RESEARCH ARTICLE OPEN ACCESS

Computational Design and Analysis of Core Material of Single-Phase Capacitor Run Induction Motor

Gurmeet Singh*, Gurlad Singh**, Mohd. Afaque Iqbal***
* (Department of Electrical & Instrumentation, SLIET Longowal University, Punjab-148106)
** (Department of Electrical Engineering, Aryabhatta group of institutes, Barnala, Punjab-148101)
*** (Department of Electrical & Instrumentation, SLIET Longowal University, Punjab-148106)

ABSTRACT
A Single-phase induction motor (SPIM) has very crucial role in industrial, domestic and commercial sectors. So, the efficient SPIM is a foremost requirement of today's market. For efficient motors, many research methodologies and propositions have been given by researchers in past. Various parameters like as stator/rotor slot variation, size and shape of stator/rotor slots, stator/rotor winding configuration, choice of core material etc. have momentous impact on machine design. Core material influences the motor performance to a degree. Magnetic flux linkage and leakage preliminary depends upon the magnetic properties of core material and air gap. The analysis of effects of core material on the magnetic flux distribution and the performance of induction motor is of immense importance to meet out the desirable performance. An increase in the air gap length will result in the air gap performance characteristics deterioration and decrease in air gap length will lead to serious mechanical balancing concern. So possibility of much variation in air gap beyond the limits on both sides is not feasible. For the optimized performance of the induction motor the core material plays a significant role. Using higher magnetic flux density, reduction on a magnetizing reactance and leakage of flux can be achieved. In this thesis work the analysis of single phase induction motor has been carried out with different core materials. The four models have been simulated using Ansys Maxwell 15.0. Higher flux density selection for same machine dimensions result into huge amount of reduction in iron core losses and thereby improve the efficiency. In this paper 2% higher efficiency has been achieved with Steel_1010 as compared to the machine using conventional D23 material. Out of four models result reflected by the machine using steel_1010 and steel_1008 are found to be better.
***Keywords* -** Single-Phase induction motor, core material, Maxwell 15.0

I. Introduction

Induction motors are widely used in commercial and industrial sectors due to their robustness, simplicity and cost-effectiveness [1]. SPIM is one of the types of induction motors which have a crucial role in domestic, agricultural and industrial sectors.

With the growing demand and importance, SPIM has different merits from other motors i.e. ease of maintenance, reliable in size, easy operation and good running characteristics with low cost. A large number of fractional kW ac motors are designed to operate from single-phase supply. In general use, fractional kW motors used about 80% of the total annual production. A single-phase motor is not self-starting operates on poor power factor, lower capacity and reduced efficiency. It has pulsating air-gap field. On the basis of starting types, SPIM is classified as: (1) Split-phase (2) Shaded pole (3) Repulsion type. Split-phase is further divided into two categories as: (a) Resistor-split phase (b) Capacitor-split phase. Capacitor-split phase is categorized into three types as: (i) Capacitor-start (ii) Capacitor-Run (iii) Capacitor-start/run [2]. In this paper, capacitor-run motor has been investigated. Where no three-phase lines (commercial & agricultural) and low powered loads are present, Capacitor-run motors are mostly used in that fields. In this world, many regions have only single-phase power which means that a large quantity of single-phase motors is a primary requirement of today's market. So it is necessary to reduce the energy consumption by enhancing the performance of these motors [3].

Capacitor-run motors are widely used in domestic as well as in industrial fields. This motor has oval shaped rotating magnetic field in air-gap which results poor starting torque performance. However, it has better running performance. Currently, the optimization work focus on the starting performance improvement. There are various parameters consisting in motor design and the objectives functions and constraints for optimization are limited. So, it is impossible to take all parameters into account at same time [4].

With the increasing demand of oil and enhancement in electrical energy cost including relative development in the material technology, more attention towards the high efficient induction motors has been paid by designers. With the growing demand of Single-phase induction motor (SPIM) in industrial and commercial sectors, its design optimization becomes an immense importance. The design optimization has crucial influence in obtaining improved model of SPIM. In the past, major research work has been carried out for optimization of core material, stator winding, slot variation and slot design but optimization for core material of both stator and rotor has paid least emphasis. Core material is one of the parameter influences the performance of the SPIM.

