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Design and performance analysis of Interior Permanent Magnet Motor (IPMSM) using RMXPRT – ANSYS MAXWELL

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ABSTRACT

This During manufacturing of any motor optimum design and performance check are vital. In this regard right selection of material and efficient design improves the performance of electric motor. For this very purpose Ansys RMxprt is much suited software for accurate and cost effective design of various electrical machines. This article explains about application of RMxprt for machine design and also presents the model and analysis of IPMSM. Further this paper highlights explains about the simulated results along with 2D and 3D mapping of various aspects of an IPMSM
Keywords— *IPMSM, Ansys Maxwell, Motor design, Permanent Magnet, RMxprt design*

1. INTRODUCTION

Reliability is an important factor for any machine used in industries. Interior Permanent Magnet Synchronous Motor (IPMSM) drives are widely used in EV applications and traction. Pulse width modulated (PWM) inverters are among the most used power electronic circuits in practical applications. These inverters are capable of producing ac voltages of variable magnitude as well as variable frequency.

In EV application 80% of the motors used are IPMSM hence PWM inverter fed IPMSM is taken for design and analysis Interior Permanent Magnet Synchronous Motor (IPMSM).

When a 3Ø voltage is applied to the IPMSM, Inductance at the rotor coil produces RMF (Rotating Magnetic field) in the motor. RMF is produced inside the motor, when stator is supplied three phase voltage. When the frequency is increases at the supplied side, The speed of RMF also rise when a 3Ø AC voltage is feeding to an IPMSM, which has permanent magnets in its rotor, attractive or repulsive force rises between the permanent magnets in the rotor and the RMF generated by the 3Ø AC voltage. When this happens, the rotor of the motor rotates in synchronization with the travelling speed of the RMF.

The motor will undergo stresses, damage and faults during various stages from manufacturing till end user application so these fault, damage, stress could affect the reliability and cause serious equipment damage so important to design and analysis using Rmxprt and FEM respectively
Characteristics of IPMSM:
a) High Efficiency
b) Compact size
c) Enhanced speed control with accuracy

For analysis purpose 0.5 KW, 220 V, 1800 rpm and 60 HZ IPMSM is taken and inverter type is 3 phase sinusoidal PWM inverter

2. RMXPERT

An RMxprt software expedite the design and development process of rotating electric machines. The easy to use machine users to create motor design, assign materials, running strategies and drive circuit to calculate machine performance, make initial sizing decisions. RMxprt can then automatically setup a complete Maxwell 3D or 2D project including geometry, motion and mechanical set-up, material properties, core loss, winding and source setup including the drive circuit for rigorous electromagnetic analysis to refine parameters calculated by RMxprt and enhance accuracy.

Ansys RMxprt is the template based electrical machine design tool to provide fast analytical calculations of machine performance to allow engineers to zero error in an appropriate design. We can select many motor type from Maxwell RMxprt to creates custom design quickly using our design specifications and its create ready to solve 2D and 3D models for detailed transient finite element calculations in Ansys Maxwell

Ansys Maxwell simulates 2D and 3D electromagnetic and electro mechanical devices using most advanced modelling technology. It uses an automated finite element method to solve static frequency domain and time varying electromagnetic and electric fields for motor. It is most advanced modelling methods for laminations, non linear materials, temperature dependent, demagnetization . hysteresis, magnetization process and core loss.

Ansys Maxwell is developed in most advanced modelling technology so it can predict motors electromagnetic behaviour accurately. This tool produces efficiency maps, torque and speed curves etc.

Key Benefits are
(a) Fast design
(b) Motor performance data such as air gap flux density, winding voltage, winding current, torque, speed, efficiency can be calculated quickly.
(c) Performance of the motor can be verified with already produced motor
(d) Powerful scripting
(e) E. Can create IPMSM Maxwell 2D and IPMSM Maxwell 3D geometry from designed RMxprt model
(f) Produces readymade datasheets for a particular motor

3. DESIGN DETAILS

3.1 IPMSM Machine

Table 1. shows analysis setup for motor design. Based on these given general input parameters RMxprt will solve for other parameters.

