International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Design and Analysis of PMSM Motor in Skewing Process

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Abstract-

The remarkable growth in automobile and heavy industry have created huge demand for fuel-efficient and cost- effective drive system. The different types of motor are currently used in automobiles as a drive to eliminate the fossil fuelled internal combustion. Currently non-skewed rotor electric motors are used. Cogging torque and torque ripple affect the performance of electric motors. The skewing process in rotor will reduce the cogging torque and torque ripple to obtain the greater performance in PMSM motor. This process helps in reducing the stator, rotor friction to obtain greater efficiency. In this context, an objective was set to investigate the performance of the Permanent Magnet Synchronous Motor (PMSM) by skewing the rotor at different angles. The Permanent Magnet Synchronous motor are expected to find application in electric vehicles. The performance of PMSM motor was analysed in the current project and results are presented for four skew-angles such as 10^0, 15^o, 20^0, 25^o.

KEYWORDS: Skewing Process, Cogging Torque, reduction of vibration, SolidWorks, Ansys Workbench, Ansys MotorCad.

INTRODUCTION

The remarkable growth in commercial Automobile and heavy industry such asLocomotive manufacturing, Aerospace, Machine tools industries has recently endeavored to create more fuel-efficient, cost-effective drive system. The different types of motor are currently used in automobile industries to eliminate the fossil fueled internal combustion. Dual Power (hybrid) and fully electrified vehicles on the road consumer traction into more efficient and environmentally sensitive Propulsion system to control the automobile emission. The future generation is going to establish the electrified vehicle system to control the emission. The several type of motor application has been proposed for the Permanent Magnet Synchronous Motor (PMSM) solution because of the possibilities of higher thrust, less complicated design and less maintenance. In order to improve the design and performance analysis of skewing process of PMSM motor the software simulation and multi-physical calculations of Permanent Magnet Synchronous Motor has approached. The study based on Permanent Magnet Synchronous Motor possess inherent cogging torque that always induce vibration, acoustics noise, possible resonance, speed ripple and position inaccuracy to the motor performance particularly at light load and low speed.

METHODOLOGY

The Design and Analysis of PMSM motor has followed the steps and process flow as shown in the Figure 1.1

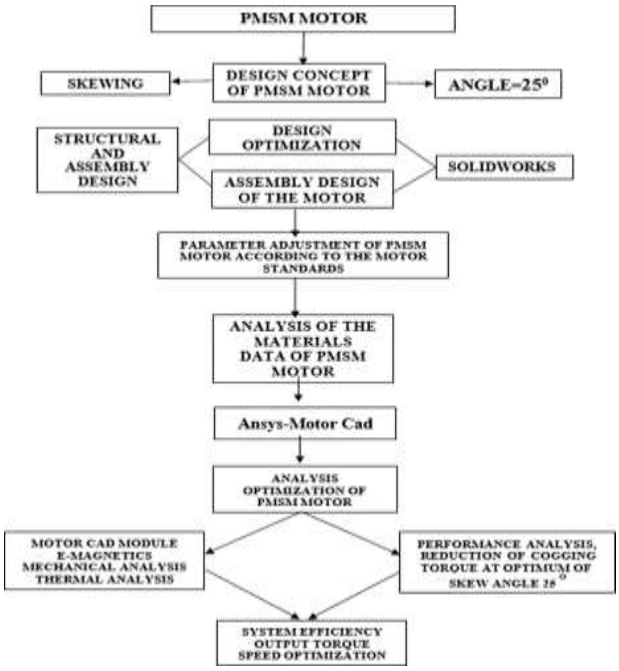

Figure 1.1 Methodology of Design and Analysis of PMSM motor COMPUTATIONAL MODEL OF PMSM MOTOR

The computational PMSM 3D motor model has simulated with the motor cad simulation software to find out the motor performance and reduction of cogging torque in motor. The computational model of PMSM motor show in the figure 1.2

Figure 1.2 Computational PMSM motor 3D-model

1.1 DESIGN PHASE CONFIGURATION

1.1.1 ROTOR SKEWING PROCESS

The rotor skewing technique of the Permanent Magnet Synchronous Motor has shown in the Fig 1.3

