$

T_{Ci} : Detent foce value of i steps, ns : Analysis steps



(a) C-type yoke (1st chromosome) (b) Magnet (2nd chromosome) (c) C-type yoke (3rd chromosome)

Fig.9 Searching region

This method for analyzing makes the finite element method parallel by distributing the individual with a different gene to each slave. That is, it calculates in parallel with three PC by the master-slave method to control GA by mastering. The version of CentOS 5.4(64 bit) for OS and the compiler uses Intel FORTRAN Compiler 11.1 072.

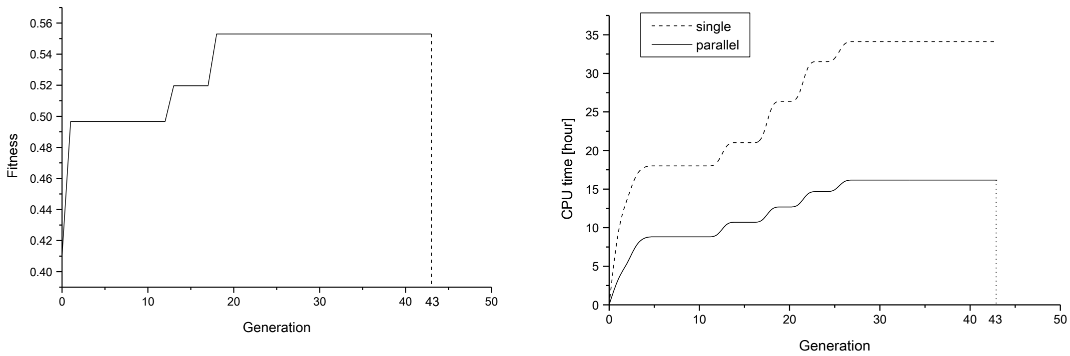
Table I shows the parameter for GA. As for the population size, used by the analysis, because the computer that operates the Server script is three, the multiple of three is preferable. Therefore, the population size is assumed to be 12. Moreover, because three population in 12 remain as it is in the next generation by the generation gap, it can be expected that the number of target population at the second generation for the analysis is nine (multiple of three).

Table I Specification of genetic algorithm

Cross over type	One point
Selection method	Elite and Tournament
Elite size	3
Mutilation rate	0.05
Population size	12
Gene length	3
Allele	0 ~ 9
End of generation	100
Judgment of generation	25

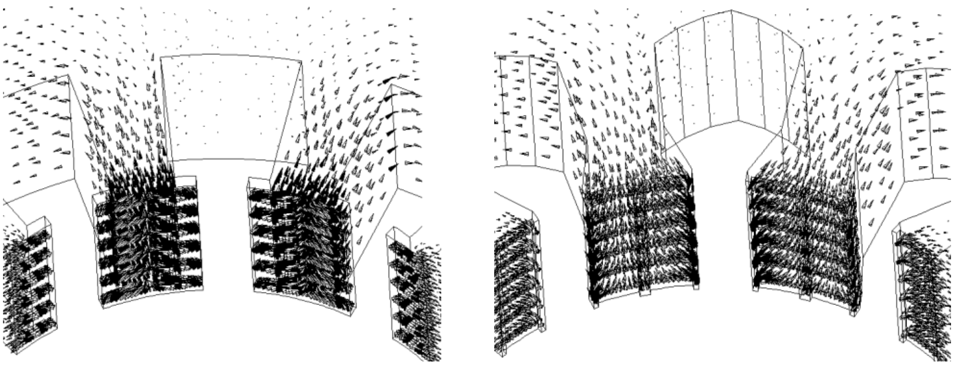
Analysis Results

Fig.10 shows the analysis result for GA of SPMSM. Fig.10 (a) is shown relationship between fitness and generation, (b) is computation time. and Fig.11 is comparison initial and optimal shapes. Fig.12 is cogging torque waves. It was 0.553 and 1.35 times in the best shape according to Fig.10 (a) compared with fitness 0.410 of the initial shape. The peak magnitude has decreased by 30% according to the cogging torque waves of Fig.11. The total computing time of GA was 16 hours and 10 minutes, and GA computing time that required by each gene was requested, it was 34 hours and 7 minutes. Therefore, according to Fig.10 (b), the computing time became 47.4% compared with the parallel operation of three PC, it became below the half.



