IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

TO STUDY THE ROTOR DESGIN OF A SYNCHRONOUS RELUCTANCE MOTOR TO IMPROVE THE TORQUE AND EFFICIENCY

A.VENKATESH[1], Dr .S.NARASIMHA[2], B.BHAVANI[3], A.VAMSHI[4], B.AJAY[5]

[1]ASSISTANT PROFESSOR OF EEE DEPARTMENT,[2]HOD OF EEE,[3,4,5]TKR COLLEGE OF ENGINEERING AND TECHNOLOGY, EEE DEPARTMENT, HYDERABAD, INDIA

Abstract— *This project focuses on studying the customised rotor synchronous reluctance motor. The analysis is performed to estimate the influence of the number of stator slots and non-magnetic areas in the rotor on the electromagnetic torque and torque ripple of the studied motor. It is concluded that the increase in the in the number of the stator slots Z= 6 to Z= 36 causes an approximately two fold decrease in the ripple factor, but torque increases by some extent. Electromagnetic torque will be increased, if non -magnetic flux barriers are created in the rotor of the studied synchronous reluctance motor.*

In this, the results of development and experimental research of a synchronous reluctance motor are presented. Experimental research of the main characteristics of the synchronous reluctance electric motor powered by electric network and frequency inverter, is carried out in the testing centre Comparison of the characteristics SYNRM and induction motor (IM) development showed advantages of SYNRM in terms of energy, weight and overall dimensions. On the basis carried out research, are formulated the basic directions of works on development and industrial use of SYNRM.

I. INTRODUCTION

Have you ever thought about where we would be without electric motors? They're now in everything from our cars to our toothbrushes. Electric motors are also employed to make the things that allow us to live in the modern world. Have you ever thought about where we'd be without electric motors? Today Because electric motors are so important now, let's take a look back at their history to understand how we got here.

Global warming and climate change are exacerbated by industrial development. There is a strong demand for effective systems when considering human impact on the environment in terms of resources. This fact prompts researchers to look into alternative advancements in the realm of electrical machines. Motors in buildings and industrial applications now turn 45 percent of all electricity into motion. Clearly, as the world's reliance on electric motors grows, we must increase our energy efficiency.

An electric motor is an electromechanical device that transforms electrical energy to mechanical energy. It works on the idea that when a current-carrying conductor is placed in a magnetic field, it experiences a mechanical force whose direction is determined by Fleming's lefthand rule and magnitude is determined by

$$F=BIL \text{ Newton.}$$

Where F=force

B=magnetic flux density

I= current

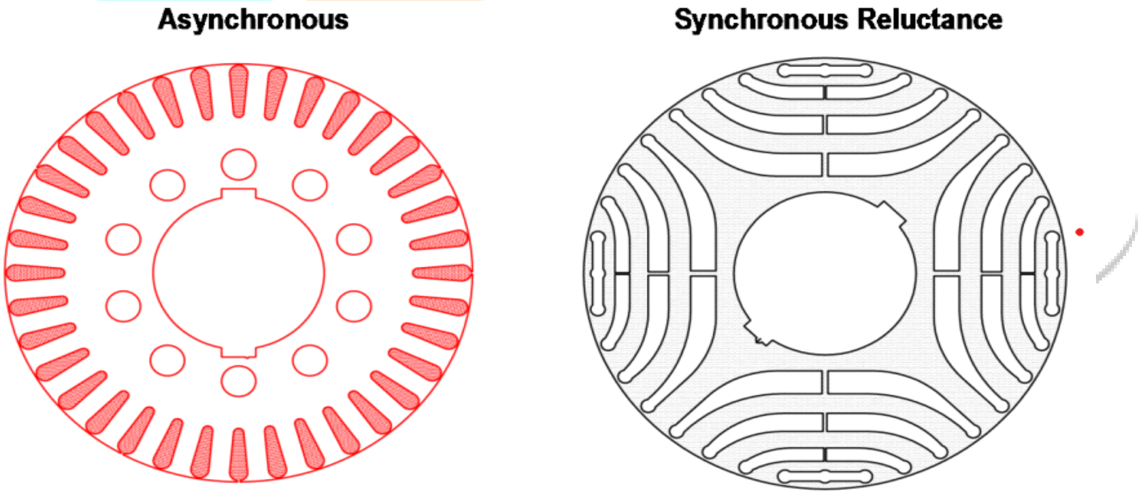
L= length

When current carrying conductor is placed in a magnetic field and a current is passed through it, a force acts on the conductor which rotates continuously.