Using Ansys Maxwell 15.0, this paper designs the optimal model in terms of the choice of core material. Four models are simulated by changing the core material of both stator and rotor. D23, M19_24G, steel_1008 and steel_1010 are used as core material in the proposed work. All models are simulated and investigated along with conventional model and the calculated results are compared to each other. Model-4 is the best optimal solution with best results out of all simulated models as well as conventional model.

II. Ansys Maxwell 15.0

Rmxprt is a common function package of the two dimensional electromagnetic field analysis software among MAXWELL, produced by Ansoft Corp. Maxwell 15.0 is professional design software of rotary motor, which can calculate the performance quickly of a variety of motor, such as induction motor, synchronous motor, electronic or mechanical commutator motor, etc. RMxprt can evaluate thousands of design projects quickly, and can optimize the pre-choice project. After optimal design, it can automatically generate a reasonable two/three-dimensional finite element analysis model according to the symmetry. The Rmxprt software provides an effective tool for engineers to evaluate and balance the project in production design process [4].

III. Proposed Model

The research work was carried out to investigate the performance of the machine under test with different core material of both stator as well as rotor core. The other parameters like size of machine, dimension of stator and rotor, slot configuration, winding material, connections etc. are kept unchanged. Four models are simulated as given in table 1.

TABLE 1: Different types of core material

Models	Core-Material
Model-1	D23
Model-2	M19_24G
Model-3	Steel_1008
Model-4	Steel_1010

IV. Motor Geometry

In this work, squirrel cage motor with two-pole, 24 stator and 18 rotor slots is used as conventional model. The overview of conventional model of the machine is shown in fig. 1 [4]. However, the core material of designed motor has been changed in the present work and all four models are simulated.

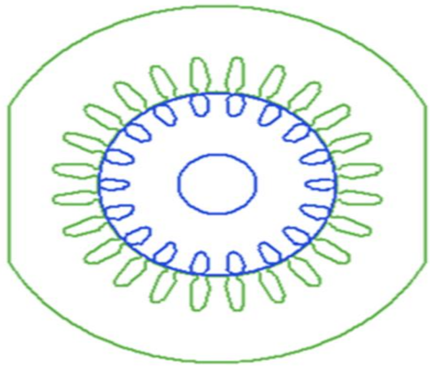

Fig. 1: Overview of designed model

In this paper, the motor performance is analyzed by changing the core material of stator and rotor but other parameters like size and number of slots, inner and outer diameters, type of slot all are kept unchanged. Four type of core material has been selected for the simulation work after analyzing their magnetic, electric and mechanical properties in which model-1 presented the conventional design.

The specification of machine used under test is given in table 2 and the design parameters for stator and rotor are shown in table 3 and table 4 respectively [4].

TABLE 2: Specification of machine under test

Parameters	Specification
Rated Power Output	250 W
Rated Voltage	220 V
Number of Poles	2
Rotor Position	Inner
Type of load	Constant
Operating Temperature	75^{o}C
Capacitor	8 µF

TABLE 3: Design parameters of Stator

Parameters	Specification
Number of stator slots	24
Outer diameter of stator	120 mm
Inner diameter of stator	60 mm
Length of stator core	45 mm
Stacking Factor of stator core	0.95
Top Tooth Width	4.01875 mm
Bottom Tooth Width	7.5842 mm

Main-Phase Wire Diameter	0.6 mm
Aux.-Phase Wire Diameter	0.53 mm
Slot Insulation Thickness	0.2 mm
Layer Insulation Thickness	0.2 mm
Limited Slot Fill Factor	75 %
Wire Resistivity	0.0217 ohm-mm^2/m
Auxiliary Wire Resistivity	217 ohm-mm^2/m