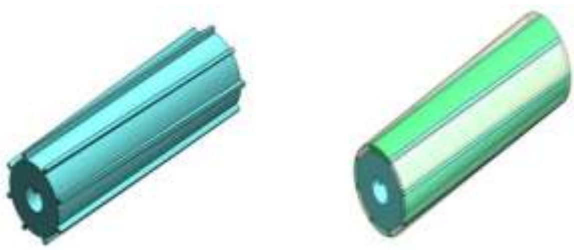

Fig. 1.3 Rotor skewing (Ø = 250)

The rotor of the PMSM motor is parallelly skewed through angle of 250 thus the optimal rotor skew angle results in the optimal reduction of cogging torque for the PMSM motor resulting in reduced vibration. The main purpose of skewing is to reduce the magnetic logging between the stator and the rotor. Rotor conductors are skewed because of the following reasons: Primarily to prevent the Cogging Phenomenon. It is a phenomenon in which, if the rotor conductors are straight, there are chances of magnetic locking or strong coupling between Rotor & Stator. Table 1.1

Table 1.1 Rotor skewing

ROTOR SKEWING PARAMETER	
SKEWING ANGLE	25
NO. OF. POLES	4 No's
SKEWING TYPE	PARALLEL SKEW

1.1.2 MOTOR SPECIFICATIONAL DESIGN PARAMETERS

The specification design shows the parameter that has been used in the construction model of the PMSM motor to obtain more sufficient result. Based on the design optimization the motor has been modelled by the parameters shown in the Table 1.2

Table 1.2 Specification of motor material

MOTOR MATERIAL SPECIFICATION	
MOTOR TYPE	SURFACE PERMANENT MAGNET
POWER CAPACITY	5KW, 48 VOLT
NO. OF. PHASE	3 PHASES
COPPER WINDING	CW004A
COPPER WINDING THICKNESS	0.6706 mm (AWG 22.5)
ROTOR	AISI 1010
STATOR	AISI 1010
NO.OF. SLOTS	12 No's
NO. OF. NdFeB MAGNET	8 No's

By using the parameters thus, the Permanent magnet synchronous motors for vehicles have the characteristics of light weight, high efficiency, simple structure, stable operation have been achieved by preventing the losses such as cogging torque, vibration and thermal loses which affect the performance of the motor.

1.1.3 DESIGN CONSTRUCTION OF PMSM MOTOR

The sectional view of the Permanent Magnet Synchronous Motor has shown in the Fig.1.2

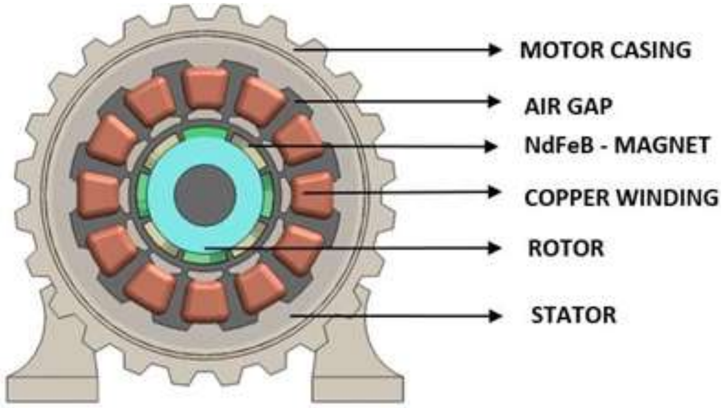

Figure 1.4 Sectional view of PMSM motor

The approach starts with basic motor geometrical constraints of the PMSM motor to optimize the dynamic efficiency. By the standard motor parameters, the design construction of the PMSM motor has optimized.

1.1.4 STRUCTURAL DESIGN OF PMSM MOTOR

The Permanent Magnet Synchronous Motors are one of the types of AC synchronous motor or otherwise it is also known as Mid-drive motor. The structural view of PMSM Motor is shown in Fig. 1.5

Fig. 1.5 Structural Design of PMSM

The structural design of the PMSM motor consist of 8-poles of magnet which has been skewed in the rotor at the angle of 250 to optimize the good dynamic performance in skewing process. The permanent magnet synchronous motors are very efficient, brushless, very fast, safe, and give high dynamic performance when compared to the conventional motors. It produces smooth torque, low noise and mainly used for high- speed applications like robotics and other automobile application.