II. SYNCHRONOUS RELUCTANCE MOTOR

A ferromagnetic rotor, which lacks windings but induces non-permanent magnetic poles, is used in a form of electric motor known as a reluctance motor. Magnetic reluctance is used to generate torque in this rotor. Individually excited motors with a non-symmetrical rotor are employed in this motor. Synchronous reluctance motors, variable reluctance motors, switching reluctance motors, and variable stepping reluctance motors are all examples of reluctance motors. Due to the complexity of designing and regulating this motor in the early twenty-first century, it was only employed in limited circumstances. As a result, through enhancing design tools, theory, and embedded systems, this can be overcome.

The torque of a synchronous reluctance motor is due to the disparity of magnetic conductivities across the rotor's direct axes as well as quadrature, and it does not use permanent magnets or field windings. Because of its simple and sturdy design, this type of motor is currently gaining popularity as an option for electric and hybrid vehicles. The main advantage of this motor is the lack of rotor cage losses, which allows for a higher permanent torque than an Induction Motor of the same size. High efficiency at synchronous speed without the use of rare earth permanent magnets is one of the major characteristics of synchronous reluctance motors. The SRM is comparable to all Asynchronous motors in terms of structure and manufacturing. The only important change is the rotor design; the SRM rotor is anisotropic (not symmetrical).


Asynchronous

Synchronous Reluctance

Fig 1.1 Rotor Design of Synchronous and Asynchronous

- The rotor has several similar slots that are symmetrically placed and have the same dimensions and form.
- The rotor has identical sectors with multiple different slots, all of which are different in size and shape and are not distributed symmetrically.

A. Why SYNCHRONOUS RELUCTANCE MOTOR?

Synchronous: Because the rotor mechanical speed is perfectly synchronised with the spinning magnetic field when it rotates. Reluctance: Because the magnetic design of the rotor has areas of high RELUCTANCE (white areas, air) and areas of low RELUCTANCE (black areas, water), there is reluctance (blue areas, iron).

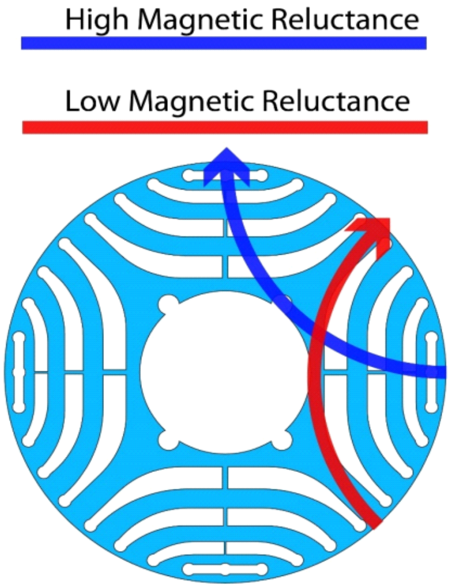


Fig 1.2 Reluctance in Synchronous Reluctance Motor

B. What is the reluctance:

The RELUCTANCE is the polar opposite of the permeance and is a magnetic resistance. The rotor reluctance is caused by "empty" patches on the rotor laminations, which act as a magnetic barrier, preventing the flux from flowing freely.

The rotor's mechanical construction appears to be simple because it does not require aluminium /copper casting or magnet assembly, but its design is complicated by the "shape" of the rotor slots, which must maintain the required robustness while minimising the connection sectors between the rotor "poles."

C. How does it function!

A magnetic field is formed when the stator windings are energised, and the rotor aligns its most magnetically conductive axis (d-axis) with the applied field to reduce reluctance in the magnetic circuit.

Synchronous Reluctance motors are designed with rotors that have "designated" sectors (depending on the number of poles) and are built of magnetically conductive and magnetically insulating materials (air).