TABLE 4: Design parameters of Rotor

Parameters	Specification
Number of rotor slots	18
Outer diameter of rotor	59.4 mm
Inner diameter of rotor	20 mm
Air-gap	0.6 mm
Height of End Ring	14.8 mm
Width of End Ring	7.9 mm
Bar Resistivity	0.0434783 ohm-mm^2/m
End Ring Resistivity	0.0434783 ohm-mm^2/m
Rotor Core Length	45 mm
Rotor Stacking Factor	0.95

V. Dimensions of slot used

In this type of slot configuration, the geometric parameters of stator and rotor slots are given as table number 5and 6 respectively. The shape of the slot both stator and rotor are shown in fig. 2 and 3 respectively. The two dimensional overview obtained in Ansys Maxwell simulation is shown in fig. 4.

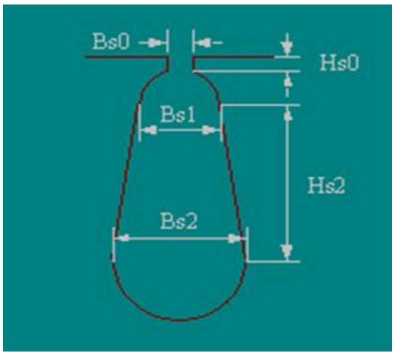

Fig. 2: Stator slot

Table 5: Geometric parameter for stator slot

Parameter	Dimension
Hs0	0.7 mm
Hs2	8 mm
Bs0	2.5 mm
Bs1	4.9 mm
Bs2	3.5 mm

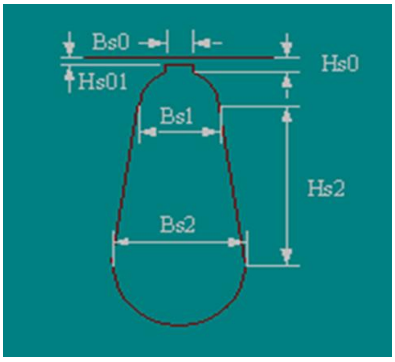

Fig. 3: Rotor slot

Table 6: Geometric parameter for rotor slot

Parameter	Dimension
Hs0	0.2 mm
Hs1	0.2 mm
Hs2	4.6 mm
Bs0	0.1 mm
Bs1	5 mm
Bs2	3 mm

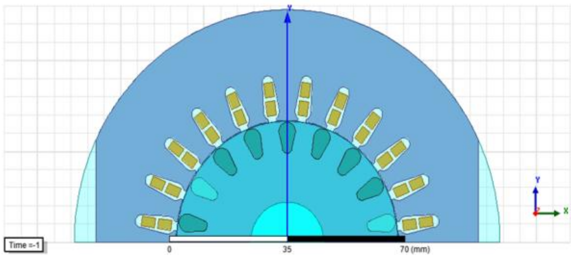

Fig. 4: Overview of stator and rotor slot

Model-1 with D23 core material consider as conventional model. Model-2 use M19_24G, Model-3 use Steel_1008 and Model-4 use Steel_1010 as core material. After simulation work, results has been calculated and comprised.

VI. Simulation Results

The investigations and analysis of single phase capacitor run induction motor has been carried out by changing the core material of both stator and rotor. The simulation results for all four models are tabulated below in table 7.

Table 7: Comparison of simulation result

Parameters	Model-1	Model-2	Model-3	Model-4
Capacitor Loss (W)	3.8285	3.8117	3.86648	3.7824
Copper Loss of Stator Winding (W)	28.413	28.288	27.358	29.12

Copper Loss of Rotor Winding (W)	21.529	20.513	22.7337	18.100
Iron-Core Loss (W)	13.719	88.679	0.000325871	0.000323095
Frictional and Windage Loss (W)	19.041	19.033	19.0531	19.012
Total Loss (W)	86.530	80.325	73.0116	70.015
Input Power (W)	336.60	330.40	322.854	320.09
Output Power (W)	250.07	250.08	249.843	250.07
Efficiency (%)	75.5	77	78	78.75
Power Factor	0.9803	0.9864	0.967	0.9984

6.1 Variation of efficiency with speed for different models

The variation of efficiency with speed is for Model-1 which uses core material as D23 is given in fig. 5 the efficiency recorded 75.5% at speed 2800 RPM.

