الجمهورية الجزائرية الديمقراطية الشعبية
PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA
وزارة التعليم العالي والبحث العلمي
MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH
جامعة عمّار ثليجي بالأغواط
AMAR TELIDJI UNIVERSITY OF LAGHOUAT

كلية التكنولوجيا
FACULTY OF TECHNOLOGY

قسم الالكتروتقني
DEPARTMENT OF ELECTROTECHNIC

Master's thesis

Domain : Sciences and Technologies
Field : Electrical Engineering
Option : Industrial Electrical Engineering

Theme

Contribution To Optimize Induction Machines Performance Using New Magnetic Material

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Publicly supported ahead of a jury composed of:

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Academic year 2021/2022

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ACKNOWLEDGEMENT

First and foremost, praises and thanks to the God, the Almighty, for his showers of blessings throughout our research work to complete the research successfully.

We would like to express our deep and sincere gratitude to our research supervisor, Mr. **Tahar SEGHIER**. Professor and head of laboratory, Centre for Information Technology and Engineering, AMAR TELIDJI University, laghouat, for giving us the opportunity to do research and providing invaluable guidance throughout this research. His dynamism, vision, sincerity and motivation have deeply inspired us. He has taught us the methodology to carry out the research and to present the research works as clearly as possible.

It was a great privilege and honor to work and study under his guidance. We are extremely grateful for what he has offered to us. We would also like to thank him for his friendship, empathy, and great sense of humor. We mention the professors Who supported and guided us. Mr. **BOURENNANE Hocine** Mr. **BENDJEDIA Bachir** and Mr. **CHEKNANE Abdelmalek** (PhD Student) We are extending our heartfelt thanks to the professors who were with us in the research center, they were like a family to us. thanks for their acceptance and patience during the discussion We had with them on the research work and the thesis preparation.

We sincerely thank our friends **Seghier. A** and **Boulehia. M** and **Mihoubi. O** and **Bensekrane. A** for their mental support and cheering us with the best they could.

We would like to thank the jury members for agreeing to judge and value our work.

Finally, our thanks go to all the people who have supported us to complete the research work directly or indirectly.

First of all, this work would not be possible without the help of all mighty god, and He who does not thank people, does not thank Allah. This work is dedicated to:

A loving mother and father, Djamel Boutassouna and Zine Amina, who were there giving me strength and unconditional support from day one, through thick and thin, I wouldn't be half of the man that I am today without them, and for that, I thank them, may God protect them?

My uncle, Zine Nacer, who never ceased encouraging me through all of the hardships. Thank you.

My grandfather, Zine Mohamed, who even in sickness, expresses concern and curiosity in my work, who never ceased encouraging me through all of the hardships.

A relentless partner with an inspiring work ethic. Djerfaf Med Yacine.

To my friends Aissa, Madani, Harzallah, Omar for their friendship, unconditional support and encouragement.

Every student, classmate and teacher that I have had the honor of working with or learning under, Thank you

BOUTAASOUNA SALAH ELDDINE

Dedication

Say, `If every ocean became ink for (recording) the words and creation of my Lord, surely, the oceans would be spent up before the words and creation of my Lord came to an end, even if we brought to add (therewith) as many more (oceans)'. 109 Al-Kahf

Highly Exalted is therefore Allâh, the true King. And make no haste to recite the Qur'ân (and anticipate the early fulfillment of its prophecies) before its revelation is completed to you. But say (in prayer), `My Lord, increase my knowledge'. 114 Ta-Ha

I thank Allah for having me able to complete this modest work!

I dedicate this work to my beloved parents who, through their prayers, their advice and their guidance, made me love studies and persevere in them. who always support me either in happiness or sorrow and also give me some courage to stand when I fall and give me spirit when I am hopeless. Thanks to them for their selflessness and their efforts which pushed me to reach the end of this important stage of my life.

To my partner Salah and his parents

To my teachers

who have made every effort to transmit their knowledge to us while expending themselves. Their serious work and their efforts have opened up many horizons for me. Thanks to each of them by name.

A special dedication for my grandparents, for my brothers and sisters, for my uncles and aunts, whom I love all of them, and whose presence in my life has encouraged me and raised awareness a lot.

All my friends and everyone who has helped me during the writing of this thesis. I am very thankful for all that support and the wishes you have given to me.

Djerfaf Mohammed Yacine

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GENERAL INTRODUCTION

Electric motors are widely used in commercial and industrial applications. Electric motors are an important part of any electrical system as they consume approximately 65% to 70% of the electricity generated. The increased interest in induction motors is due to their superiority over other types of industrial motors.

These advantages are simplicity, robustness, low initial cost and ease of maintenance. It is important to increase the efficiency of induction motors and improve other properties Parameters can also minimize energy consumption and contribute to an environmentally friendly society. Improved performance through better engine design is a major talking point question.

In this thesis, we tried to contribute in enhancing the performance of the Induction Motor (IM) using new Materials with high-quality magnetic property. We are interested in the performance of this prototype, Using COMSOL-Multiphysics software.

In the first chapter, we present general information on induction machines, giving its principle of operation and its different structures as well as the classification, the characteristics, the field of application, the advantages and the disadvantages of each type of induction motor and the most used ones.

In the second chapter, we will present COMSOL-Multiphysics in general as well as presentation of the finite element method about the two-dimensional (2D) model of the studied Motor (Induction Motor IM), using two physics.

In The third chapter we will present the parameters of the Induction Motor studied, also we'll be discussing and comparing the simulation results of the two materials obtained by COMSOL-Multiphysics software.

Finally, a conclusion that summarizes the work and some perspectives end the research.

