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Structural Optimizations of a 12/8 Switched Reluctance Motor using a Genetic Algorithm

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Abstract

Structural design optimization of 12/8 switched reluctance motor using single objectives genetic algorithms is explored. The objective of this optimization is to maximize the output torque using four parameters, namely rotor width of tooth root, rotor width of tooth tip, half of stator tooth width, and stator outer diameter. The result is the optimized motor has higher average torque of 25% compared to the initial design. The evaluation of motor model is finite element method. The 12/8 switched reluctance motor will be applied in a mini electric vehicle.

Keywords

Switched reluctance motor; JMAG; Finite element analysis; Electric vehicle; Single objective genetic optimization

1 Introduction

Switched Reluctance Motor (SRM) is one of the most promising drivetrains for an electric vehicle, this motor has several advantages such as low cost, robust construction, and high starting torque [1]. The designing procedure of SRM has been widely documented, but only few papers discussed the design optimization. The classic method for shape modification can optimize the electric motor, such as hill climbing [2]. However, this method has several disadvantages: (1) this algorithm effectiveness depends on starting point, (2) this algorithm can be trapped in local optimum, and (3) a huge time is required to explore the searching space [3].

Genetic Algorithm (GA) is one of the widely used optimization processes due to its robustness [4]. The GA has many advantages: (1) the parallel ability to work in the population of points, (2) the ability to locate the global optimum with higher probability, (3) the ability to handle discrete parameter, and (4) reasonable computation time. Faiz et al. [5] has explored the maximization of an average output torque of the SRM using GA. In this paper, the adaptation of the GA for structural optimization of SRM is presented.

2 Motor Design Methodology

The motor design optimization method aims to find the vector $X = (X_1, \ldots, X_n)$ which most represents the design variables and corresponds with the objective function $F(X)$. It can be minimized or maximized with the limited constraint. The lowest and highest boundaries are $G_X = \left(g_1(X), \ldots, g_n(X)\right)$. This method is applied to the initial motor design. It consists of vector X which represent the constraints of the geometrical parameters. The geometrical parameter has to be constructed to ensure the dimensional feasibility of the electric motor. In this paper, the geometric parameters are (1) rotor width of tooth root, (2) rotor width of tooth tip, (3) half of stator tooth width, and (4) stator outer diameter. Figure 1 shows the typical 12/8 SRM.

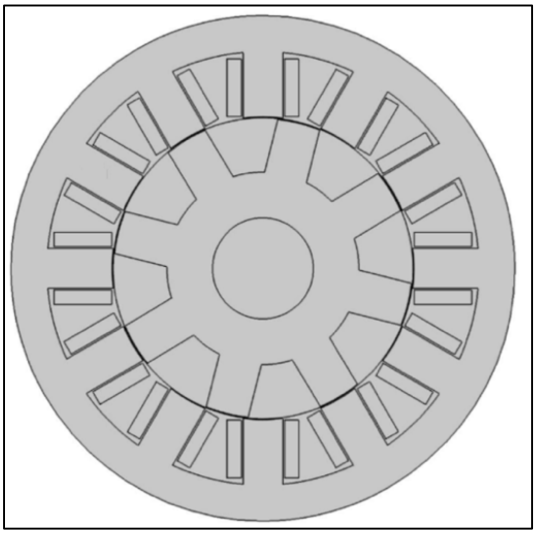

Figure 1 Typical 12/8 switched-reluctance motor

3 Genetic Algorithm

GA introduces the method that basically consists of searching tools. This algorithm is adapted from the mechanism of organism genetics and environmental selection process. This algorithm runs on a habitant of several individual's solutions and employs the survival

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base of the best individual to evolve. The best results will be chosen to optimize the solutions. In GA, contender solutions are referred to as individuals. The characteristic of these individuals (parameters) are encoded to chromosomes which composed of a series of genes [6].

GA has three unique operators. The first is selection, the second is crossover, and the last is mutation. In every iteration or generation, these operators are used on a population of possible solution to improve their compatibility. Each individual is represented by chromosomes. These individuals are similar to the natural chromosomes. The number of individuals are randomly created, and then the reproduction starts until one of the three conditions are met: (1) a stopping criterion is met, (2) the certain number of generations is reached, or (3) no further improvement among the individuals.

There are three main kinds of GA operator: selection, crossover, and mutation. Crossover operation takes two candidates from the population and makes two new solutions. Mutation takes a single individual and alters it. The usage of these two types of operators depends on the applied encoding method to the chromosomes [7].

