유전자 알고리즘과 상용 설계도구를 이용한 유압 펌프 시스템용 SRM 설계기법

論 文
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Design Technique of SR Machine for Hydraulic Pump System using Combined CAD and Genetic Algorithm

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Abstract – In this paper, an optimal method for determining design parameters of a Switched Reluctance Motor is researched. The dominant design parameters are stator and rotor pole arc and switching on and off angle. The parameters affecting performance are examined and selected using evolutionary computations and commercial CAD program. The simulated design method is compared with conventional procedure.

Key Words : Switched Reluctance Motor, Optimal Design Method, Genetic Algorithm, Commercial CAD Program

1. Introduction

The design methods of a conventional Switched Reluctance Motor (SRM) are divided into two classes. The first is the reiterative design method applied by an experienced designer. Specific parameters are investigated, with most of the main design parameters restricted within limited conditions. This method can satisfy the desired specification by reiterative design using exclusive design tools, but it takes a lot of time and effort to design since the combination of design parameters for pertinent conditions are varied. Also, it is difficult to verify that the results are optimal[1].

The second approach is to use the output equation from equivalent model of a motor. The desired specification of a motor is obtained using an iterative design and optimization algorithm. However, the results of the output equation can be different from real measured values due to approximations and limitations of the model[2]. In this paper, the general purpose software, PC-SRD, was used and a program was developed to input parameters to the software automatically. A Genetic Algorithm(Below GA) was implemented to select optimum parameters and satisfy the required machine specifications. The design results of this method were compared to the results of the conventional design method for the prototype motors. The SR Motor has various complicated parameters necessary to design the motor and it is difficult to consider all of the parameters when designing SRM[1][2]. This paper presents prototype motors selected from standard design equations and compares the performances based on the selected design parameters. The features were simulated numerically and tested to analyze the drive characteristics with the design parameters.

2. Design of SR Motor

It is required to analyze each design parameter in order to apply GA to the design of SRM. Each of the design parameters has a specific range, affect the motor's essential performance. The parameters must be set within the search range of intellectual design of GA[3]. The performances ofthe SRM are varied in accordance with the combinations of design parameters. Therefore, this paper presents proper data for the design of SRM according to the manipulation of the design parameters. The 6/4 and 12/8 pole motors are simulated and the output performances for both motors are analyzed.

2.1 Stator/Rotor Radius and Stack Length

The first set of design parameters for the SRM is to determine the stator radius, rotor radius and stack length according to the required specifications. These are important factors to determine the shaft torque of motor as shown in (1). If the rotor radius was decided by equation 1, the stator radius is given by the ratio of rotor radius and stator radius according to the number of

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poles. The effective range of the ratio of rotor radius and stator radius is 0.5 to 0.55. The stack length is selected from the ratio of the length and rotor diameter. The value is typically chosen to be equal to 1 [1].

$$T = KD_r^2 L_{stk} \quad (1)$$

2.2. Rotor parameters

After determining the rotor radius, the next step is selection of the rotor pole arc. For a self starting motor, the rotor pole arc needs to be larger than the stroke angle. The stroke angle is the rotating angle when one phase is excited, in the case of 12/8 pole and 6/4 pole motors, the angles are 15° and 30°respectively. If the rotor pole arc is smaller than the stoke angle, then torque will not be generated throughout the entire angular position, therefore the selected angle must be larger than the stroke angle.

$$Min(\beta_s, \beta_r) \geq \varepsilon \quad (2)$$

$$\beta_r \geq \beta_s \quad (3)$$

A reference value of rotor yoke thickness is 20~40[%] of rotor pole width, the thickness should be sufficient to carry the peak rotor flux without saturation. The rotor pole height should not be small in order to enlarge the inductance ratio of the aligned and unaligned position. If the pole height is too large, then flanging will occur. These two constraints provide the range for the pole height.

2.3. Stator parameters

In general motor design, the stator outer diameter is restricted, If it is not limited, the size should be designed to the minimum value in the range. The stator pole arc should be smaller than the rotor pole arc and larger than the stroke angle.

The stator yoke thickness needs to be thick enough to account for flux flow, mechanic stiffness and acoustic noise. The winding area will be reduced by increasing the thickness. The stator yoke thickness is 40~60[%] greater than rotor yoke thickness. The stator height is determined by subtracting the selected parameters out of the stator radius.

3. The coupling of GA and the general purpose software

3.1. GA concept

Genetic algorithms have been developed to solve various optimization problems by imitation of nature from 1960. GA have been developed based on the concept that an organism can continuously and effectively adapt to a changing environment. The development has been based on Evolution Computation, EC, together with Evolution Strategies, ES, and Evolutionary Programming, EP.

GA explores not one solution but multiple possible solutions(population) in order to find an optimum condition for solving a problem. Among the selected population of solutions, GA produces a new solution set and repeats the process to find the optimal solution for the problem. In this process, GA generates solutions in each phase by using crossover, mutation, and Elitism [3] [4].

