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단상 유도형 동기 전동기의 효율 향상을 위한 회전자 형상 최적화

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Optimal Design of Line-start Permanent Magnet Motor for High efficiency Performance with double-barrier rotor design

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Abstract - This paper examines an design of double-barrier rotor structure for improving the efficiency performance in a single-phase line-start permanent magnet(LSPM) motor. By utilizing the advantages of double-barrier rotor design that by increasing reluctance torque generation to compensate magnet torque production, the copper loss reduction is achieved. The optimal approach of response surface methodogy(RSM) is performed for determining a optimum double-barrier rotor structure. The improving of efficiency performance is confirmed by finite element method(FEM) and test.

1. Introduction

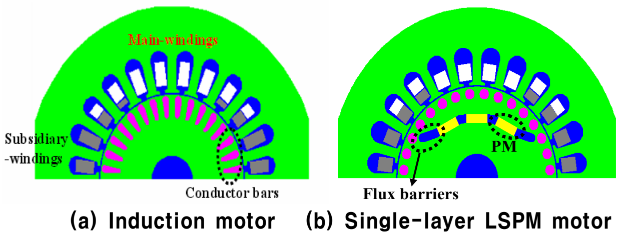
The single-phase line-start permanent magnet(LSPM) motor operates with commercial electricity without additional power electronic switching devices and position sensor, therefore having higher maintenance than other inverter fed electrical motors[1],[2].

Compare to the conventional single-phase induction motor, the LSPM improves the torque characteristics by adding permanent magnets to the rotor part. Therefore, the LSPM motor has attributes of both induction motor(IM) and interior PM(IPM) synchronous motor. For having a better torque performance, the conductor bars are buried inside the rotor core, which products asynchronous starting torque at the beginning operation[2],[3].

Compare with the inductance motor, the LSPM motor can improve efficiency performance obviously, although the buried conductor bars inevitably produce additional copper loss[2].

Moreover, the efficiency performance of LSPM motor can also be improved by applying double-barrier structure to the rotor design as proposed in this paper. As some reports of the multi-barrier rotor design in synchronous reluctance motor, that the increasing barrier design benefits to reduce flux leakage and improve the rotor saliency[3]. Correspondingly, the advantage on efficiency performance over the conventional single-barrier rotor design is achieved. The double-barrier rotor design is adopted in the optimal design of rotor structure for practical consideration, that as simplicity for manufacturing, the easiness of inserting PM into the rotor core and the mechanical robustness[4],[5].

In this paper, a popular optimization approach of response surface methodogy(RSM) is performed to search optimal design variables, which deal with multiple objective functions with considering the interaction effect between each others[6]. For increasing reluctance torque generation, the higher rotor saliency is desired in the rotor design. The increased reluctance torque helps to lower the dependency of magnet toque, which closely relates to the copper loss in the stator windings and benefits to the efficiency improvement[5].



(a) Induction motor (b) Single-layer LSPM motor
<Fig. 1> Single-phase IM and LSPM motor configuration

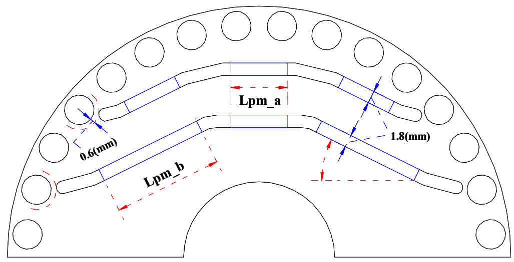
2. Analysis Model and Design Approach

2.1 Prototype LSPM motor

An exiting induction motor(IM) used as compressor in air-condition is introduced as the analysis model, as Fig. 1(a) shows. And, another designed LSPM motor model with the same stator structure of the induction motor is built as Fig. 1(b) given, in which the permanent magnets are buried inside the rotor core with single-barrier design.

2.2 Double-barrier rotor structure

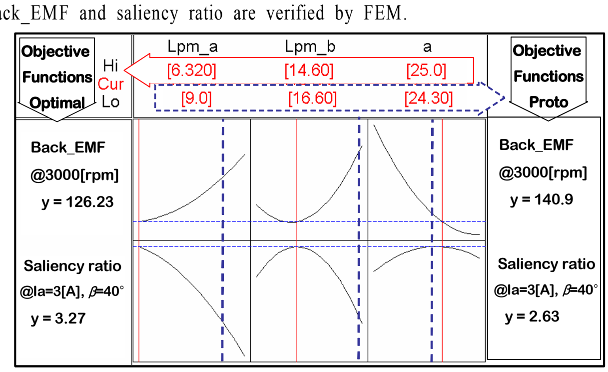
For improving the efficiency performance, a double-barrier rotor structure is adopted with using the same amount of PM. The base model of double-barrier rotor structure is given in Fig. 2, where all the design variables and assumptions for optimal design are marked.