TABLE 1. GENERAL INPUT PARAMETERS OF IPMSM

Sl.No	Parameter	Value
1.	Rated Output Power (KW)	0.5
2.	Rated Voltage (V)	220
3.	Rated Speed (rpm)	1800
4.	Operating Temperature (°C)	75

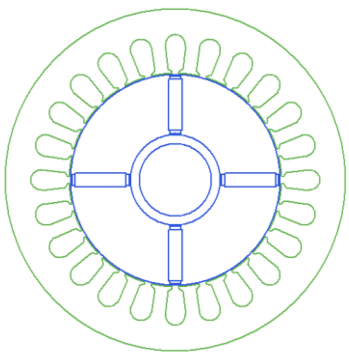

FIG.1 IPMSM - RMXPRT MACHINE DESIGN

3.2 Stator Core

TABLE 2. STATOR DIMENSIONS

Sl. No	Parameter	Value
1.	Number of Poles	4
2.	Number of Stator Slots	24
3.	Outer Diameter of Stator (mm)	120
4.	Inner Diameter of Stator (mm)	75
5.	Length of Stator Core (mm)	65
6.	Stacking Factor of Stator Core	0.95
7.	Steel Type of Stator	M19_24G

The Fig.2 shows stator model of 24 slots developed in RMxprt tool

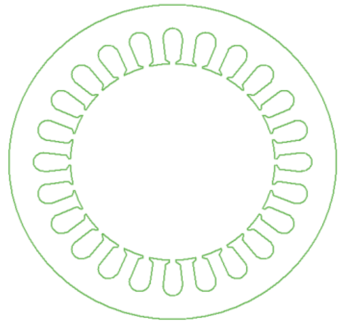

FIG.2 STATOR CORE RMXPRT

3.3 Stator Slot

TABLE3. SLOT DIMENSIONS

Sl.No	Parameter	Value
1.	Hs0 (mm)	0.5
2.	Hs1 (mm)	1
3.	Hs2 (mm)	8.2
4.	Bs0 (mm)	2.5
5.	Bs1 (mm)	5.6
6.	Bs2 (mm)	7.6

The Fig.3 shows stator slot designed in RMxprt tool

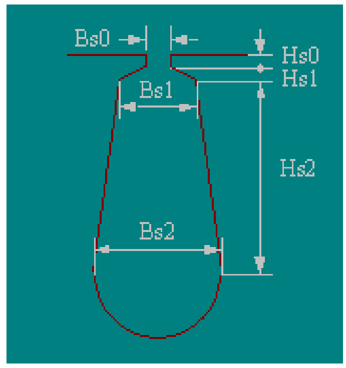

FIG.3 STATOR SLOT RMXPRT

3.4. Stator Winding

3Ø, 2 layer winding is arranged in 24 slots 4 pole machine

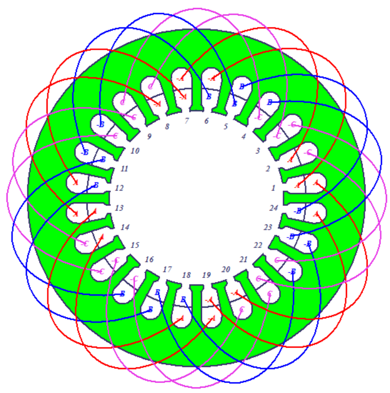

FIG.4 STATOR WINDING RMXPRT

3.5. Rotor Core

TABLE 4. ROTOR DIMENSIONS

Sl.No	Parameter	Value
1.	Number of Poles	4
2.	Outer Diameter of Rotor (mm)	74
3.	Inner Diameter of Rotor (mm)	26
4.	Length of Rotor Core (mm)	65
5.	Stacking Factor of Rotor Core	0.95
6.	Steel Type of Rotor	M19_24G

7.	Magnet Thickness (mm)	5
8.	Magnet Width per Pole (mm)	18
9.	Magnet Type	XG196/96
10.	Max. Magnet Width per Pole (mm)	19.9143

The Fig.5 shows rotor model of 4 pole developed in RMxprt tool.

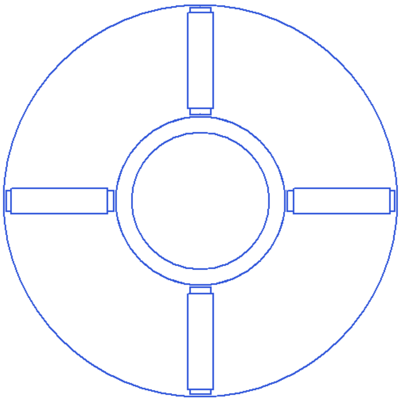

FIG.5 ROTOR CORE RMXPRT

3.6. Maxwell 2D

Maxwell 2D showing cross section view of the stator slots, conductor and rotor assembly