Chapter Ⅰ

Generality of Induction Machines

I.1 INTRODUCTION

An electric motor converts electrical power to mechanical power in its rotor (rotating part). There are several ways to supply power to the rotor. In a DC motor this power is supplied to the armature directly from a DC source, while in an induction motor this power is induced in the rotating device. An induction motor is sometimes called a rotating transformer because the stator (stationary part) is essentially the primary side of the transformer and the rotor (rotating part) is the secondary side. Induction motors are now the preferred choice for industrial motors due to their rugged construction, absence of brushes (which are required in most DC motors) and the ability to control the speed of the motor.

An induction motor (IM) is a type of asynchronous AC motor where power is supplied to the rotating device by means of electromagnetic induction. The induction motor with a wrapped rotor was invented by Nikola Tesla Nikola Tesla in 1882 in France but the initial patent was issued in 1888 after Tesla had moved to the United States. In his scientific work, Tesla laid the foundations for understanding the way the motor operates. The induction motor with a cage was invented by Mikhail Dolivo-Dobrovolsky about a year later in Europe. Technological development in the field has improved to where a 100 hp (74.6 kW) motor from 1976 takes the same volume as a 7.5 hp (5.5 kW) motor did in 1897. Currently, the most common induction motor is the cage rotor motor [1].

I.2 INDUCTION MOTOR

An induction motor (also known as an asynchronous motor) it is referred to as ‘asynchronous motor’ because it operates at a speed less than its **synchronous speed** and it is a commonly used AC electric motor. The induction motor works on the principle of induction where an electromagnetic field is induced into the rotor when the rotating magnetic field of the stator cuts the stationary rotor. The rotor of an induction motor can be a squirrel cage rotor or wound type rotor. It is most widely used for industrial applications due to its self-starting attribute [2].

Synchronous speed is the speed of rotation of the magnetic field in a rotary machine, and it depends upon the frequency and number poles of the machine. The induction motor always runs at speed less than its synchronous speed [2].

The rotating magnetic field produced in the stator will create flux in the rotor, hence causing the rotor to rotate. Due to the lag between the flux current in the rotor and the flux current in the stator, the rotor will never reach its rotating magnetic field speed (i.e., the synchronous speed).

I.3 CONSTRUCTION

A typical motor consists of two parts namely stator and rotor like other type of motors.

1. An outside stationary stator ha-ving coils supplied with AC current to produce a rotating magnetic field.

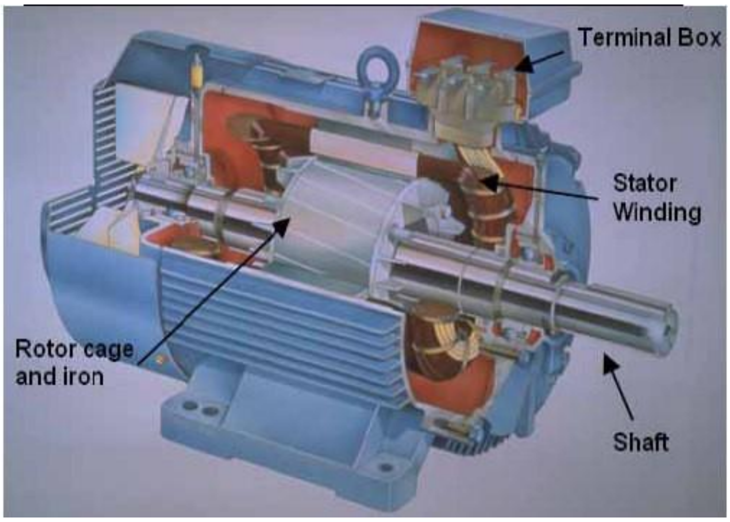


Figure I.1: Induction motor

2. An inside rotor attached to the output shaft that is given a torque by the rotating field [1].

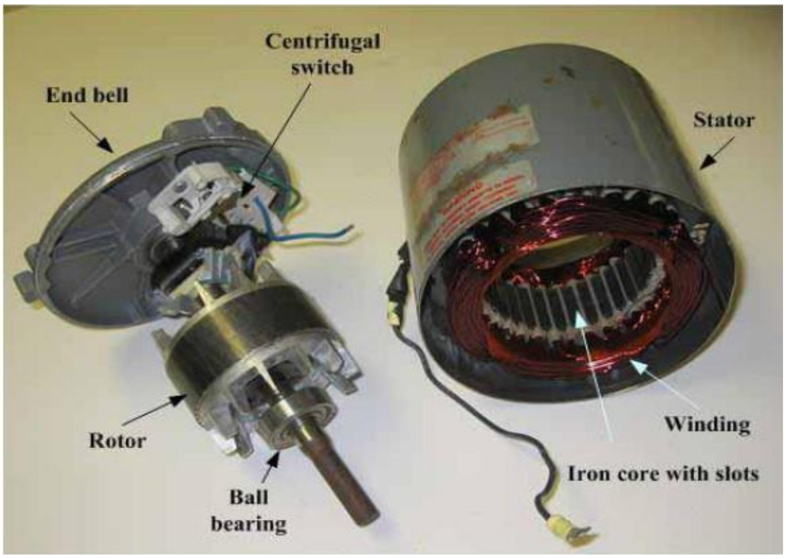


Figure I.2: Induction Motor components

I.4 PRINCIPLE OF OPERATION

1. An AC current is applied in the stator armature which generates a flux in the stator magnetic circuit.

2. This flux induces an emf in the conducting bars of rotor as they are “cut” by the flux while the magnet is being moved ($E = BV$L (Faraday’s Law))

3. A current flow in the rotor circuit due to the induced emf, which in term produces a force, ($F = BI$L) can be changed to the torque as the output.