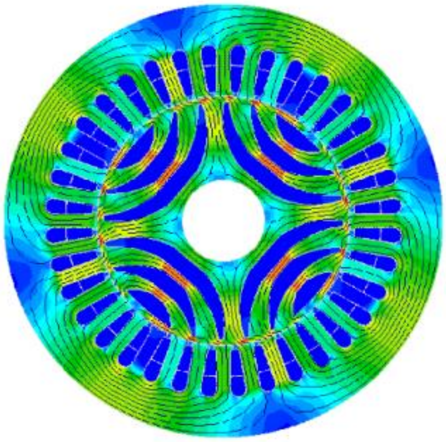


Fig 1.3 Magnetic Flux in Synchronous Reluctance Motor

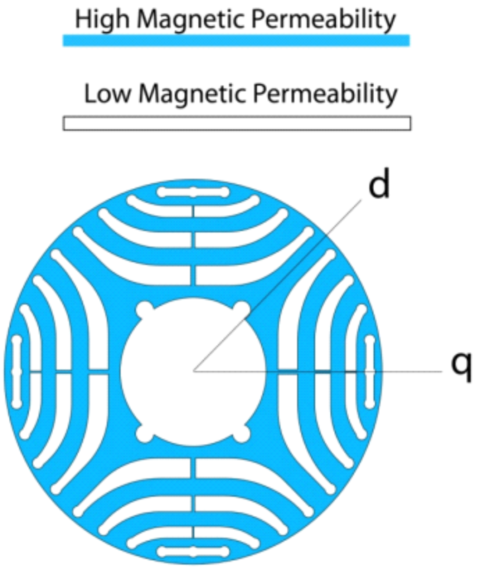


Fig 1.4 d-axis and q-axis in Synchronous Reluctance Motor

D. WORKING PRINCIPLE OF SYNCHRONOUS RELUNCTANCE MOTOR

A rotating magnetic field is created in the air gap of the electric motor by the alternating current travelling through the stator windings. Torque is formed when the rotor tries to align its most magnetically conductive axis (d-axis) with an applied field in order to reduce the magnetic circuit's reluctance (magnetic resistance). The difference between the direct Ld and quadrature Lq inductances is exactly proportional to the torque amplitude. As a result, the bigger the differential, the more torque is generated.

The main concept can be explained using the diagram below. The conductivity of anisotropic material in object "a" varies along the d and q axes, but the conductivity of isotropic magnetic material in object "b" is constant in all directions. If there is an angle between the d axis and the magnetic field lines, the magnetic field applied to the anisotropic object "a" produces a torque. Obviously, if the object's d axis does not coincide with the magnetic field lines, the object will cause distortions in the magnetic field. In this situation, the deformed magnetic lines' direction will correspond with the object's q axis.

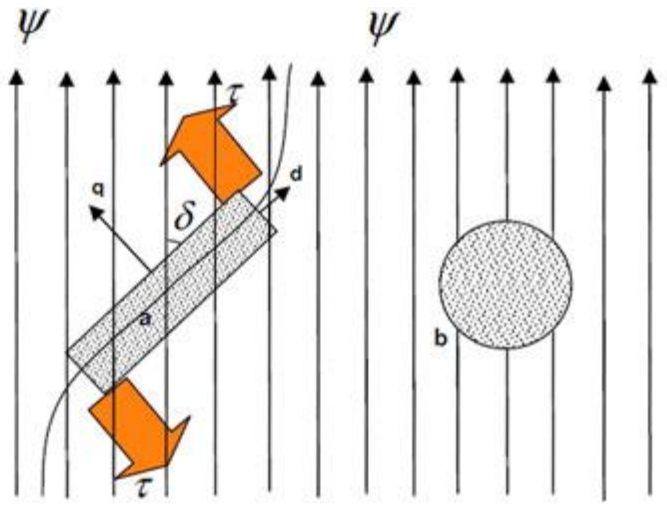


Fig 1.5 An object with anisotropic geometry (a) and isotropic geometry (b) in a magnetic field

E. TORQUE EQUATION OF SYNCHRONOUS RELUCTANCE MOTOR

If the magnets are demagnetized, the operation of both the permanent magnet synchronous motor and the synchronous reluctance motor is similar. Below is the torque equation for a synchronous reluctance motor. Because of the field, the first component of this equation is included. To obtain the torque equation, this component must be removed. The next component in the equation can be characterised as reluctance torque.