3.2. Coupling of GA and commercial design software

In this paper, the design parameters generated by GA were calculated using PC-SRD (SRD), one of the most frequently used programs in designing SRM. The accuracy of performance calculation can be guaranteed by using the SRD as the benchmark. Moreover, it is possible to attain simulations closest to the results of real performance of SRM by adjusting various settings provided by the program. Control options such as switching on/off timing are available.

An initial set of parameters are produced by GA and provided to SRD. These parameters are supplied by an external program. SRD performs the machine analysis based on these parameters. Then, the results for calculating the objective functions are sent to the GA program to determine the fittest solution. The number of the calculation processes must be equal to the number of sample solutions. The design of an optimal SRM cannot be achieved without exchanging correct information among the programs. Therefore, a coupling program was made.

3.3. Application of GA

Fig. 1 shows a flowchart of the genetic algorithm for design procedure optimization applied to SRM when using the real number type GA and SRD program[4].

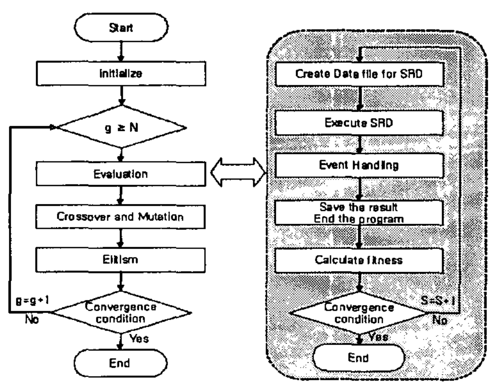


Fig 1. A flowchart of optimal design using GA

The summary of the process for the optimal selection of SRM parameters is described as follows.

3.3.1 Constitution of population

The table in fig. 2 shows the variables and the population of solutions, which were used in the design process.

S_1	K_{10}	K_{11}	· · ·	K_{1n}
S_2	K_{20}	K_{21}	· · ·	K_{2n}
	· · ·			
S_1	K_{m0}	K_{m1}	· · ·	K_{mn}

K_6: Stack length
K_7: Turn per pole
K_8: turn-on angle
K_9 : turn-off angle

* Sn: number of string

Fig 2. The design parameters and the population.

3.3.2 Evaluation and reproduction

Fig. 3 illustrates the interpretation process for evaluating each reproduced string. When the SRD program finishes the calculation process, the GA program offers a certain set of fitness by using the fitness function as below.

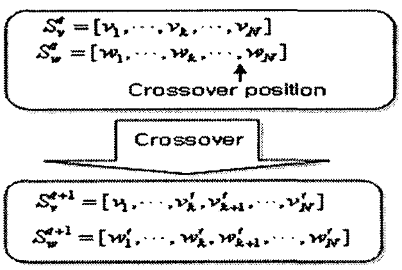
$$Fitness = \frac{1}{(\alpha \times Power + \beta \times Eff.)} \quad (4)$$

The roulette wheel method, which produces each string in proportion to the fitness, was used.

3.3.3 Crossover, Mutation, and Elitism

In this work, the real number type GA was used to produce the fittest solution when designing SRM. This approach can shorten computation time and add mathematical method. Simple crossover and uniform mutation were applied to obtain the next generation of parameters. The simple crossover provides new descendent populations from two randomly selected strings chosen from the parent populations.

As shown in fig. 3, if the two randomly picked strings out of t generation cause crossover in k variable, the group of offsprings of t+1 generation evolve as follows.



α1,α2 : Random number between 0 and 1
υ1,υ2 : The value between maximum and minimum numbers of each variable.
N : The number of variables constitutes each string

Fig 3. Simple crossover

If a k variable in a string from the populations of t generation produces mutation in simple crossover, the offsprings of t+1 generation evolve as shown in Figure 5.

Fig. 4 Uniform mutation

In order to acquire a group of the fittest offsprings, elitism, the method of reproducing the fittest individual, was applied.

4. Comparison with the conventional method

4.1. Condition and range of simulation

In this study, in order to verify the performance of SRM explored by GA, a simulation was tested with the same limited conditions and range of the conventional motor. A 12/8 SRM was investigated and compared to an equivalent motor geometry obtained using the conventional design method. The performance is shown in Table 1. The motor was designed with the iteration method, in which the shaft diameter and the stator radius parameters ranges were determined by an experience designer for hydraulic pump system application. Therefore, in the simulation using GA, the stator radius, the shaft diameter and the airgap were identical for both the conventional design and GA design. The remaining design parameters of the motor geometry were adjusted so that the motor would generate optimum power and torque.

Table 1. The performance of the primitive motor and parameters

Ds	135[mm]	Bs / Br	15 / 16 [deg]
Dr	70[mm]	ys / yr	11 / 16 [mm]
Power	2.5[kW]	Airgap	0.3 [mm]
Torque	5.6[Nm]	turn-on	21[deg]
Eff.	85.4[%]	turn-off	36[deg]

4.2 Adjustment of the geometry and performance

Fig. 5 illustrates the fitness of each generation, and Fig. 6 represents the performance of the motor with different fitness. The final geometry developed by the GA is consistent with the parameter selection criteria suggested in section II. Table 2 shows the simulated motor performance and associated specifications. The overall geometry of the final design and the performance and specifications are changed and improved.