In a 3-phase induction motor, the three-phase currents i_a, i_b and i_c, each of equal magnitude, but differing in phase by 120°. Each phase current produces a magnetic flux and there is physical 120 °shift between each flux. The total flux in the machine is the sum of the three fluxes. The summation of the three ac fluxes results in a rotating flux, which turns with constant speed and has constant amplitude. Such a magnetic flux produced by balanced three phase currents flowing in three-phase windings is called a rotating magnetic flux or rotating magnetic field (RMF). RMF rotates with a constant speed (Synchronous Speed). Existence of a RFM is an essential condition for the operation of an induction motor [1].

If stator is energized by an ac current, RMF is generated due to the applied current to the stator winding. This flux produces magnetic field and the field revolves in the air gap between stator and rotor. So, the magnetic field induces a voltage in the short-circuited bars of the rotor. This voltage drives current through the bars. The interaction of the rotating flux and the rotor current generates a force that drives the motor and a torque is developed consequently. The torque is proportional with the flux density and the rotor 6 bar current (F=BLI). The motor speed is less than the synchronous speed. The direction of the rotation of the rotor is the same as the direction of the rotation of the revolving magnetic field in the air gap [1].

However, for these currents to be induced, the speed of the physical rotor and the speed of the rotating magnetic field in the stator must be different, or else the magnetic field will not be moving relative to the rotor conductors and no currents will be induced. If by some chance this happens, the rotor typically slows slightly until a current is reinduced and then the rotor continues as before. This difference between the speed of the rotor and speed of the rotating magnetic field in the stator is called slip. It is unitless and is the ratio between the relative speed of the magnetic field as seen by the rotor the (slip speed) to the speed of the rotating stator field.

Due to this an induction motor is sometimes referred to as an asynchronous machine [1].

I.5 SLIP

The relationship between the supply frequency, *f*, the number of poles, *p*, and the synchronous speed (speed of rotating field), n_s is given by:

$$n_s = \frac{120\,f}{p} \tag{I.1}$$

The stator magnetic field (rotating magnetic field) rotates at a speed, n_s, the synchronous speed. If, n= speed of the rotor, the slip, s for an induction motor is defined as:

$$s = \frac{n_S - n}{ns} \tag{I.2}$$

At stand still, rotor does not rotate, $n = 0,\ s_0\ s = 1.$

At synchronous speed, $n = n_S$; $S = 0$

The mechanical speed of the rotor, in terms of slip and synchronous speed is given by:

$$n = (1 - s)\, n_S \tag{I.3}$$

I.6 TYPES OF INDUCTION MOTORS

The types of induction motors can be classified depending on whether they are a single phase or three phase induction motor.

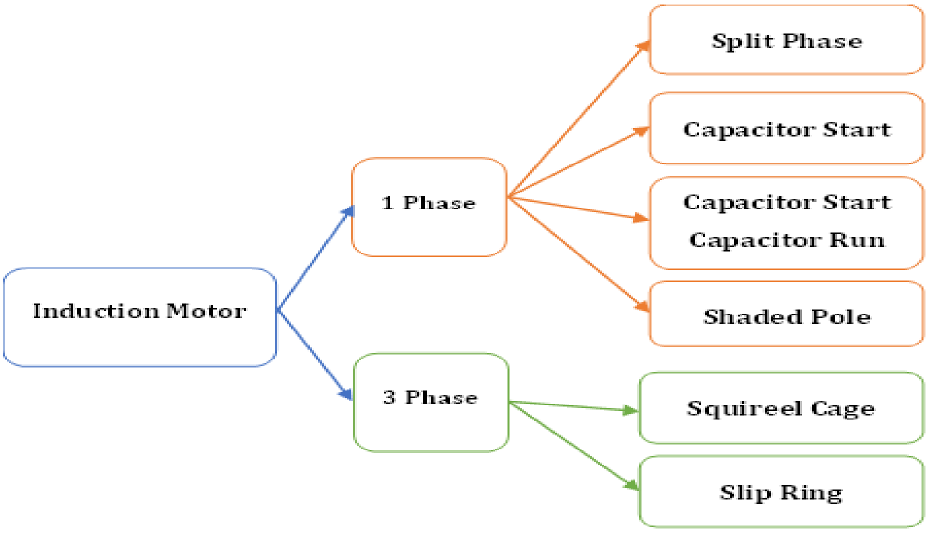


Figure I.3: Types of Induction Motors

I.6.1 Single Phase Induction Motors

The types of single-phase induction motors include:

- Split Phase Induction Motor :

An alternate name of a split-phase induction motor is a Resistance Start Motor. This kind of motor includes a stator and single cage rotor where the stator includes two windings called starting winding as well as main winding. These two windings are moved 90 degrees within space. The starting winding includes less inductive reactance and high resistance whereas the main winding includes extremely less resistance as well as a high inductive reactance [3].

The Split phase induction motor diagram is shown below. The following diagram can be built with main winding resistance (R_m), main winding inductive resistance (X_m), series resistor (R_a), inductive reactance with auxiliary winding (X_a), relay or centrifugal switch (S). In this motor, the main winding has less resistance & high inductive reactance whereas the auxiliary winding has less inductive reactance and high resistance.