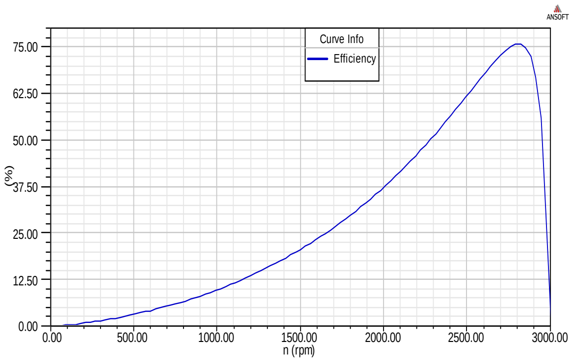

Fig. 5: Curve of efficiency of D23 design

For model-2 the variation of efficiency with speed is shown in fig. 6 the maximum efficiency recorded 77% at speed 2850 RPM.

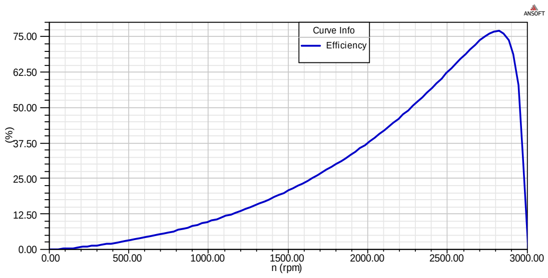

Fig. 6: Curve of efficiency of M19_24G design

Similarly the variation of efficiency with speed for using core material Steel_1010 is plotted using graphical output in the software is shown in fig. 7. In this the maximum efficiency recorded is 78% at speed 2850 RPM.

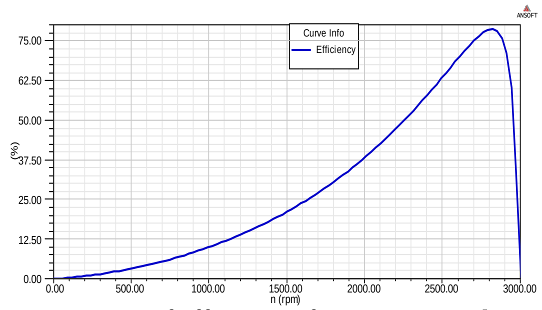

Fig. 7: Curve of efficiency of STEEL_1008 design

Variation of efficiency with speed for model-4 is graphically presented in fig. 8. The maximum efficiency recorded is 78.75% at speed 2800 RPM.

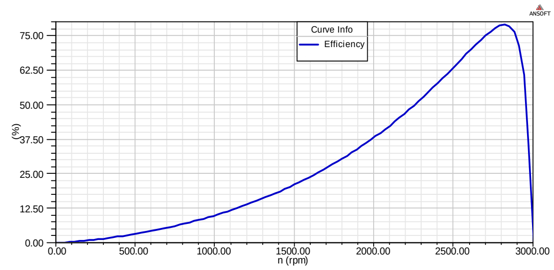

Fig. 8: Curve of efficiency of STEEL_1010 design

VII. Discussion

The analysis of the outcome of the results obtained in all the four models gives reflection of the nature of core material on the performance of machine.

The efficiency of the machine in model-1 using D23 as core material is recorded as 75.5% where as it is recorded 78.75% in the model-4 in which Steel_1010 used as core material. This improvement in the efficiency is because of the better magnetic properties, higher operating flux- density and decrease in leakage flux of steel_1010 in comparison to other materials. The efficiency bar graph of all four models is shown in fig. 9.