3.1 Operators of GA

The selection function performs a crucial role in the GA. This operator selects which individuals will live or vanish in the next generations. Based on the selection theory, fitted individuals have better opportunity to live. Afterward, the random numbers are generated and compared against the cumulative probability of the population. There are two kinds of selections such as roulette wheel selection and tournament selection.

The selection of roulette wheel method determines the selection probability for each chromosome as proportional to the fitness value. This method is based on spinning an imaginary "roulette wheel" which the number of times equal to the size of the population. In contrast, tournament selection is different since this method does not require selection probabilities assignment. The requirements are to select *k* individuals randomly (with replacements) and to choose the best of them (using the fitness function) to be in the new population. This process is repeated until the same number of individuals in the new population is obtained.

Crossover is the recombination of two or more parental solutions to produce a new individual which has a chance to get better results. There are many ways of accomplishing this, and the performance of the operator depends on a properly designed crossover technique. The child property value of the two parents will not resemble the parents' value. This operator has two kinds of operators such as single and multi crossover point techniques. The single crossover point is randomly selected, and the genes of the parents are exchanged after the crossover point. Multi crossover point technique is randomly chosen, and the genes of the parents are exchanged in between the crossover points.

In natural evolution, mutation happens as the product of an error in copying the gene information. As an analogy to this, mutation in GA is a process of changing some information genes on chromosomes randomly. The main role of mutation operator is to keep the diversity of individual in the population. Normally, in the canonical GA using binary representation, mutation operator turns over the selected bit value between two individuals.

3.2 Fitness and constraints

The final step is the evaluation stage where each individual gets a fitness value. This step determines the chance of being in the next generation. In an optimization problem, this is normally done by the objective function $F(X)$. The minimization or maximization of $F(X)$ is the objective of the optimization problem. In a constrained optimization case, the constraint vector $G(X)$ has to be considered. This is going to influence the original objective function in such a way that if any of constraints are not fit for one of the individuals, so the value of the fitness value will be so low. This individual will probably not be going to be chosen for the next generation. This can be done by penalizing the objective function for these cases, which yields the final fitness function $F(X)$. This technique will evaluate the model of the problems [8].

4 12/8 SRM Optimization

The initial dimension SRM has been chosen to start and compare the optimization results. The initial design is a 3 kW, 60 V, 3 phases, 3000 rpm, and air-cooled SRM. The fixed parameters of this motor are: maximum current density (J_{max}) of 10,007×103 A/m^2, shaft diameter (D_{sh}) of 0.039 m, and maximum flux density (B_{max}) of 2.094 T.

The objective of this optimization is to maximize the output torque. The design variables of the main parameters are the rotor width of tooth root parameters, rotor width of tooth tip parameters, half of stator tooth width parameters, and stator outer diameter. This method is expected to improve the output torque and output power.

JMAG is an analysis software for finite element analysis. This simulation software used for electric machine design applications. By using this software, a motor is designed with the initial dimension described in Table 1. The dimension of motor stator is illustrated in Figure 2 while the dimension of the motor rotor is described in Figure 3.

Table 1 Geometric Parameters

Parameters	Description	Values
p_s	Number of stator poles	12
p_r	Number of rotor poles	8
l_g	Air gap length	0.5 mm
D_{so}	Stator outer diameter	140 mm
D	Bore diameter	83 mm
$Length$	Core length	80 mm
C	Back iron width	16 mm
N_p	Number of turn/phase	150
β_s	Width of stator pole	11 mm
β_{rr}	Width of rotor pole tip	12 mm
β_{rt}	Width of rotor pole root	12 mm
D_{sh}	Shaft	28 mm
N	Speed	3000 r/min
P	Output power design	3000 W

5 12/8 SRM Optimization Results

The results of single objectives optimization using GA with JMAG software are obtained. The generation design in 10 iterations of each generation has 15 motor populations. Each iteration generates 5 children. The step size dimensional searching is 0.5 mm. Figure 4 plots all the motor case in 10 generations and their correlation with the output torque. This optimization used 10 generations and 10 individuals in each generation.