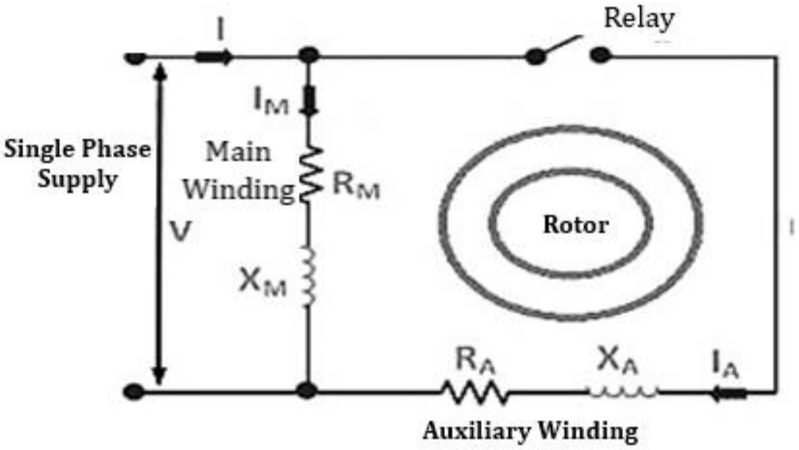


Figure I.4: Split-phase induction motor

In the above diagram, both the resistor & the auxiliary winding are connected in series. The flowing current in the windings cannot be equal consequently the rotary field is not consistent therefore, the initial torque is little. At the beginning of the motor, the two windings are allied in parallel [3].

- The Torque Speed Characteristic of the Split Phase motor is shown below:

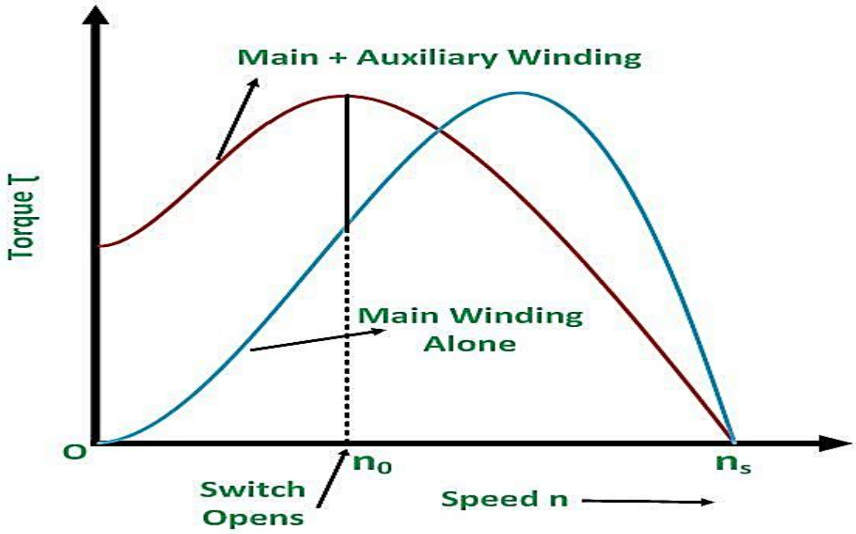


Figure I.5: The Torque Speed Characteristic of the Split Phase motor

Here, n_0 is the point at which the centrifugal switch operates. The starting torque of the resistance start motor is about 1.5 times the full load torque. The maximum torque is about 2.5 times the full load torque at about 75% of the synchronous speed. The starting current of the motor is high about 7 to 8 times the full load value.

The direction of the Resistance Start motor can be reversed by reversing the line connection of either the main winding or the starting winding. The reversal of the motor is possible at the standstill condition only [3].

- Advantages

- The motor is economical & can be changed once it wears out before trying to reverse it.
- These are available in different frame sizes so that they can be placed effortlessly in most of the machines.

- Disadvantages

- These motors have less starting torque, so not suitable for above 1 KW.
- The disadvantage of this motor is power output and efficiency. As compared to a 3-phase motor, these are unsuccessful while changing the energy from electrical to working.

- These motors rely simply on the different resistance & inductance of the starting winding.
- These are used where high starting torque is mandatory like an air compressor.
- These are suitable for the loads which start easily such as fans, grinding wheels, etc.

- Applications

The applications of this motor include in different loads which are used for general purpose. Generally, these loads are AC, grinders, lathe machine, drilling, washing machines, AC fans, drill presses, Centrifugal pumps, floor polishers, blowers, mixer grinder, heating blowers with belt-driven and conveyors with tiny belt-driven.

-This motor is used where the distribution of the three phases is not required.

-This motor does not give lots of starting torque, thus the load should be quite small, and where mechanical gain can be used to assist the motor to begin [3].

- Capacitor Start Induction Motor:

Capacitor Start Motors are single-phase Induction Motors that employ a capacitor in the auxiliary winding circuit to produce a greater phase difference between the current in the main and the auxiliary windings. The name capacitor starts itself shows that the motor uses a capacitor for the purpose of starting. The figure below shows the connection diagram of a Capacitor Start Motor.