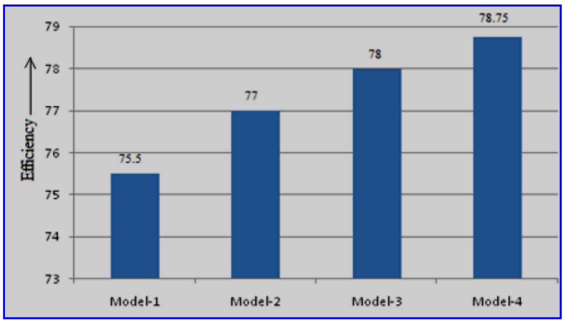

Fig. 9: Bar graph of efficiency

The rotor reactance offered in the model-4 is 12.37 ohm which is minimum in all the four models which reflects that the rotor reactance is directly affected by magnetic properties of the core material of rotor core. This will reduce the percentage leakage reactance of flux and therefore improve the efficiency. Similarly the magnetic reactance recorded to be 281.56 ohm in the model-4 using steel_1010 is minimum as compared to other models. This affects the magnetizing component of current as well as the power factor of the machine in the results the maximum improvement in the power factor recorded as 0.998 in the model-4, the best one in all the four models.

The power factor bar graph plotted for all the four models shown in fig. 10. The poor power factor of model-3 is because of the improper orientation of the rolled steel material. The highest power factor recorded in the model-4 which uses steel_1010 has been recorded. This achievement in the power factor is on the ground of improved magnetic properties.

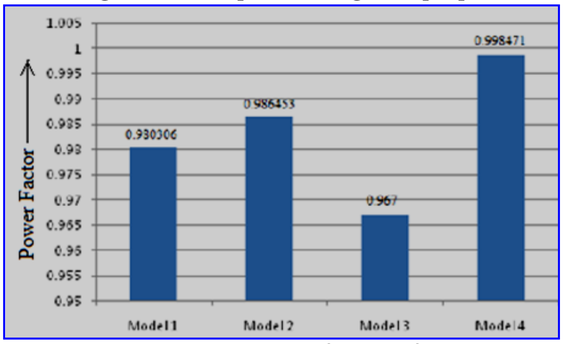

Fig. 10: Bar graph of power factor

This improvement in power factor has reduced the overall running current proportionally. The running current in the model-4 is 1.45 ampere which is lowest level as compared to 1.56 ampere in the model-1 the highest one.

The bar graph in fig. 11 presented stator line current drawn by the machine in each simulation model.

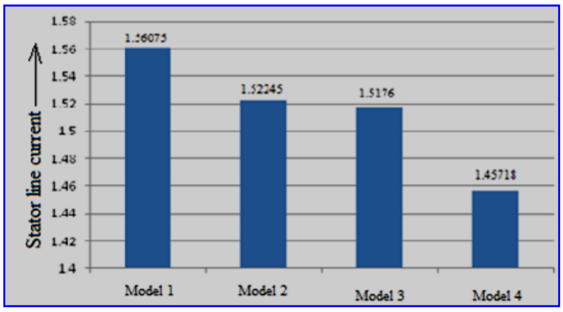

Fig. 11: Bar graph of Stator line current

This reduction in running current reduces copper loss and maximum temperature level and is better for insulation co-ordination of stator winding as well as rotor winding. Though may the overload capacity is not much more affected by the core material but there is an overall improvement in the overload capacity of the machine as compared to base model it is approximately recorded up to 200% in all the models.

The rotor leakage reactance is the function of magnetic properties of core material with the upgrading of the magnetic properties of steel_1010 reduction in leakage reactance as shown in bar graph fig. 12.

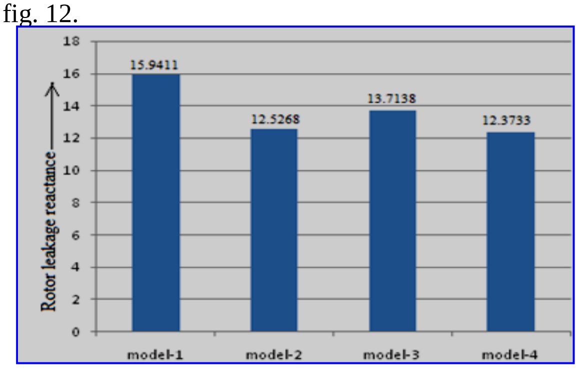

Fig. 12: Bar graph of rotor leakage reactance

The fact of the core material on the starting torque has also been observed. In the base model the starting torque developed is 0.379 N/M In the model-1 develops starting torque 0.485 N/M. In the model-3 the starting torque developed is recorded 0.480 N/M and that in model-4 it is highest 0.488N/M. This improvement in the starting torque of the machine with the steel_1010 is because of the magnetic properties of the material. For the same starting torque developed the magnetic flux density required in the model-4 is minimum or for the same torque, same flux density proportionally core size is reduced.