As a result, the produced torque of a reluctance motor can be stated as follows.

$$T = \frac{3}{2}\frac{P}{2}(Ld - Lq)Id.Iq.$$

'T' is the developed torque

'p' is the no. of poles

'Ld' is the direct axis inductance.

'Lq' is the Quadrature axis inductance.

'Id' is the direct axis current.

'Iq' is the quadrature axis current.

Synchronous reluctance motors are reliable, low-cost, and efficient. These motors spin at incredibly high rates. Because of the low saliency, or low ratio of Ldm/Lqm, traditional motors have low efficiency, low power factor, and low torque density.

However, the present development of these motors has a high Ldm/Lqm ratio, which has significantly improved power factor, efficiency, and torque density.

The following is a phasor diagram of a synchronous reluctance motor. The consistent speed of this motor is its most important feature. If the rotor fails to link through the magnetic field of the stator at first, damper winding comes to mind. In synchronous motors, they are also used. Because of the difference in relative speeds between the rotor and the stator magnetic field, these windings can be arranged within pole shoes, which provide damping torque.

F. COMPARISION OF INDUTION MOTOR AND SYNRM

The main difference between these two motors is that in synchronous motors, the rotor speed is equal to the stator speed, whereas in induction motors, the rotor speed is less than the synchronous speed. Induction motors are also known as asynchronous motors because of this.

Slip—the difference between the rotational speed of the shaft and the speed of the motor's magnetic field—is created by the asynchronous nature of induction motors, allowing for higher torque. The stator provides power, while the rotor induces current, hence the name "induction" motor. Because the stator and rotor are in sync, synchronous motors do not slide and require an external AC power source.

Synchronous motors are doubly stimulated machines because they have two electrical inputs. The stator winding required for torque generation in three-phase synchronous motors is often supplied by three-phase AC or another input. DC is frequently utilised as the rotor supply, which either begins or stimulates the rotor. The motor is now synchronous when the stator and rotor fields lock together. These motors are utilised in a variety of applications, including power plants, manufacturing operations, and transmission line voltage control.

Induction motors, unlike synchronous motors, can start when electricity is supplied to the stator, removing the requirement for a power source to excite or start the rotor. The squirrel-cage or winding design of these motors has led to the development of motor types such as capacitor start induction run motors, squirrel cage induction motors, and double squirrel cage motors. Centrifugal fans and compressors, conveyors, lathe machines, and lifts all require induction motors.