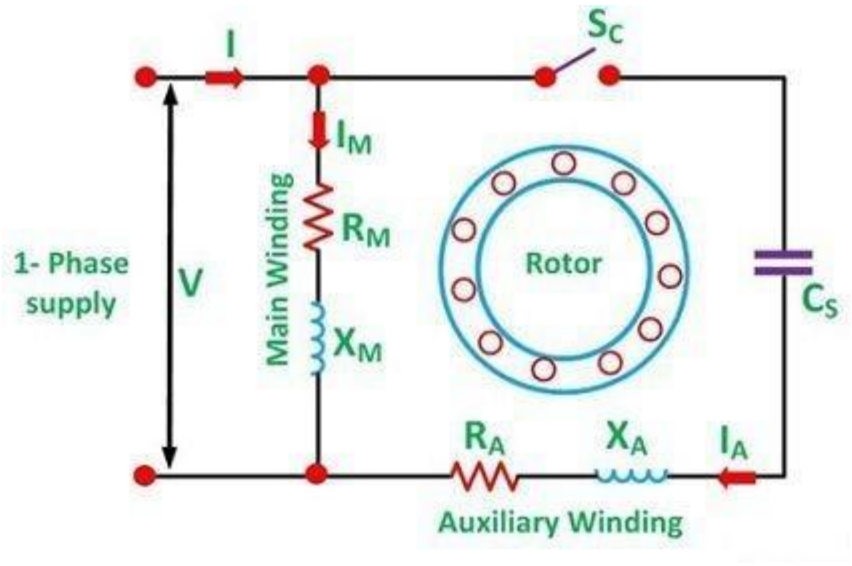


Figure I.6: Capacitor Start Induction Motor

The capacitor start motor has a cage rotor and has two windings on the stator. They are known as the main winding and the auxiliary or the starting winding. The two windings are placed 90 degrees apart. A capacitor CS is connected in series with the starting winding. A centrifugal switch SC is also connected to the circuit [4].

- Characteristics of the Capacitor Start Motor:

The capacitor starts motor develops a much higher starting torque of about 3 to 4.5 times the full load torque. To obtain a high starting torque, the two conditions are essential. They are as follow:-

- The Starting capacitor value must be large.
- The valve of the starting winding resistance must be low.

The electrolytic capacitors of the order of the 250 µF are used because of the high Var rating of the capacitor requirement.

The Torque Speed Characteristic of the motor is shown below:

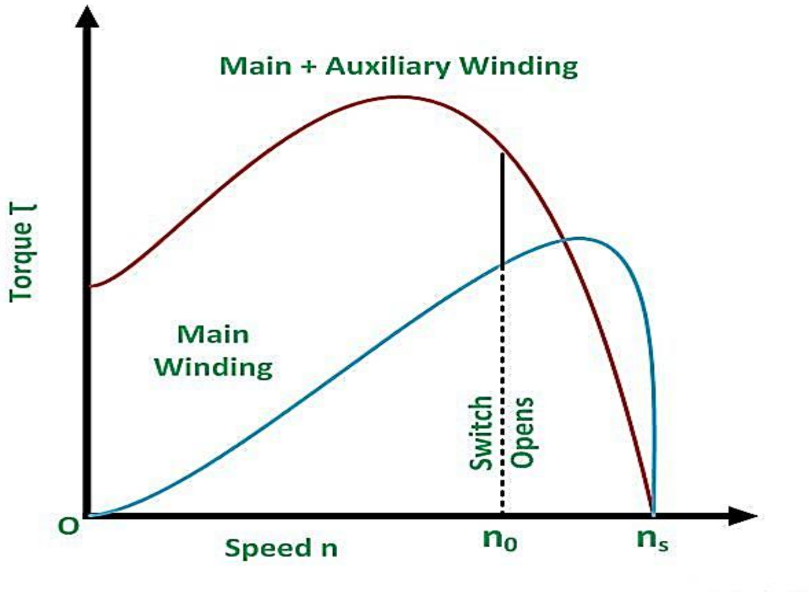


Figure I.7: The Torque Speed Characteristic of Capacitor Start Induction Motor

The characteristic shows that the starting torque is high. The cost of this motor is more as compared to the split-phase motor because of the additional cost of the capacitor. The Capacitor start motor can be reversed by first bringing the motor to rest condition and then reversing the connections of one of the windings [4].

- Applications of the Capacitor Start Motor:

The various applications of the motor are as follows

- These motors are used for the loads of higher inertia where frequent starting is required.
- Used in pumps and compressors.
- Used in the refrigerator and air conditioner compressors.
- They are also used for conveyors and machine tools.

- Capacitor Start and Capacitor Run Induction Motor

The Capacitor Start Capacitor Run Motor has a cage rotor, and its stator has two windings known as Main and Auxiliary Windings. The two windings are displaced 90 degrees in space. There are two capacitors in this method one is used at the time of the starting and is known as starting capacitor. The other one is used for continuous running of the motor and is known as RUN capacitor.

So, this motor is named Capacitor Start Capacitor Run Motor and is sometimes known as Two Value Capacitor Motor. The connection diagram of the two valves Capacitor Motor is shown below.