The model-4 is the optimized model out of the four models investigated in the paper.

VIII. Conclusion

Selection of core material of the motor significantly affects the performance of motor. The flux linkage and leakage both are directly concerned with nature of core material. Today, D23 is used as core material. Working flux density of D23 is 1.60 tesla and maximum flux density is 1.64. The efficiency of the material which depends upon hysteresis and eddy current loss partly is affected by core material. In the simulation work it is observed that the maximum efficiency of D23 is 75.5% and total losses are 86.53 watt. The efficiency with steel_1010 is approx. 3% more than D23. This result is because of reduced iron core losses. Further thermal conductivity of steel_1010 is high and rise of temperature problem also shorted to some extent. Due to steel_1010 is used as core material over fluxing is avoided in the core. The mechanical strength of steel_1010 is higher leads to higher speed.

The simulation work reflects the influence of magnetic properties of the core material on the reactance which in turn affects the power factor and input current and up to certain extent harmonics level. The steel_1010 offered the least reactance and better results further running current in the model is 1.45 ampere which is less in all the four models. This reduction in running current reduces copper loss and better for insulation co-ordination of stator winding as well as rotor winding.

The overall enhancement in the performance of fourth model is on account of the better magnetic properties of the core material which therefore justifies the work that core material plays a significant role in the optimization of induction machine.

References

[1] G. Lee et al. *"Optimal Shape Design of Rotor Slot in Squirrel-Cage Induction Motor Considering Torque-Characteristics", IEEE Trans. on magnetics,* Vol. 49, No. 5, 2013, pp. 2197-2200.

[2] S. Sobhani et al. "*Optimize efficiency and torque in the single-phase induction motor by adju*sting the design parameters", *International conference on Environment and Electrical Engineering (EEEIC*-2013), pp. 237-241.

[3] M.S. Alshamasin, "*Optimization of the Performance of Single-Phase Capacitor-Run Induction Motor*" *American-Journal of Applied Sciences*, 2009, pp. 745-751.

[4] Z. Rui et al. "*Optimal Design of Single-Phase Induction Motor Based on MAXWELL-2D Rmxprt*", *International conference on Electrical machines and Systems (ICEMS*-2010), pp. 1367-1370.

[5] Claudia A. da Silva et al. "*Analysis of Single-Phase Induction Motors with Centrifuged Rotors*", *International Electric Machines & Drives Conference (IEMDC*-2013), pp. 1305-1309.

[6] Y. Yanawati et al. "*Efficiency Increment of 0.5 hp Induction Motor by Using Different Thickness of Rotor Lamination Steel Sheet via FEM" 5th International Power Engineering and Optimization Conference*, Malaysia, 2011, pp. 188-192.

[7] H. Yoon and C. S. Koh "*Influence of Vector Hysteretic Property of Non- Oriented Silicon Steel Sheet on Three-Phase Induction Motor Model*" pp. 1-2.

[8] G.C. Paap "*The analysis of 3-phase squirrel-cage induction motors including space harmonics and mutual slotting in transient and steady state*" IEEE Transactions on Energy Conversion, Vol. 6, No. 1, March 1991, pp 69-82.

[9] K.J. Park et al. "*Optimal Design of Rotor Slot of Three-Phase Induction Motor with Die-Cast Copper Rotor Cage*", *International conference on Electrical machines and Systems (ICEMS*-2009), pp. 61-63.

[10] S. Salon, D. Burow, M. De Bortoli, C. Slavik "*Effects of Slot Closure and Magnetic Saturation on Induction Machine Behavior" IEEE transactions on magnetics*, Vol. 30, No. 5, 1994, pp. 3697-3700.