(a) Evolution process (b) Comparison CPU time between single mode and parallel mode

Fig.10 The results of genetic algorithm



(a) Initial shape (b) Optimal shape

Fig.11 Comparison the form between default and optimized model

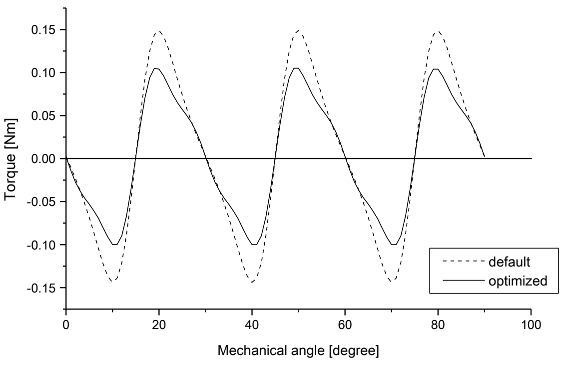


Fig.12 Comparison cogging torque waveform between default and optimized model

Fig.13 shows the analysis result for GA of 2-DoF actuator. Fig.14 is shown initial and optimal shapes of C-type yoke. and Fig.15 is flux density distributions, Fig.16 is detent torque waves. The detent force is improved about 2.5 times, and the total calculation time was able to be shortened by below 1/2.

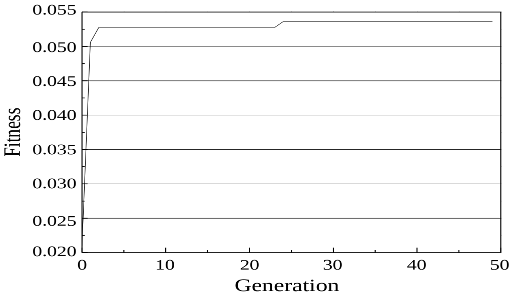


Fig.13 Evolution process

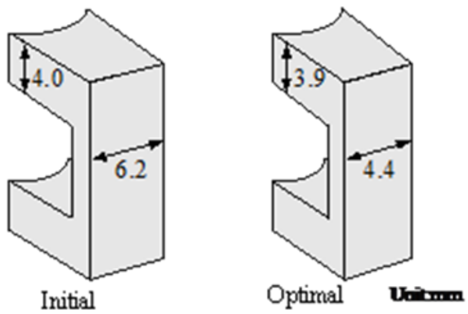


Fig.14 Initial shape and Optimal shape

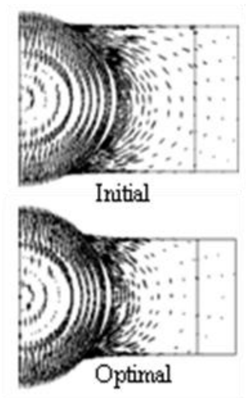


Fig.15 Flux density vector of initial and optimal shape

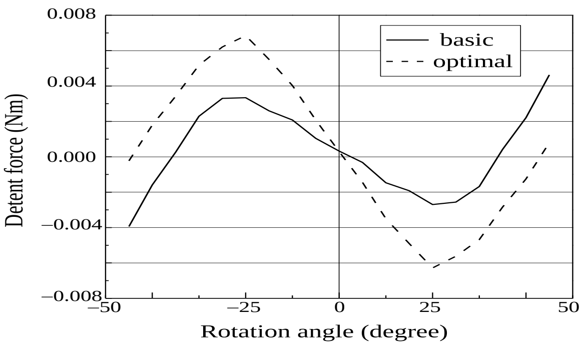


Fig.16 Torque characteristics

Conclusion

It was able to confirm to decrease 30% of the cogging torque of SPMSM, and the improvement about 2.5 times the detent force of the 2 degree of freedoms actuator by using this embedding the 3-dimensional finite element method with GA, and using the analytical result as fitness. Moreover, GA was able to be made parallel by distributing the gene to several PC, and the total calculation time was able to be shortened by below 1/2. It will be corresponding to other electromagnetic equipment such as IPMSM and the induction machines and actuators in the future.

References

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[3] W.Kitagawa, Y.Ishihara, T.Todaka and K.Hirata: “Fast Computation Technique of Genetic Algorithm Based on Finite Element Method”, *IEEJ Trans. IA*, Vol. 127, No. 9, pp.1009-1012, 2007