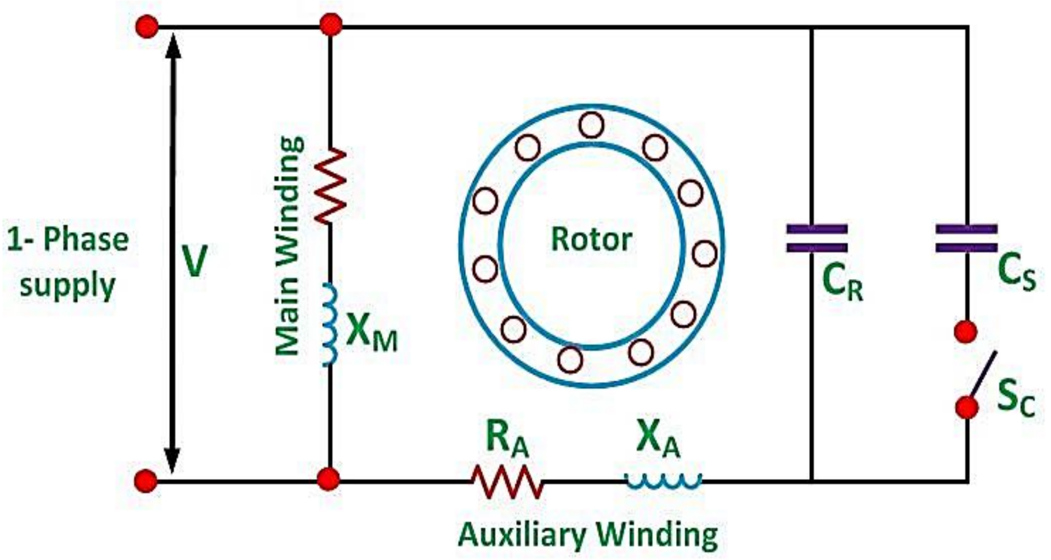


Figure I.8: Capacitor Start and Capacitor Run Induction Motor

There are two capacitors in this motor represented by Cs and C_R. In the starting, the two capacitors are connected in parallel. The capacitor Cs is the Starting capacitor is short time rated. It is almost electrolytic. A large amount of current is required to obtain the starting torque. Therefore, the value of the capacitive reactance X should be low in the starting winding. Since, $X_A = 1/2\pi fC_A$, the value of the starting capacitor should be large [5].

The rated line current is smaller than the starting current at the normal operating condition of the motor. Hence, the value of the capacitive reactance should be large. Since, XR = 1/2πfCR, the value of the run capacitor should be small [5].

As the motor reaches the synchronous speed, the starting capacitor Cs is disconnected from the circuit by a centrifugal switch Sc. The capacitor C_R is connected permanently in the circuit and thus it is known as RUN Capacitor. The run capacitor is long time rated and is made of oil-filled paper [5].

The torque-speed characteristic of a two-value capacitor motor is shown below:

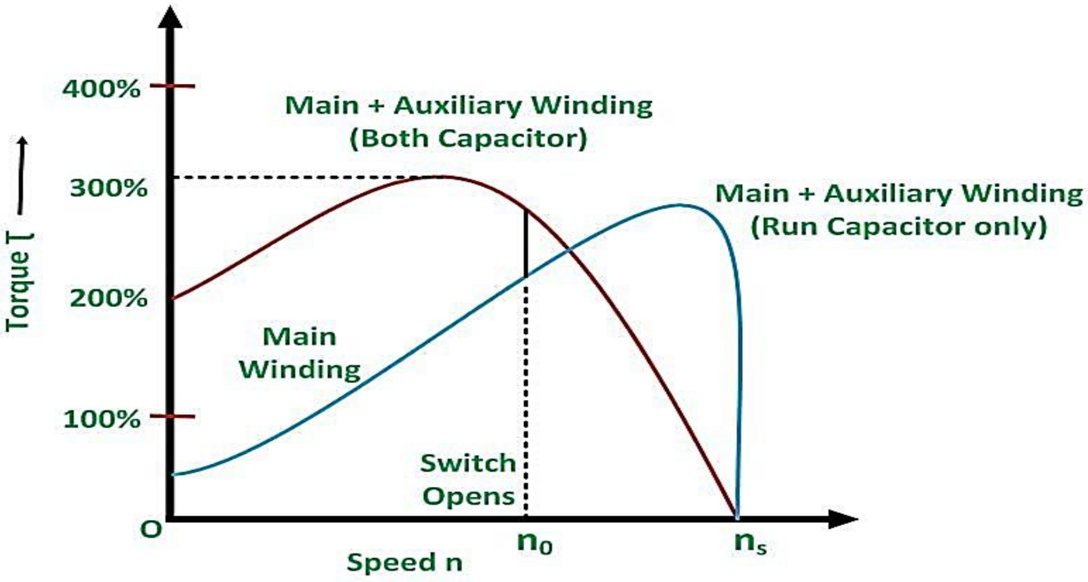


Figure I.9: The Torque Speed Characteristic of the motor

This type of motor is quiet and smooth running. They have higher efficiency than the motors that run on the main windings only. They are used for loads of higher inertia requiring frequent starts where the maximum pull-out torque and efficiency required are higher. The two value capacitor motors are used in pumping equipment, refrigeration, air compressors, etc [5].

- Shaded Pole Induction Motor

The shaded pole induction motor is simply a self-starting single-phase induction motor whose one of the poles is shaded by the copper ring. The copper ring is also called the shaded ring. This copper ring acts as a secondary winding for the motor. The shaded pole motor rotates only in one particular direction, and the reverse movement of the motor is not possible [6].

- Shaded Pole Induction Motor Working

When the supply is connected to the windings of the rotor, the alternating flux induces in the core of the rotor. The small portion of the flux link with the shaded coil of the motor because it is short-circuited. The variation in the flux induces the voltage inside the ring because of which the circulating current induces in it.

The circulating current develops the flux in the ring which opposes the main flux of the motor. The flux induces in the shaded portion of the motor, i.e., a, and the unshaded portion of the motor, i.e., b has a phase difference. The main motor flux and the shaded ring flux are also having a space displacement by an angle of 90° [6].