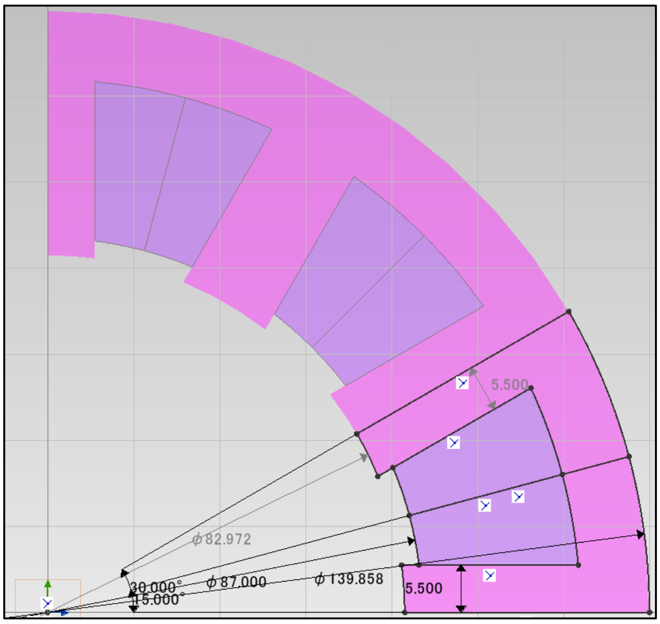

Figure 2 Stator dimension of 12/8 switched reluctance motors (unit in mm).

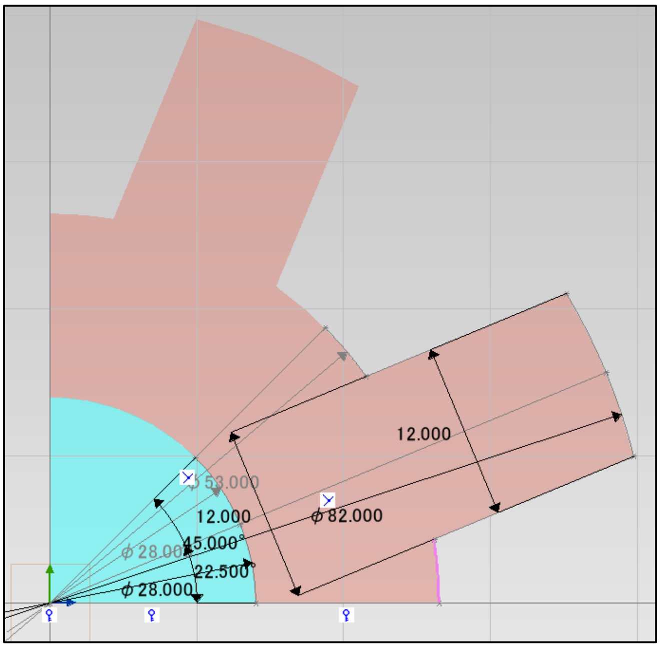

Figure 3 Rotor dimension of 12/8 switched reluctance motors (unit in mm).

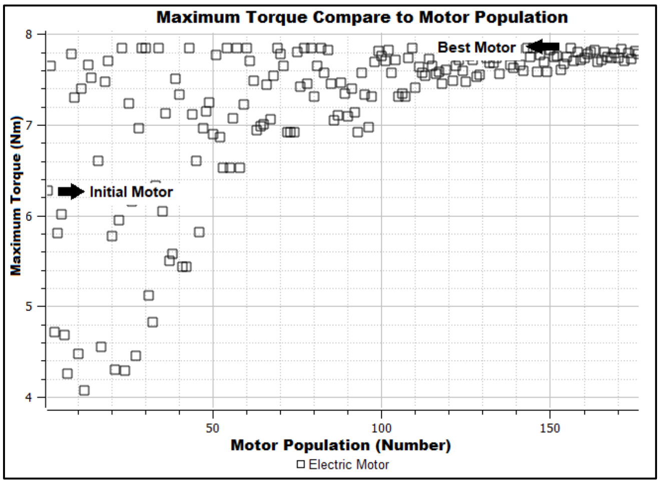

Figure 4 Correlation between output torque and all SRM motors.

5.1 Optimization results

The effect of motor rotor width of tooth root to the output torque is described in Figure 5. The correlation between output torque and rotor width of tooth tip shown in Figure 6. The correlation the between output torque and half of stator tooth width is described in Figure 7. The correlation the between output torque and stator outside diameter is described in Figure 8. Based on this result, it is shown that the output torque has a non-linear correlation compared to the geometric parameters. There are two motors with the same outer stator diameter that produce higher output torque (T_{max}), they are motor number 77 and number 101 with output torque 7.84 Nm and 7.71 Nm, respectively. The description is shown in Figure 8 and Table 2.