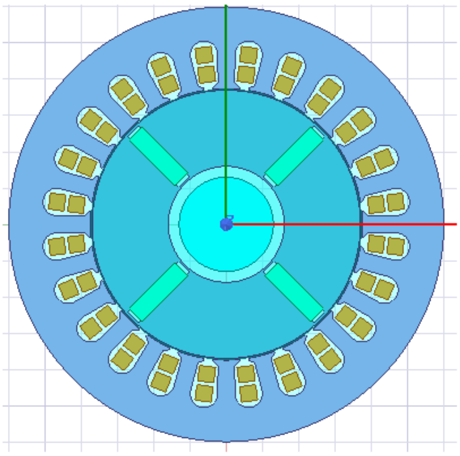

FIG.6 IPMSM MAXWELL 2D VIEW

3.7. Maxwell 3D

Maxwell 3D view showing the diameter of stator, rotor and winding assembly

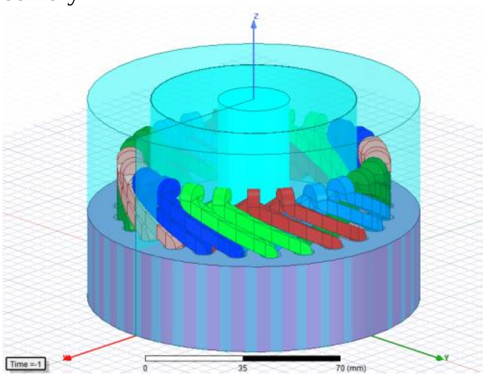

FIG.7 IPMSM MAXWELL 3D VIEW

TABLE5. OTHER PARAMETERS

SL. NO	PARAMETER	VALUE
1.	AVERAGE INPUT CURRENT (A)	2.92168
2.	FRICTIONAL AND WINDAGE LOSS (W)	6
3.	IRON-CORE LOSS (W)	8.63534
4.	ARMATURE COPPER LOSS (W)	72.3811
5.	TRANSISTOR LOSS (W)	4.90662
6.	DIODE LOSS (W)	0.844526
7.	TOTAL LOSS (W)	92.7676
8.	OUTPUT POWER (W)	550.001
9.	INPUT POWER (W)	642.769
10.	EFFICIENCY (%)	85.5675
11.	RATED SPEED (RPM)	1800
12.	RATED TORQUE (N.M)	2.91785
13.	CONTROL TYPE	PWM
14.	TRANSISTOR DROP (V)	0.7
15.	DIODE DROP (V)	0.7
16.	MODULATION INDEX	0.9
17.	CARRIER FREQUENCY TIMES	40
18.	STATOR TOOTH FLUX DENSITY (TESLA)	0.905606
19.	STATOR YOKE FLUX DENSITY (TESLA)	1.2865
20.	STATOR YOKE FLUX DENSITY (TESLA)	1.2865
21.	ROTOR YOKE FLUX DENSITY (TESLA)	0.84187
22.	MAGNET FLUX DENSITY (TESLA)	0.852535
23.	AIR-GAP FLUX DENSITY (TESLA)	0.429582