1.2 MAGNET MATERIAL

1.2.1 SELECTION OF MAGNETS - NEODYMIUM

The Neodymium magnet for the Permanent Magnet Synchronous Motor has shown in the Figure 1.6

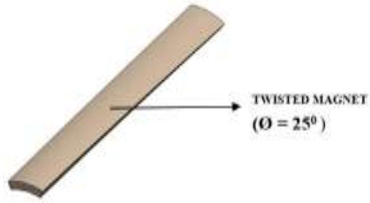

Figure 1.6 Permanent Magnet Neodymium

1.2.2 THERMAL CHARACTERSTICS OF (GRADE - N35)

The N35 grade Neodymium focuses on major thermal properties, namely, thermal conductivity, heat capacity, and specific heat. It describes the important properties such as relative permeability (Pr), temperature coefficient (Ct), density of magnet(µd), thermal conductivity (K), which possess the most pronounced effect on the performance of the PMSM system, its efficiency, and selection of main design parameters. Thus, the N35 -neodymium magnet helps to produce more efficient result in motor application. The thermal parameter of neodymium is shown in the Table 1.3

Table 1.3 Thermal Characteristics

S.NO	PARAMETER	VALUE
MATERIAL TYPE – ISOTROPIC GRADE TYPE		
1	RELATIVE PERMEABILITY	1.05
2	TEMPERATURE CO-EFFICIENT	0.12^0C
3	MAGNET DENSITY	7500 Kg/m^3
4	THERMAL CONDUCTIVITY	K= 7.7 w/mk
5	CURIE TEMPERATURE	350^0C

Comparing to other grade of Neodymium magnet the N35 grade has optimized as high grade and efficient torque producing magnets in motor applications. It reduces the thermal losses in magnet and stator pole interaction and reduce the friction lose in the stator pole of the magnet. Thus, the N35 -neodymium magnet helps to produce more efficient result in motor application.

1.3 PMSM MOTOR MODEL SIMULATION

1.3.1 PERFORMANCE SIMULATION PHASE

The simulation phase of the PMSM motor has been carried out by using ANSYS MotorCad V15 simulation. By the MotorCad simulation the E-magnetics simulation and mechanical simulation of the motor which produce the mechanical data and provide the stable result in the motor. The computation PMSM motor model consists of Performance analysis, thermal analysis produce the output value of the motor such as maximum possible torque, shaft torque, toque per rotor volume, reduction of cogging torque, maximum speed of motor, total loss produced in motor, improvement in speed of motor in 250 skewing angles improved in On-load condition has optimized. By this parameter the field simulation process of the PMSM motor and the computational calculation has been analysed by the output parameter to produce the more stable result in PMSM skewing process. The performance analysis process flow given in Figure 1.7

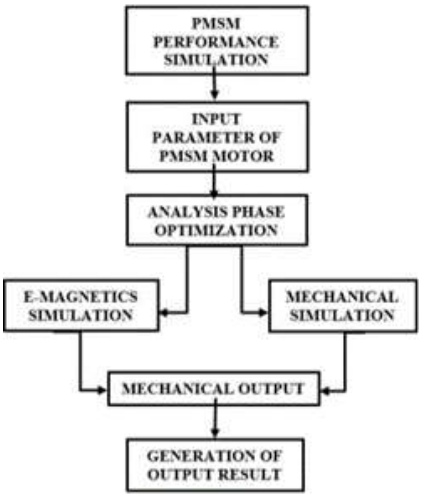

Figure 1.7 PERFOMANCE ANALYSIS PROCESS FLOW

1.3.2 GEOMETRICAL CONSTRAINS OF MOTOR SIMULATION

The geometry of the simulation model consists of three phase such as radial, axial and 3D geometrical constrains in Ansys MotorCad. In axial segment of PMSM simulation model the parameter such as slot type, rotor type, stator duct and rotor duct has constructed to build a stable structure. In radial segment the shaft type and radial duct has been constructed in the simulation. Finally, by the furnished constrain data the 3D model of the PMSM motor has been constructed to produce the good performance in PMSM motor drive. The cross-sectional view is shown in the Figure1.8