G. ROTOR AND STATOR LAMINATIONS

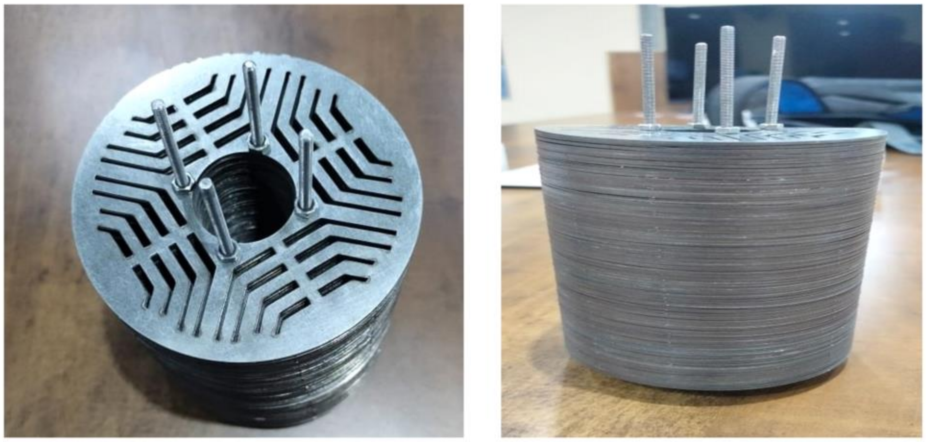


Fig1.6 Top view and Side view of Rotor laminations

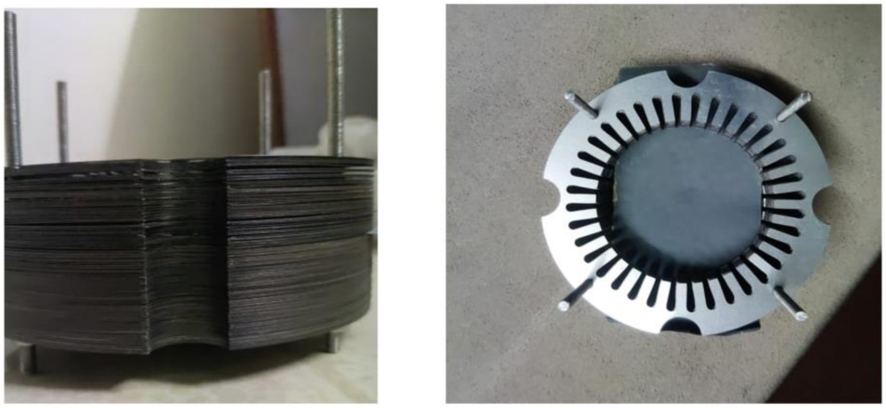


Fig 1.7 Top and Side view of Stator Laminations

H. MATERIAL

EN 10106 is the material utilised in this project. The maximum core losses and minimum magnetic polarisation values for these devices are likewise specified in the EN 10106 standard. Modest-alloyed steels, which are highly