The connection diagram of the Shaded Pole Motor is shown below:

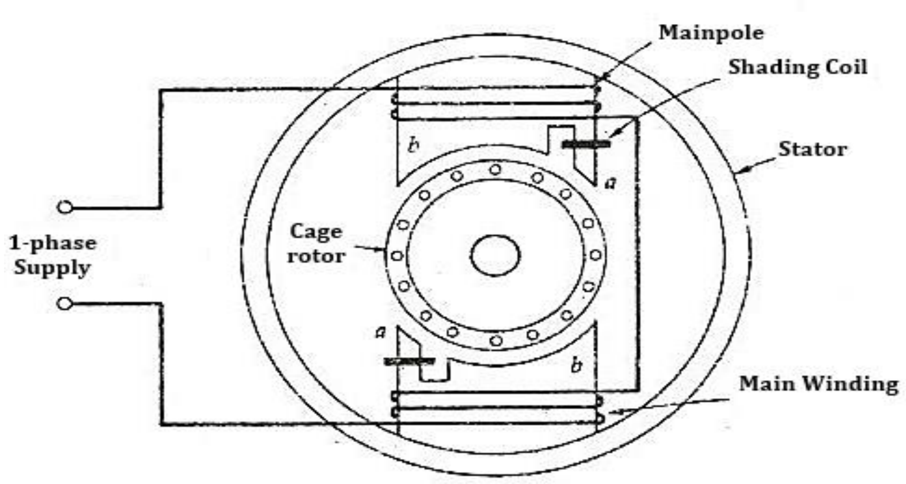


Figure I.10: Shaded Pole Induction Motor

As there is time and space displacement between the two fluxes, the rotating magnetic field induces in the coil. The rotating magnetic field develops the starting torque in the motor. The field rotates from the unshaded portion to the shaded portion of the motor.

- Applications of the Shaded Pole Induction Motor

The various applications of the shaded poles motor are as follows:

- They are suitable for small devices like relays and fans because of their low cost and easy starting.
- Used in exhaust fans, hairdryers, and also table fans.
- Used in air conditioning and refrigeration equipment and cooling fans.
- Record players, tape recorders, projectors, photocopying machines.
- Used for starting electronic clocks and single-phase synchronous timing motors.

I.6.2 Three Phase Induction Motor

The types of three phase induction motors include:

- Slip Ring Induction Motor

A slip ring induction motor is referred to as an asynchronous motor as the speed at which it operates is not equal to the synchronous speed of a rotor. The rotor of this type of motor is wound type. It comprises of a cylindrical laminated steel core and a semi-closed groove at the outer boundary to accommodate a 3-phase insulated winding circuit [7].

- Working of Slip Ring Induction Motor

This motor runs on the principle of Faraday's law of electromagnetic induction. When a stator winding is excited with an AC supply, the stator winding produces magnetic flux. Based on faraday's law of electromagnetic induction, the rotor winding gets induced and generates a current of magnetic flux. This induced EMF develops torque that enables the rotor to rotate [7].

However, the phase difference between the voltage and current do not meet the requirements to generate high starting torque as torque developed is not unidirectional. The external resistance of high value is connected with the circuit to improve the phase difference of a motor. As a result, inductive reactance and phase difference between I and V is reduced. Consequently, this reduction helps the motor to generate high stating torque.

The slip ring induction motor diagram is shown below:

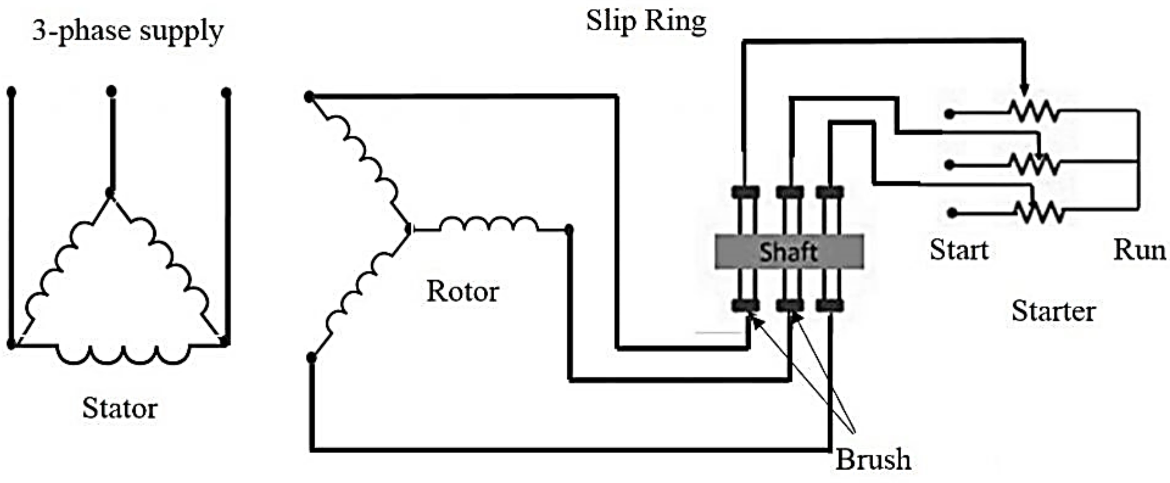


Figure I.11: Slip Ring Induction Motor Connection Diagram

- Slip Ring Induction Motor Resistance Calculation

The peak torque occurs if

$$r = S_{max}.X \tag{I.4}$$

Where

S_{max}: The Slip at pull-out torque

X: Inductance of a rotor

r: resistance of rotor winding

Adding external resistance R to equation (I.4),

$$r + R = S'_{max} \tag{I.5}$$

From equation (I.4) and (I.5),

$$R = r\,(S'_{max}/S_{max} - 1) \tag{I.6}$$

By definition of Smax, we get

$$S_{max} = 1 - (N_{max}/N_s) \tag{I.7}$$

Putting $S'_{max} = 1$ in equation (I.4), we get

$$R = r.\,(1/S_{max} - 1) \tag{I.8}$$

- Slip Ring Induction Motor Speed Control

The speed control of this motor can be done using two methods which include the following.

- Effect of Adding External Resistance

Generally, the initiation of these motors occurs when it draws full line voltage which is 6 to 7 times higher than the full load current. This high current can be controlled by external resistance connected in series with the rotor circuit. The external resistance acts as a variable rheostat during the motor kick-off and tweaks automatically to high resistance to get required starting current.