3.8. Control Circuit of IPMSM

The Fig.8 shows system generated control circuit of PWM inverter fed IPMSM motor

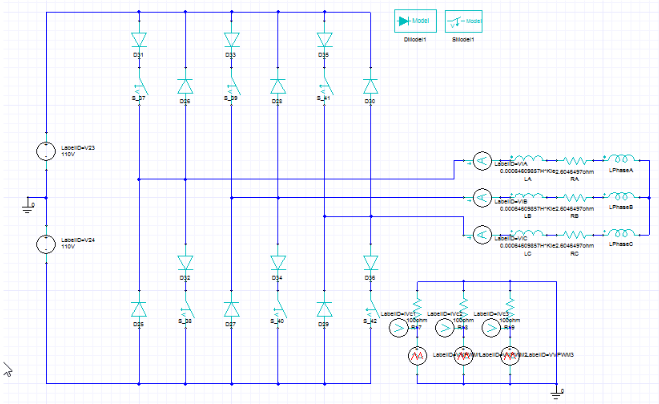

FIG.8 MAXWELL CIRCUIT OF IPMSM

3.9. IPMSM Output Waveform

The Fig.9 shows the Phase A, Phase B, Phase C current with respect to time

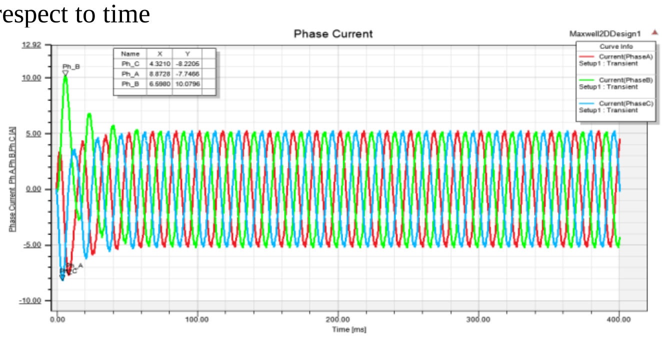

Fig.9 Supplied Current Vs Time

The Fig.10 shows the Coil-1, Coil-2, Coil-3 rotor induced voltages

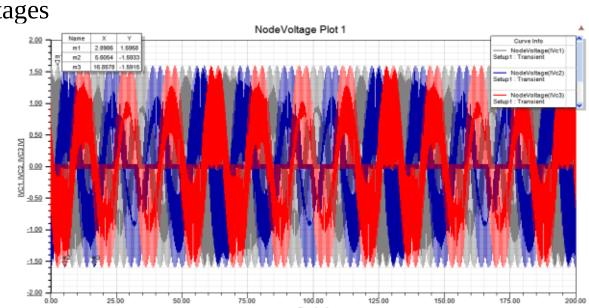

Fig.10. Induced Voltage Vs Time

The Fig.11 shows moving speed of the motor

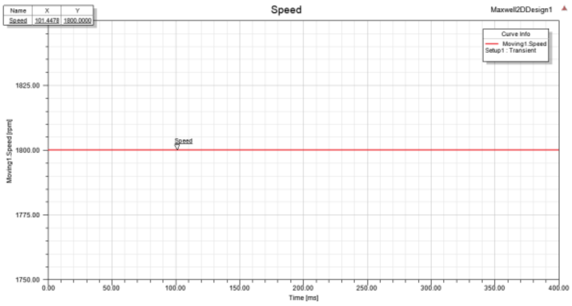

Fig.11 Speed Vs Time

The Fig.12 shows the flux density in stator and rotor. In 2D motor view geometry, white color region represents the high flux line and red color represents medium flux line and blue color represent low flux line level

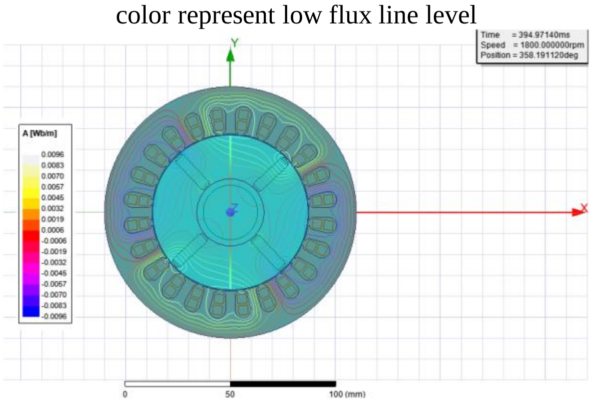

Fig. 12 Flux lines in all the objects

The Fig.13 shows the flux density across stator, rotor parts. In the 2D motor view geometry, white color region represents the high flux density, red color represents medium flux density and blue color represents low flux density level.

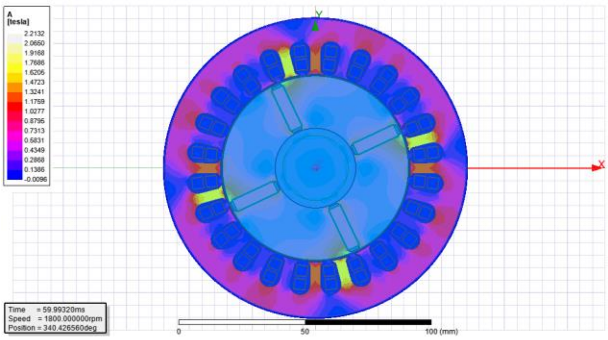

Fig.13 Flux density in all the objects

4. CONCLUSIONS

The analysis and design of IPMSM using FEM, RMxprt shows how one can efficiently design and validate the performance without any physical test. Should there be any design change modification as per the process condition, load could employ" what if" analysis to get the output for 100 plus cases without the need for physical changes. Thus optimization of design is achieved with minimal cost

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