<Fig. 2> Base model of double-barrier rotor structure

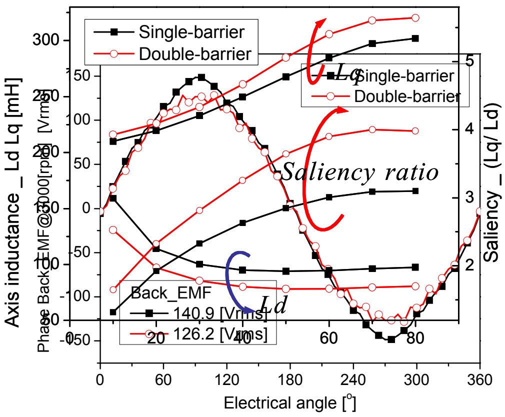
2.3 Optimal design

By using the RSM, the design high saliency rotor structure is . As is well known, that the Back_EMF is proportional to the magnet torque production and the higher the rotor saliency, the reluctance torque generated. Therefore, for simplicity consideration, the characteristics of Back_EMF and rotor saliency ratio at main operation point[3000(rpm)@Ia=3(A),$\beta=40^o$] is chosen as the objective functions in RSM to change the balance of magnet torque and reluctance torque. As the analysis above, for increasing the reluctance torque generation, the high saliency rotor is designed according to the optimization analysis by RSM. With satisfying the torque characteristics, the optimal model is determined and its objective characteristics of Back_EMF and saliency ratio are verified by FEM.



<Fig. 3> Optimization analysis of objective functions

(a) Results comparison of Back_EMF characteristic
(b) Results comparison of Saliency characteristic

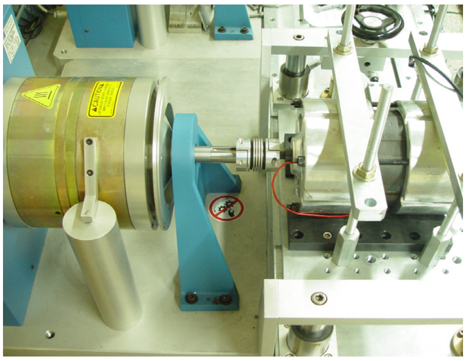


<Fig. 4> Objective functions confirmation by FEM

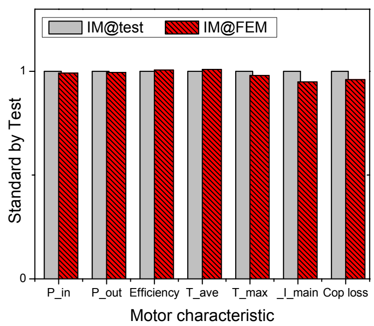
3. Results and Discussion

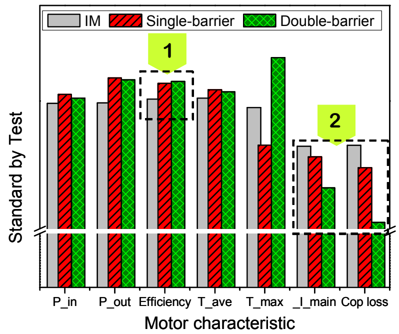
The exiting induction motor is test, as Fig. 5 illustrated, and its performances are compared with the simulation results by FEM. Take the test data as standard, the results by FEM is well verified as Fig. 6(a) shows.

Then, the improvement of efficiency performance by adopting double-barrier rotor design is confirmed by the characteristic comparisons between the induction motor, single-barrier LSPM motor model and the optimal double-barrier design LSPM motor model, as the Fig. 6(b) illustrated. With satisfying the same output torque characteristic, that including average torque and maximum torque, the double-barrier design model shows an improvement efficiency performance (region 1), since the decrease of copper loss. The copper loss is reduced with the decrease of armature current(region 2), which corroborating the change of balance between the magnet torque and reluctance torque in the hybrid torque production. The reluctance torque generation is increased with the enlarge of rotor saliency, and the magnet torque was compensated by the reluctance torque. Finally, the improving of efficiency by adopting double-barrier design in LSPM motor with the same amount of PM is proved.



<Fig. 5> Experiment setup of Induction motor test





(a) Results comparison of Induction Motor
(b) Comparison between IM, prototype single-barrier LSPM motor and optimal double-barrier LSPM motor
<Fig. 6> Motor characteristics comparison(by test and FEM)

4. Conclusion

This paper presented a optimal design of double-barrier rotor structure for improving the efficiency performance of a Single-phase Line-start permanent magnet motor. The efficiency improvement is achieved since the copper loss caused in the stator windings was reduced by lowering the magnet torque production, which was compensated by the increased reluctance torque generation due to a higher rotor saliency created by the optimal designed rotor structure. As a conclusion, the double-barrier rotor design is a effective approach to improve efficiency performance based on changing the hybrid torque characteristics without additional PM usage.

[Reference]

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