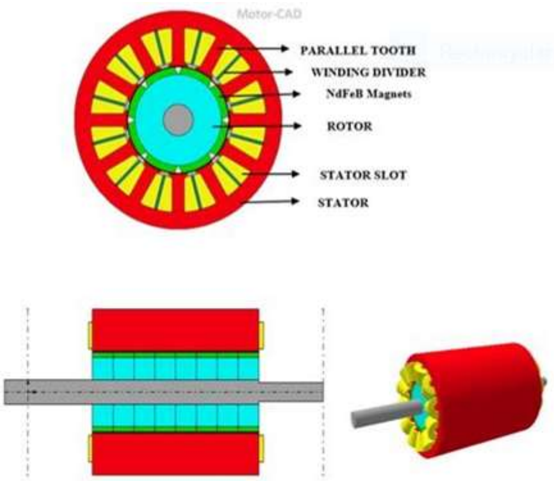

Figure 1.8 Radial, Axial and 3d View

1.3.3 WINDING DESIGN STRUCTURE DATA

The winding design structure of the PMSM motor has demonstrated to achieve the desired result as shown in the figure 1.9

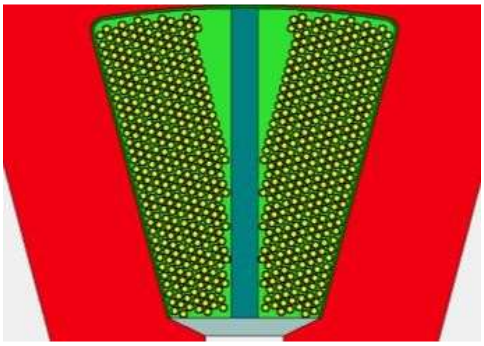

Figure 1.9Winding design structure

The winding design structure of the motor has been demonstrated with the specified standard constrain which produce less losses in winding make the motor to provide more sufficient output result. The winging data such as winding and wire gauge used for winding has built to get more sufficient result.

1.4 PERFORMANCE SIMULATION

1.4.1 E-MAGNETICS FIELD SIMULATION

The E-magnetics field simulation is the process in optimizing the valid input data in skewing process of 250 in rotor skewing process. The main way to improve the efficiency by constructing sufficient winding pattern which provide stable output torque in the motor. Thus, the output torque and reduction of the loss factors such reduction of cogging torque and loss in motor in On-load factor which produce more precise efficiency which will give the stable e-magnetics mechanical output result of the motor. Speed and torque constrain according to winding parameter is shown in the Table 1.4

Table 1.4 The speed and torque according to winding constrains

TORQUE (N.m)	1	2	3	4	5	6	7	8	9	10	11	12	13
SPEED (Rpm)	0	500	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000

1.4.2 COMPUTATIONAL MECHANICAL FIELD SIMULATION

The field simulation of the PMSM motor which produce the sufficient result in such as torque, maximum possible torque, shaft torque, toque per rotor volume, reduction of cogging torque, maximum speed of motor, total loss produced in motor, improvement in speed of motor in 25^0 skewing angle. The field simulation result shown in table 1.5

Table 1.5 Field simulation output

COMPUTATIONAL MECHANICAL FIELD SIMULATION OUTPUT	
INPUT POWER	5000 W
OUTPUT POWER	4616 W
TORQUE	13.86 Nm
REDUCTION OF COGGING TORQUE IN 25^0 SKEWING	8.47 Nm
TORQUE PER ROTOR VOLUME	15.43 KNm/m^3
INPUT SPEED	3500 Rpm
OUTPUT SPEED	3444.9 Rpm
TOTAL LOSS	400.75 W
MOTOR EFFICIENCY	92%

1.4.3 MECHANICAL STRESS ANALYSIS OF ROTOR

The continuous running of the motor cause the stress in rotor region because of the continuous rotating force of the motor shaft. Due to the continuous interaction of the motor shaft and rotor there will be some of the friction loss has been produced in the interaction of the shaft and rotor region. The stress produced in the rotor area has shown in the figure 1.10