permeable and have great thermal conductivity, to high-alloyed steels, which have low core losses, make up the grade spectrum. EN 10106 compliant electrical steel strip grades are our standard grades for many classic applications. These grades are known as non-grain-oriented, eventually annealed electrical steel strip. Tolerances for dimensions are in compliance with EN 10106.

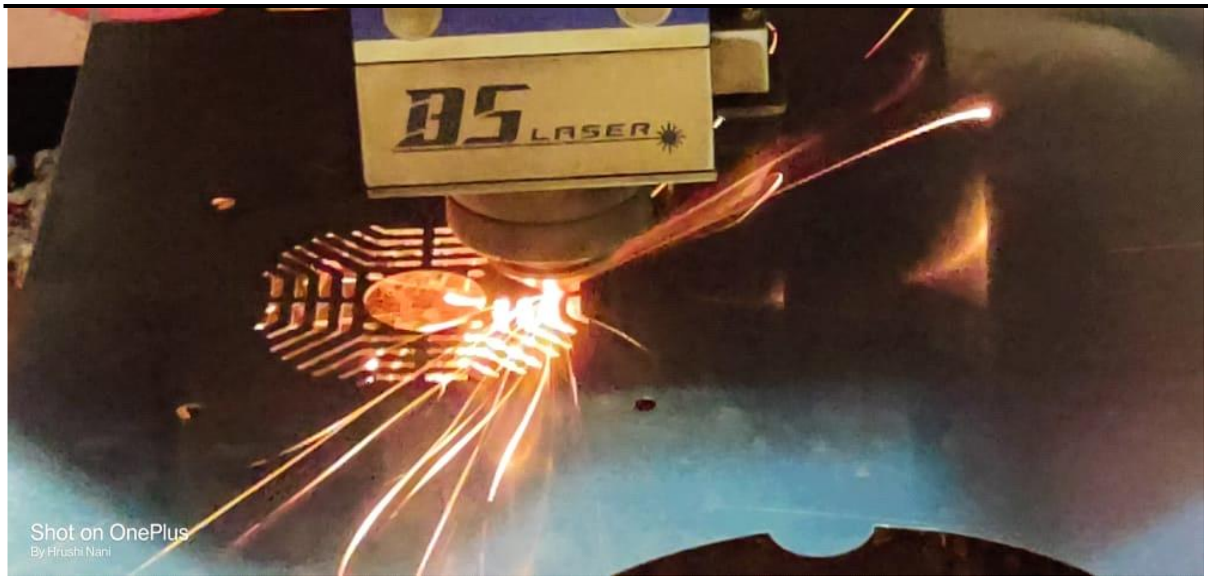
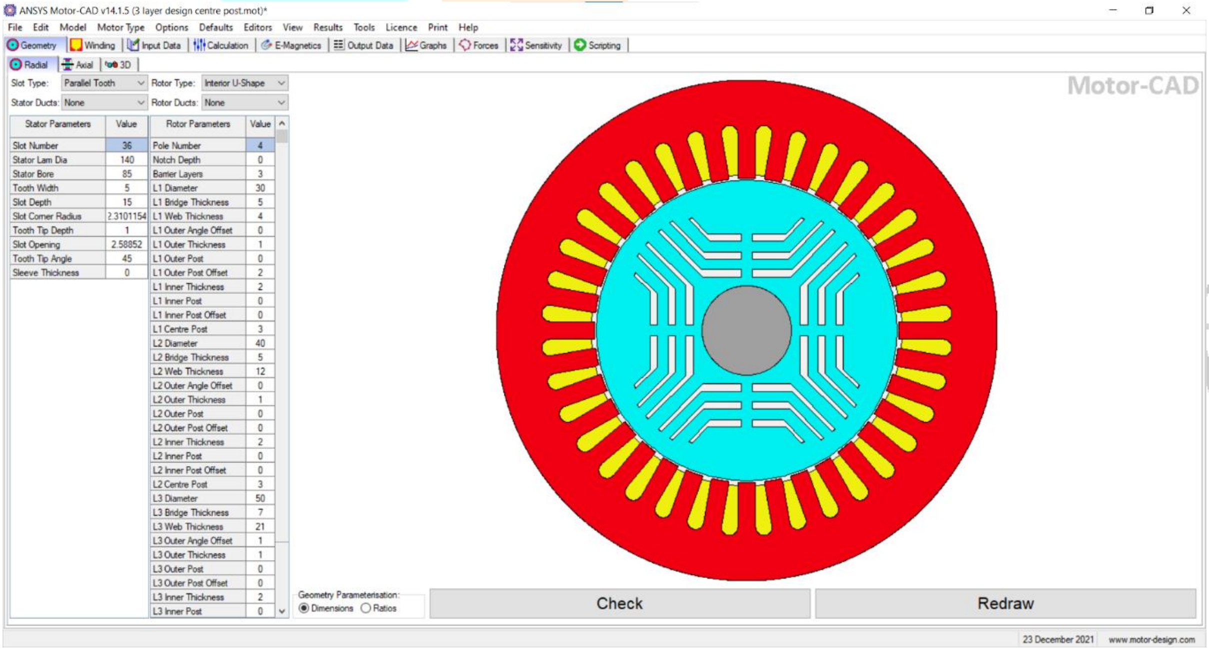