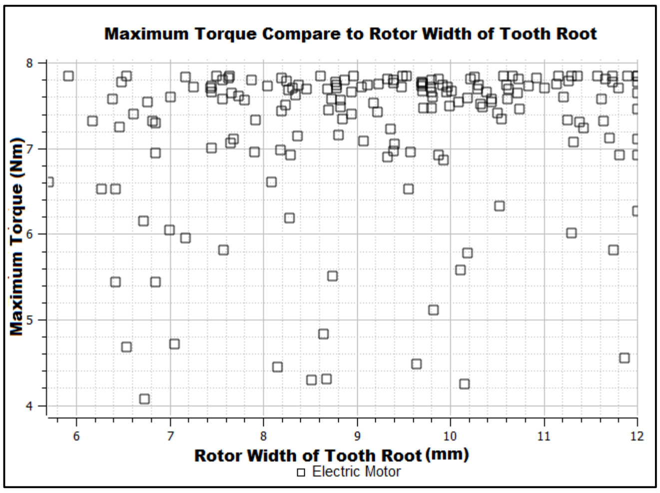

Figure 5 Correlation between output torque and rotor width of tooth root.

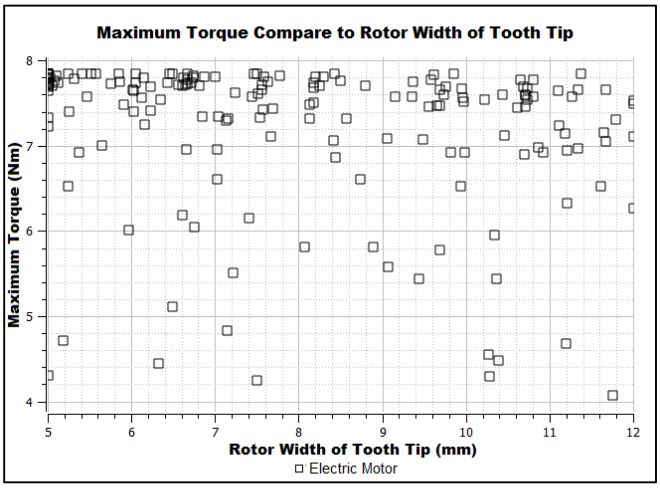

Figure 6 Correlation between output torque and rotor width of tooth tip.

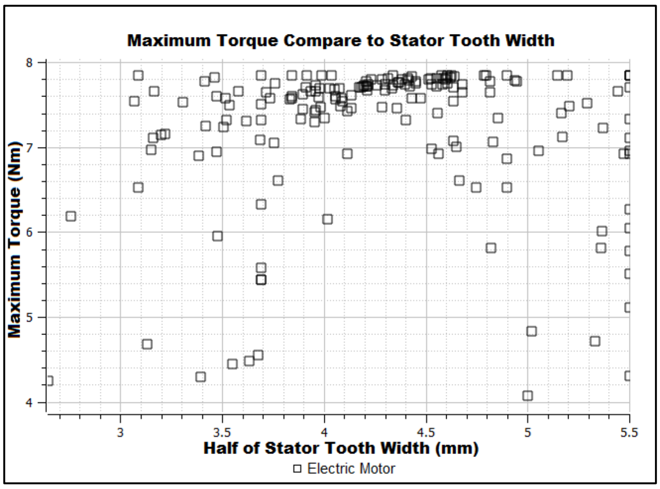

Figure 7 Correlation between output torque and half of stator tooth width.

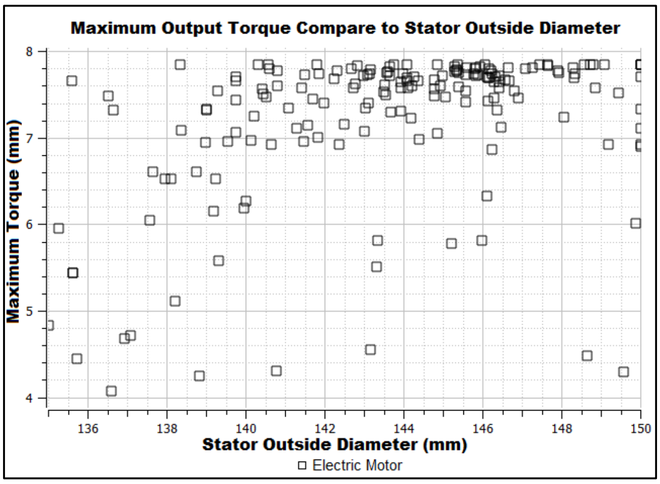

Figure 8 Correlation between output torque and stator outside diameters.