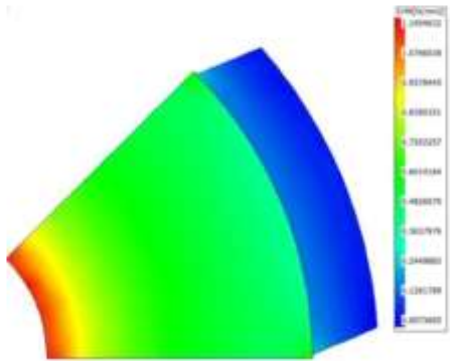

Figure 1.10 Rotor stress optimization

In high speed PMSM motor drive the evaluation of the mechanical stress is in the rotor is one of the crucial part in the design.

The rotor stress produced in the motor has produce the drop in speed of the motor at the on-load condion. The maximum stress in the rotor can exist at 10 N/mm2 it tends the motor drop in the performance. Since the stress produced in the rotor of the PMSM motor at on-load condition it exists 1.195 N/mm2 of stress occurs in the rotor. it shows the reduction of the stree in the motor at 90% has stabbly optimized. Thus the minimization of the rotor stress not affect the motors performance. Since the minimum existence in the rotor stress it tends to obtain the greater efficiency in the skewing angle of the rotor.

1.4.3 ANALYTICAL CALCULATION OF MOTOR

Based on the input data in the Table 1.8 the analytical multi-physical calculation has been calculated to get the approximate output value. The input values of mechanical field simulation of PMSM motor

Input power (Ip) = 5000 Watts

Maximum speed at On-load condition (ONm) =3500 Rpm

The output values at On-load simulation at skewing angle 250 of rotor skewing

Whereas,

Based on the Input data the multi-physical calculation for the total production of power, torque, speed and vibration of motor has been estimated.

The general power equation of the motor has been used to estimate the τm of motor

$P_{in} = \frac{2\pi NT}{60}$ …. Eq. 1.1

Here

P_m= 5000 Watts ; Nm = 3500 Rpm

P_{in}- Total input power of motor

N_{in} – Total input speed of motor

τm – Torque of DC motor

$5000 = \frac{2\pi x\, 3500 x \tau m}{6}$

The output torque of the motor,

τ_m = 13.84 N.m

By using the output torque of the motor is determination of the output speed has been estimated by

$N = \frac{P\ x\ 60}{2\pi\ x \tau m}$ Rpm ……(eq.1.2)

$N = \frac{5000 \text{ x } 60}{2\pi \text{ x}13.84}$

The output speed of motor, N = 3445 Rpm

The total output power produced in the PMSM motor has been estimated

$P0$

In high speed PMSM motor drive the evaluation of the mechanical stress is in the rotor is one of the crucial part in the design.

$Po = \frac{2\pi N0r0}{60}$

$Po = \frac{2\pi x3445x13.84}{60}$

Po = 4615 Watts

The system efficiency of the PMSM motor has been optimized by the above output parameter.

Po

$\eta = \frac{P0}{Pin}$ …..…(eq.1.4)

$\eta = \frac{4615}{5000}$

η = 0.923

Thus, the performance of the PMSM motor in 25^0 skewing has been optimized as 92%.

1.5 THERMAL ANALYSIS OF PMSM MOTOR

1.5.1 THERMAL SIMULATION

The thermal model of the PMSM motor shows the temperature difference of the complete model which is divided into thermal analysis of motor body and heat transfer analysis of straight-line airflow fins arrangement of motor casing measurements are then made for various operating conditions with different loads and speeds. By adjusting losses in the thermal model so that predicted temperatures match the measured results for various operating conditions thus estimation of different loss in motor components has been estimated. Thus, the thermal mapping of the PMSM motor shows the temperature in complete model and the losses produced due to the motors change in temperature has been optimized. The heat transfer analysis of the motor fins and how far the dissipation by using the straight air flow fin type has been optimized by using Ansys. Thermal model shown in Figure 1.11