Fig 1.8 Laser cutting of a material



Slot Type: Parallel Tooth

Rotor Type: Interior U-Shape

Stator Ducts: None

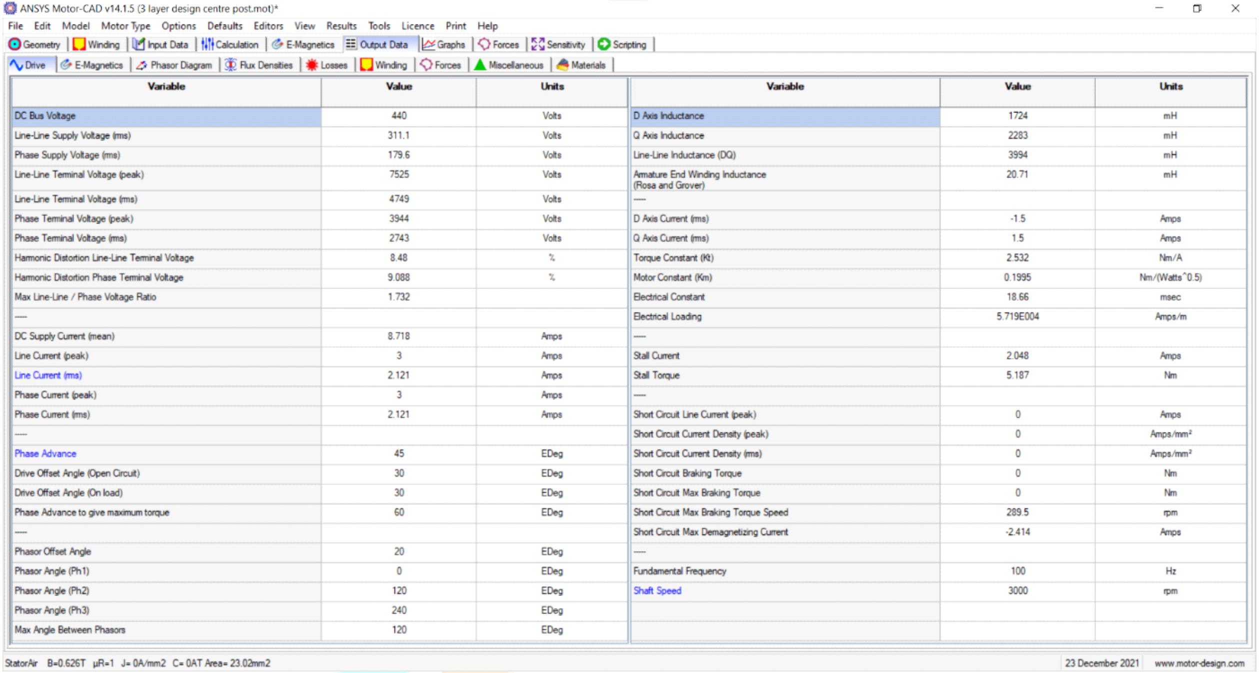
Rotor Ducts: None

Stator Parameters	Value
Slot Number	36
Stator Lam Dia	140
Stator Bore	85
Tooth Width	5
Slot Depth	15
Slot Corner Radius	2.3101154
Tooth Tip Depth	1
Slot Opening	2.58852
Tooth Tip Angle	45
Sleeve Thickness	0

Rotor Parameters	Value
Pole Number	4
Notch Depth	0
Barrier Layers	3
L1 Diameter	30
L1 Bridge Thickness	5
L1 Web Thickness	4
L1 Outer Angle Offset	0
L1 Outer Thickness	1
L1 Outer Post	0
L1 Outer Post Offset	2
L1 Inner Thickness	2
L1 Inner Post	0
L1 Inner Post Offset	0
L1 Centre Post	3
L2 Diameter	40
L2 Bridge Thickness	5
L2 Web Thickness	12
L2 Outer Angle Offset	0
L2 Outer Thickness	1
L2 Outer Post	0
L2 Outer Post Offset	0
L2 Inner Thickness	2
L2 Inner Post	0
L2 Inner Post Offset	0
L2 Centre Post	3
L3 Diameter	50
L3 Bridge Thickness	7
L3 Web Thickness	21
L3 Outer Angle Offset	1
L3 Outer Thickness	1
L3 Outer Post	0
L3 Outer Post Offset	0
L3 Inner Thickness	2
L3 Inner Post	0

Geometry Parameterisation: ● Dimensions ○ Ratios

Fig 1.9 Geometry of SYNRM



Variable	Value	Units	Variable	Value	Units
DC Bus Voltage	440	Volts	D Axis Inductance	1724	mH
Line-Line Supply Voltage (rms)	311.1	Volts	Q Axis Inductance	2283	mH
Phase Supply Voltage (rms)	179.6	Volts	Line-Line Inductance (DQ)	3994	mH
Line-Line Terminal Voltage (peak)	7525	Volts	Armature End Winding Inductance (Rosa and Grover)	20.71	mH
Line-Line Terminal Voltage (rms)	4749	Volts	-----		
Phase Terminal Voltage (peak)	3944	Volts	D Axis Current (rms)	-1.5	Amps
Phase Terminal Voltage (rms)	2743	Volts	Q Axis Current (rms)	1.5	Amps
Harmonic Distortion Line-Line Terminal Voltage	8.48	%	Torque Constant (Kt)	2.532	Nm/A
Harmonic Distortion Phase Terminal Voltage	9.088	%	Motor Constant (Km)	0.1995	Nm/(Watts^0.5)
Max Line-Line / Phase Voltage Ratio	1.732		Electrical Constant	18.66	msec
-----			Electrical Loading	5.719E004	Amps/m
DC Supply Current (mean)	8.718	Amps	-----		
Line Current (peak)	3	Amps	Stall Current	2.048	Amps
Line Current (rms)	2.121	Amps	Stall Torque	5.187	Nm
Phase Current (peak)	3	Amps	-----		
Phase Current (rms)	2.121	Amps	Short Circuit Line Current (peak)	0	Amps
-----			Short Circuit Current Density (peak)	0	Amps/mm²
Phase Advance	45	EDeg	Short Circuit Current Density (rms)	0	Amps/mm²
Drive Offset Angle (Open Circuit)	30	EDeg	Short Circuit Braking Torque	0	Nm
Drive Offset Angle (On load)	30	EDeg	Short Circuit Max Braking Torque	0	Nm
Phase Advance to give maximum torque	60	EDeg	Short Circuit Max Braking Torque Speed	289.5	rpm
-----			Short Circuit Max Demagnetizing Current	-2.414	Amps
Phasor Offset Angle	20	EDeg	-----		
Phasor Angle (Ph1)	0	EDeg	Fundamental Frequency	100	Hz
Phasor Angle (Ph2)	120	EDeg	Shaft Speed	3000	rpm
Phasor Angle (Ph3)	240	EDeg			
Max Angle Between Phasors	120	EDeg			