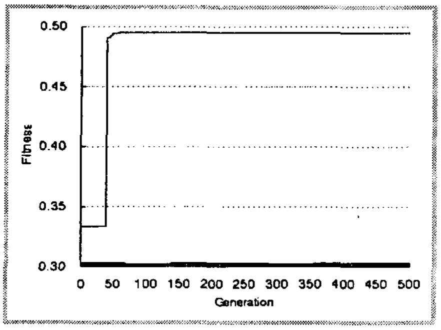


Fig. 5 The best fitness according to generation

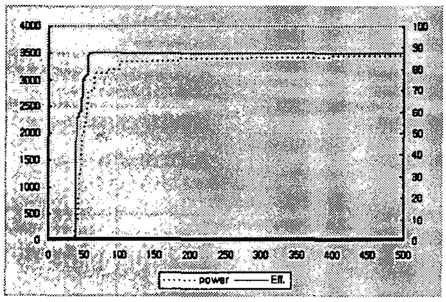


Fig. 6 Performance according to generation

Table 2. The performance and the parameters the selected motor

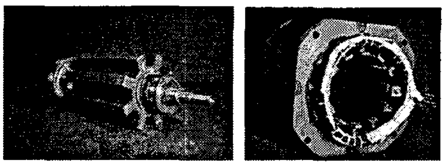
Ds	122[mm]	Bs / Br	15 / 16 [deg]
Dr	74[mm]	ys / yr	8.5 /4.4 [mm]
Power	3.4[kW]	Airgap	0.3 [mm]
Torque	10.5[Nm]	turn-on	21[deg]
Eff.	87.5[%]	turn-off	38[deg]

5. Experiments and Results

5.1 Experimental system Set-up

Fig. 7 show the rotor and stator assembly of a generated prototype SRM for Hydraulic pump application using by GA and CAD program.

The test drive system for generated motor is shown in fig. 8. The digital controller of SRM is implemented by TMS320LF2407 DSP of Texas Instruments. The speed of SRM is calculated by the 2000[ppr] optical encoder and QEP function of TMS320LF2407 at every 1.6[ms] period. Phase current signals is detected by sensors and converted as digital data at internal 10bit ADC of DSP. An asymmetric classic inverter with 600[V], 50[A] IGBT modules, supplies the pulse power to SRM.



(a) Rotor (b) Stator

Fig. 7 The generated SRM for hydraulic pump

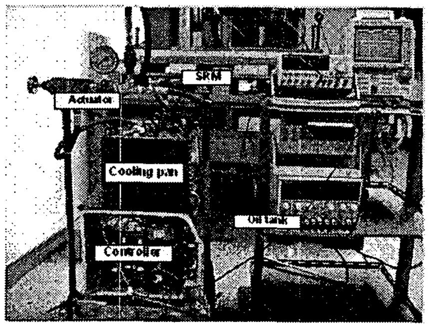


Fig. 8 the experimental set-up of generated motor system

5.2 Experimental Results

Fig. 9 shows the speed-torque and operating efficiency of the generated SR drive in applied system.

In order to keep the target oil perssure at a low speed range, output torque of SRM is 13[Nm] that is larger than required Maximum torque, 9.7[Nm]. Ther maximum operating efficiency of SR drive at full load condition is 84[%] that is lower then the designed valued 87.4[%] because of manufacturing error and control condition of classic inverter system.

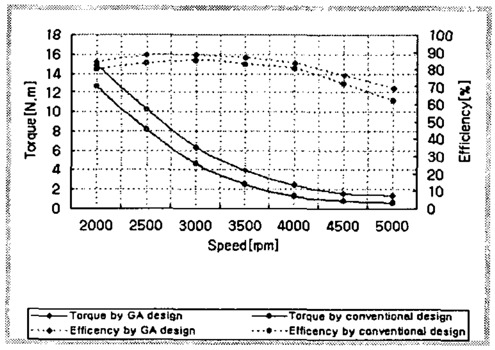


Fig. 9 Speed-torque and efficiency characteristics from simulation

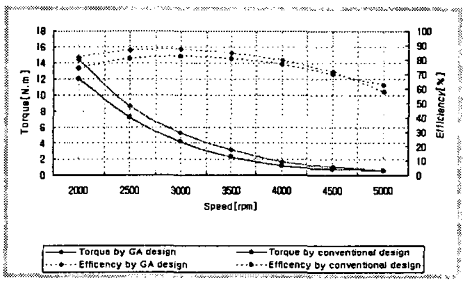


Fig. 10 Speed-torque and efficiency characteristics from experimental test

6. Conclusion

This paper detailed a design method of SRM using GA to produce a motor with improved performance. PC-SRD was used to simulate the parameters produced by the genetic algorithm. An initial set of parameters are produced by GA and provided to PC-SRD. These parameters are supplied by an external program. The effectiveness of the coupled GA/PC-SRD design method was compared to the performance of a conventionally designed SRM with equivalent specifications. The experimental result show some good advantages of hydraulic pump system with SR Drive.

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