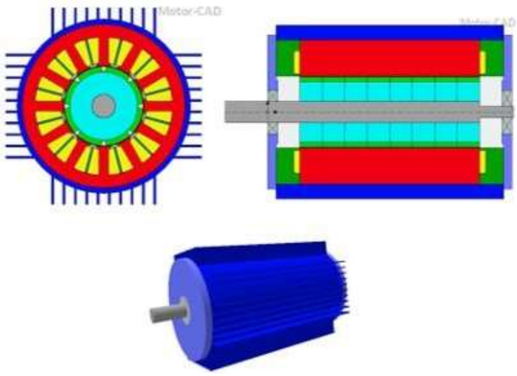

Figure 1.11 radial, axial and 3d thermal model of PMSM motor

1.5.3 TEMPERATURE MAPPING OF PMSM MOTOR

The temperature produce in the PMSM motor at the critical On-Load condition for the different parts of the motor has been estimated in radial and axial temperature mapping has shown in the Figure 1.12

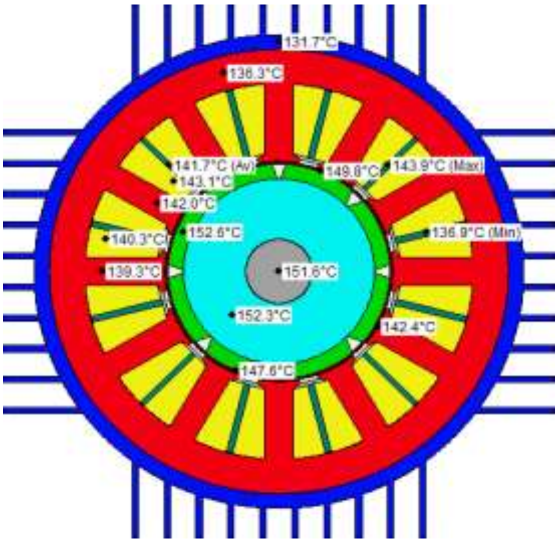

Figure 1.12 Radial temperature mapping

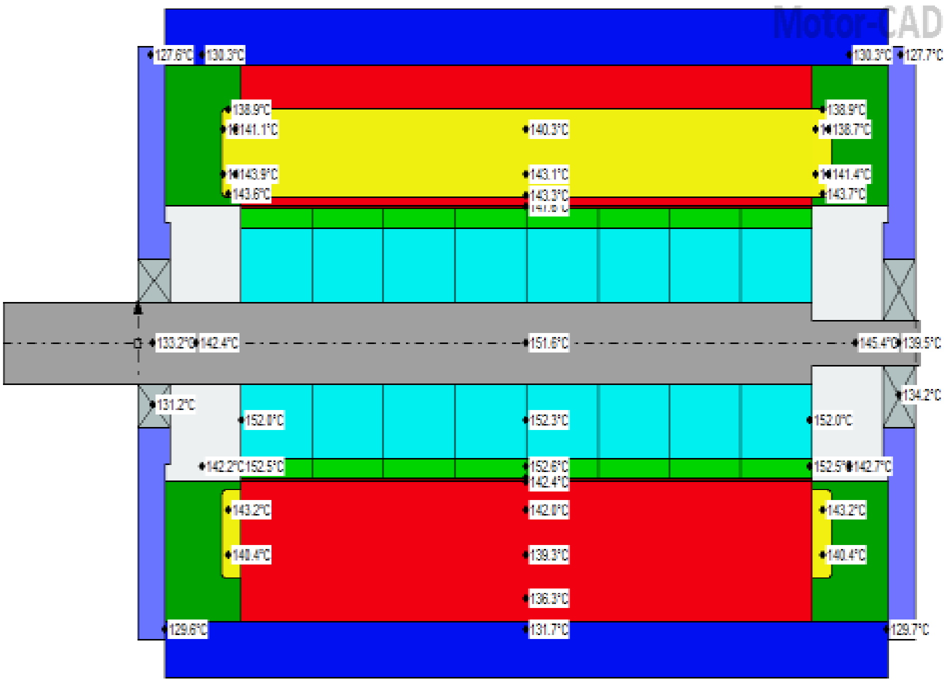

Figure 1.13 Radial temperature mapping

The temperature mapping in the PMSM motor drive has been optimized at the on-load condition of the motor in the steady state condition. Thus the temperature mapping in the motor shows the the change temperature of the PMSM motor drive specified parts of the motor to identify the inconsistence change and implement the change in the motor has identified. It produce the temperature within the estimated motor cut-off temperature iteration. It is the method of validating and qualifying the motor performane at optimum skewing method. The optimization of the thermal mapping output has been optimized and the result of the temperature has been outputed and shown in the Table 1.6