StatorAir B=0.626T μR=1 J= 0A/mm2 C= 0AT Area= 23.02mm2 23 December 2021 www.motor-design.com

Fig 1.10 Output Data

REFERENCES

[1] A. VAGATI, M. PASTORELLI, P. GUGLIELMI, A. CANOVA, “Synchronous reluctance motor based sensorless drive for general purpose application”, Dipartimento di Ingegneria Elettrica Industriale, Politecnico di Torino, Corso Duca degli Abruzzi, 24, I10129 Torino (Italy).

[2] A. Vagati, G. Franceschini, I. Marongiu, G.P. Troglia, “Design criteria of high performance synchronous reluctance motors”, Industry Applications Society Annual Meeting, 1992., Conference Record of the 1992 IEEE 4-9 Oct. 1992 Page(s):66 - 73 vol.1.

[3] A. Fratta, A. Vagati, F. Villata, "On the evolution of A.C. machines for spindle drive applications”, Industry Applications, IEEE Transactions on, Volume 28, Issue 5, Sept.- Oct. 1992 Page(s):1081 – 1086.

[4] A. Vagati, A. Fratta, G. Franceschini, P. Rosso, “AC motors for high-performance drives: a design-based comparison”, Industry Applications, IEEE Transactions on, Volume 32, Issue 5, Sept.-Oct. 1996 Page(s):1211 – 1219.

[5] J.J. Germishuizen, F.S. Van der Merwe, K. Van der Westhuizen, M.J. Kamper, “ Performance comparison of reluctance synchronous and induction traction drives for electrical multiple units”, Industry Applications Conference, 2000. Conference Record of the 2000 IEEE, Volume 1, 8-12 Oct. 2000 Page(s):316 - 323 vol.1.

[6] F. Parasiliti, M. Villani, “Synchronous reluctance motors design and performance prediction using an analytical procedure”, Electrical Engineering and Electromagnetics, WIT Press, 2003, ISBN- 1-85312- 981-X, pp. 147-156.

[7] F. Parasiliti, M. Tursini, M. Villani, “Design of synchronous reluctance motors by finite element analysis and optimization algorithm Prototype and tests”, Department of Electrical and Information Engineering, University of 'Aquila, 67100 Poggio di Roio, L'Aquila, Italy, July 15 th 2006.

[8] Rae Hwa Lee, Min Myung Lee, Jung Ho Lee, “Rotor design functional standard of Synchronous Reluctance Motor according to torque per volume using FEM & SUMT”, Manuscript received June 30, 2006. 2

[9] T. Matsuo, T. A. Lipo, “Field oriented control of synchronous reluctance machine”, Power Electronics Specialists Conference, 1993. PESC '93 Record, 24th Annual IEEE, 20- 24 June 1993 Page(s):425 - 431.

[10] P. L. Alger, “The Nature of Polyphase Induction Machines”, New York: Wiley, 1951.

[11] A. Boglietti, A. Cavagnino, M. Pastorelli, A. Vagati, “Experimental comparison of induction and synchronous reluctance motors performance”, Industry Applications Conference, 2005. Fourtieth IAS Annual Meeting, Conference Record of the 2005, Volume 1, 2-6 Oct. 2005 Page(s):474 - 479 Vol. 1.