Table 2 Motor Comparison with the same outer diameter

	Motor 1	Motor 77	Motor 101
β_s (mm)	11	7.82	8.34
β_{rr} (mm)	12	6.53	7.42
β_{rt} (mm)	12	7.45	5.05
D_{so} (mm)	140	140	139.7
T_{max} (Nm)	6.277	7.84	7.71

5.2 Motors characteristic

The three motor characteristics will be described. The output torque plot is shown in Figure 9, the flux linkage is shown in Figure 10, and the inductance characteristic for every individual plot is shown in Figure 11. The optimized switched reluctance design has an average torque of 7.8488 Nm and the initial motor has an output torque of 6.277 Nm. Thus, there is an improvement about 25% compared to the initial design. The motor number 156, 145, 143 has yield the best optimization in the population because they produced the highest output torque as shown in Figure 12 with the geometric parameters are shown in Table 3.

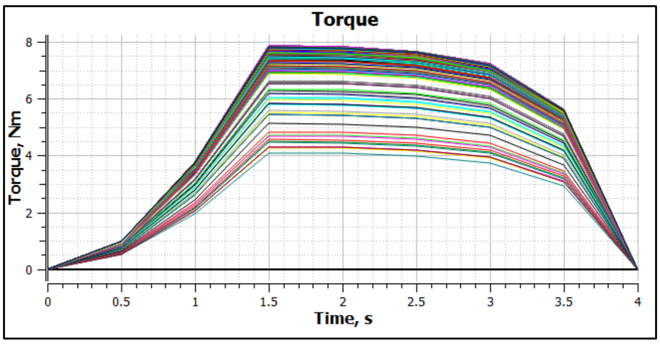

Figure 9 Static torque for every SRM motors

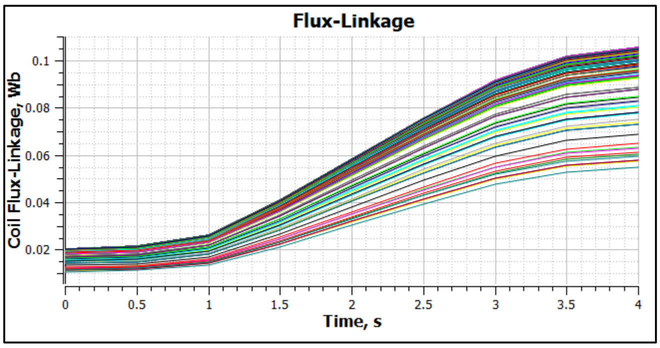

Figure 10 Flux linkage characteristic for every SRM motors.

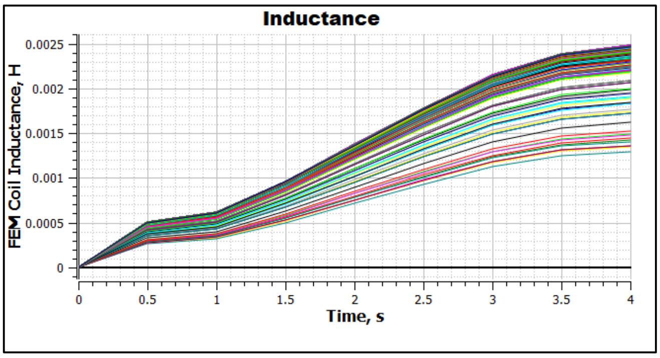

Figure 11 Inductance characteristic for every SRM motors.

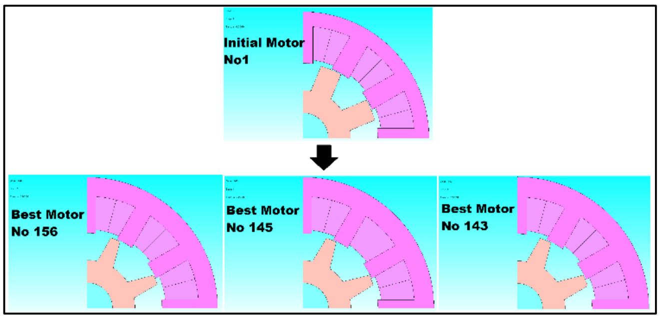

Figure 12 Best 12/8 SRM motor compared to initial motor

Table 3 Geometric Parameters

	Motor 1	Motor 156	Motor 145	Motor 143
β_s (mm)	11	9.56	9.2	10.28
β_{rr} (mm)	12	9.48	10.56	10.66
β_{rt} (mm)	12	5.5	5.84	6.45
D_{so} (mm)	140	144.8	145.36	146.03
T_{max} (Nm)	6.277	7.8488	7.8488	7.8488

6 Conclusion

This paper has built single objective optimization based on GA using JMAG software. Two-dimensional design problem of 12/8 SRM has been explored. It is found that GA is reliable for a structural SRM optimization. An important conclusion of this optimization has taken a lot of time so the termination method or generation determination is important. This optimized design will be useful for mini electric vehicle.

Acknowledgment

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