Table 1.6 Temperature Mapping

Temperature	Value [°C]
T [Ambient]	40
Maximum cut-off. Temp	350^0C
T [Housing - Active]	250.72^0C
T [Stator Lam (Back Iron)]	136.33
T [Stator Surface]	142.4
T [Rotor Surface]	147.6
T [Airgap Banding]	149.81
T [Rotor Lamination]	152.28
T [Shaft - Center]	151.63
T [Magnet]	152.56
T [Winding (A) Maximum]	143.56
T [Winding (A) Average]	141.69
T [Winding (A) Minimum]	136.9
T [Magnet Maximum]	152.56
T [Magnet Average]	152.56
T [Winding Maximum]	143.93
T [Winding Average]	141.71
T [Winding Minimum]	136.9
T [End Winding Average]	141.79
T [Model Maximum]	152.56
T [Model Minimum]	127.64

The thermal mapping of the PMSM motor has divided in 8 nodal state iteration. Thus the model provide the output value which is very consistent value compared to the maximum cut-off temperature of the motor 350^0C. The motor has obtained the overall temperature as 155^0C it results in the reduction of the thermal losses produced in the motor at the steady state condition.

1.6 HEAT TRANSFER ANALYSIS OF MOTOR HOUSING

1.6.1 MOTOR HOUSING TEMPERATURE OPTIMIZATION

The iteration of the heat transfer analysis has done by Ansys thermal steady state analysis at initial motor temperature value of motor housing at 30^0C. The temperature change in the motor cause the maximum heat dissipation in the motor housing it has leads the motor to reduce the efficiency. Thus, the maximum temperature change in the housing 250^0 C has shown in the Figure 1.14

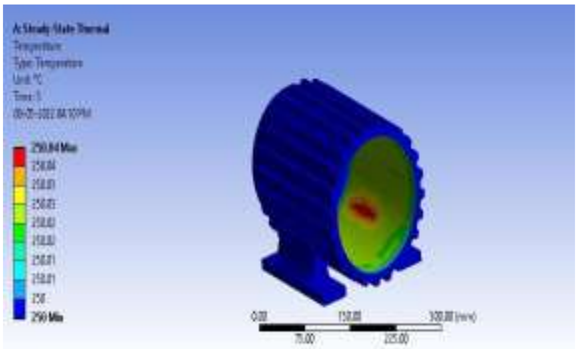

Figure 1.14 Temperature change motor housing

1.6.2 TOTAL HEAT FLUX IN MOTOR HOUSING

The heat flux distribution in the motor housing in the straight-line airflow fins. The heat flux in the motor housing of aluminum alloy has obtained the maximum value 0.000817 W/mm^2 in the motor housing exists the quick heat dissipation due straight line air flow fins arrangement. The total heat flux shown in the Figure 1.15

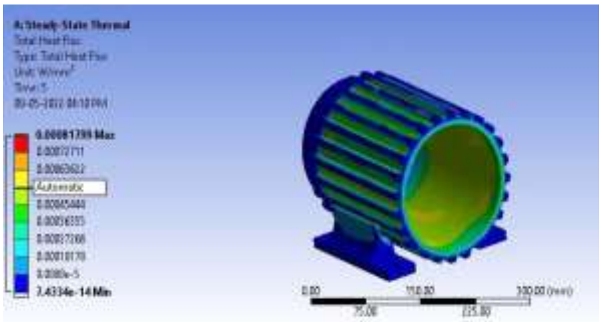

Figure 1.15 Total heat flux in motor casing

1.7 VIBRATIONAL SIMULATION MOTOR SHAFT

Shaft vibration imposes additional load on bearings and coupling components. For motor ranges from 4–10 KW size range, there must be more vibration due to the cogging torque. The present work shows the reduction of the cogging torque exist slightly with relation of the amount of torque produced. The vibration analysis of the PMSM motor shaft has shown in the Figure 1.16

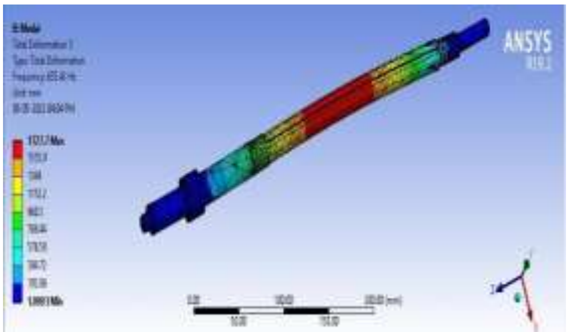

Figure 1.16Vibration analysis of motor shaft

1.8 LOSSES IN PMSM MOTOR

The losses produced in the motor has optimized in the two different stages such as fixed losses – independent of the motor load and variable losses – variable on the load. The fixed losses consist of the core losses, frictional and winding losses. Magnetic losses consist of stator loss in motor. The mechanical losses produced due to the rotating parts called mechanical losses. These losses change accordingly to the speed of the motor. Thus the maximum losses occurs in the Table 1.7

1.7 Losses in PMSM motor

Variable	Value	Units
Loss [Armature Copper]	45.25	Watts
Loss [Armature Copper] (Active)	37.51	Watts
Loss [Armature Copper] (EWdg Front)	3.87	Watts
Loss [Armature Copper] (EWdg Rear)	3.87	Watts
Loss [Stator Back Iron]	95.58	Watts
Loss [Stator Tooth]	199.4	Watts
Loss [Magnet]	57.89	Watts
Loss [Rotor Back Iron]	2.635	Watts
Loss [Rotor Banding]	0	Watts
Loss [Windage]	0	Watts
Loss [Friction - F Bearing]	0	Watts
Loss [Friction - R Bearing]	0	Watts
Loss [Total]	400.745	Watts

Thus, the total losses produced in the losses has optimized for the motor limit range of 5kW there is the maximum loss produced in the PMSM motor has achieved as 400.75 watts which has not produce the impact on the motor performance.

1.9 OVERALL OUTPUT DIFFERENT UNIQUE SKEW ANGLE

COMPARISION OF DIFFERNENT SKEWING ANGLE OPTIMIZATION IN PMSM MOTOR					
1	**SKEWING ANGLE**	10^0	15^0	20^0	**25^0**
2	**STRANDS**	6No's	6No's	6No's	**6No's**
3	**TURNS**	72No's	72No's	72No's	**72No's**
4	**INPUT POWER**	5000 Watts	5000 Watts	5000 Watts	**5000 Watts**
5	**OUTPUT POWER**	2180 Watts	3250 Watts	4020 Watts	**4616 watts**
6	**SPEED**	2681 Rpm	3150 Rpm	3350 Rpm	**3445 Rpm**
7	**TORQUE**	7.65 N.m	5.45 N.m	8 .15 N.m	**13.86 N.m**
8	**COGGING TORQUE**	3.23 N.m	4.85 N.m	6.2 N.m	**8.47 N.m**
9	**SYSTEM EFFICIENCY**	43%	65%	80%	**92%**
10	**TOTAL LOSS**	57%	35%	20%	**8%**

CONCLUSION

The optimization of the design and analysis of Permanent Magnet Synchronous Motor (PMSM) in skewing process the motor model has designed by using SolidWorks and the motor simulation process such as Performance, Thermal and mechanical analysis has been done by using Ansys and Ansys MotorCad simulation software. Thus, the project work optimization in skewing process shows the output performance of the motor such as speed, torque and output power obtained in the optimum skewing angle of the motor capacity of 48V and 5kW power. The motor has obtained huge power output with some losses. The output parameter value of the 5kW PMSM motor drive obtained the value of (Torque rm =

13.86 N.m , Output speed Nm = 3444.9 Rpm and total power output Po = 4616 W were input power input power range of Pi = 5000 Watts) in optimum skewing process. There is the loss produced in the skewing process of motor (Lm =400.75 W) is produced in the motor. Since the factor affecting the motors, performance is the cogging factor rc = 8.47 N.m has reduced in the motor. The overall efficiency of the motor is improved as 92%.

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