The external resistance reduces high resistance as soon as the motor obtains normal speed and increases the starting torque of a motor. The tweaking of external resistance also aids in decreasing of rotor and stator current but improves the power factor of a motor [7].

- Using Thyristor Circuit

Thyristor On/Off circuit is another way to control the speed of a motor. In this method, rotor AC current is connected to a 3-phase bridge rectifier and connected to external resistance through a filter. The thyristor is connected across external resistance and is switched on/off at high frequency. The ratio of on-time to off-time estimates the actual value of rotor circuit resistance that helps in controlling the speed of a motor by controlling speed-torque characteristics [7].

- Advantages and Disadvantages of Slip Ring Induction Motor

The advantages are

- High and excellent starting torque to support high inertia loads.
- It has a low starting current due to external resistance.
- Can take full load current that is 6 to 7 times higher the disadvantages are.
- Includes higher maintenance costs due to brushes and slip rings compared to squirrel cage motor.
- Intricate construction.
- High Copper loss.

- Low efficiency and low power factor.
- Expensive than 3 phase squirrel cage induction motor.

- Applications

Some of the applications of slip ring induction motor are:

These motors are used where higher torque and low starting current are required.

Used in applications like elevators, compressors, cranes, conveyors, hoists, and many more.

I.6.3 Squirrel Cage Induction Motor

A 3 phase squirrel cage induction motor is a type of three phase induction motor which functions based on the principle of electromagnetism. It is called a ‘squirrel cage’ motor because the rotor inside of it – known as a ‘squirrel cage rotor’ – looks like a squirrel cage.

This rotor is a cylinder of steel laminations, with highly conductive metal (typically aluminum or copper) embedded into its surface. When an alternating current is run through the stator windings, a rotating magnetic field is produced.

This induces a current in the rotor winding, which produces its own magnetic field. The interaction of the magnetic fields produced by the stator and rotor windings produces a torque on the squirrel cage rotor [8].

- Squirrel Cage Induction Motor Working Principle

When a 3-phase supply is given to the stator winding it sets up a rotating magnetic field in space. This rotating magnetic field has a speed which is known as the synchronous speed.

This rotating magnetic field induces the voltage in rotor bars and hence short-circuit currents start flowing in the rotor bars. These rotor currents generate their self-magnetic field which will interact with the field of the stator. Now the rotor field will try to oppose its cause, and hence rotor starts following the rotating magnetic field.

The moment rotor catches the rotating magnetic field the rotor current drops to zero as there is no more relative motion between the rotating magnetic field and rotor. Hence, at that moment the rotor experiences zero tangential force hence the rotor decelerates for the moment.

After deceleration of the rotor, the relative motion between the rotor and the rotating magnetic field reestablishes hence rotor current again being induced. So again, the tangential force for rotation of the rotor is restored, and therefore again the rotor starts following rotating magnetic field, and in this way, the rotor maintains a constant speed which is just less than the speed of rotating magnetic field or synchronous speed [8].

Slip is a measure of the difference between the speed of the rotating magnetic field and rotor speed. The frequency of the rotor current = slip × supply frequency

- Squirrel Cage Induction Motor Construction

A Squirrel Cage Induction Motor consists of the following parts:

- Stator.
- Rotor.
- Fan.
- Bearings.

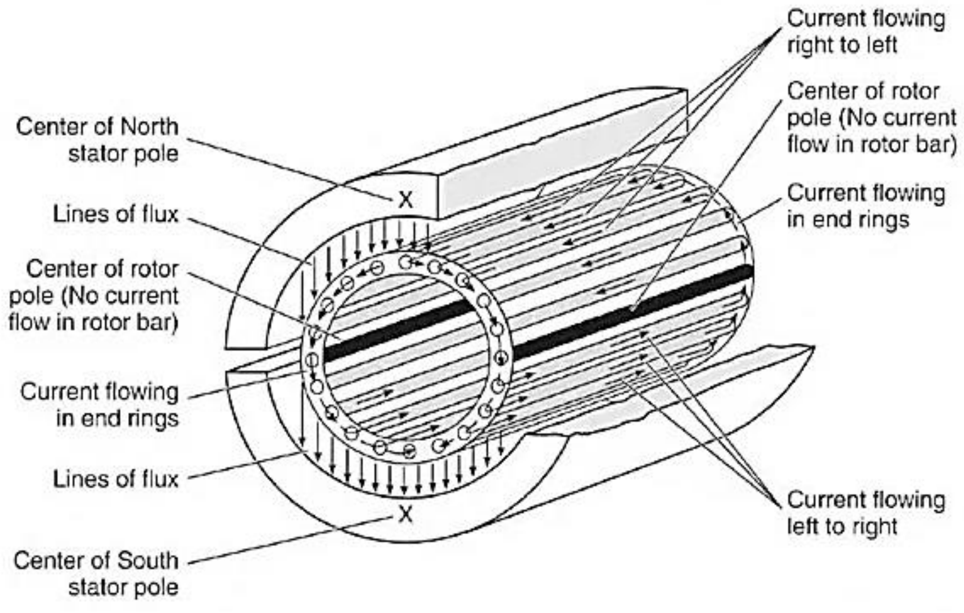


Figure I.12: Squirrel Cage Induction Motor Construction

a) Stator

It consists of a 3-phase winding with a core and metal housing. Windings are such placed that they are electrically and mechanically 120° apart from in space. The winding is mounted on the laminated iron core to provide low reluctance path for generated flux by AC currents [8].

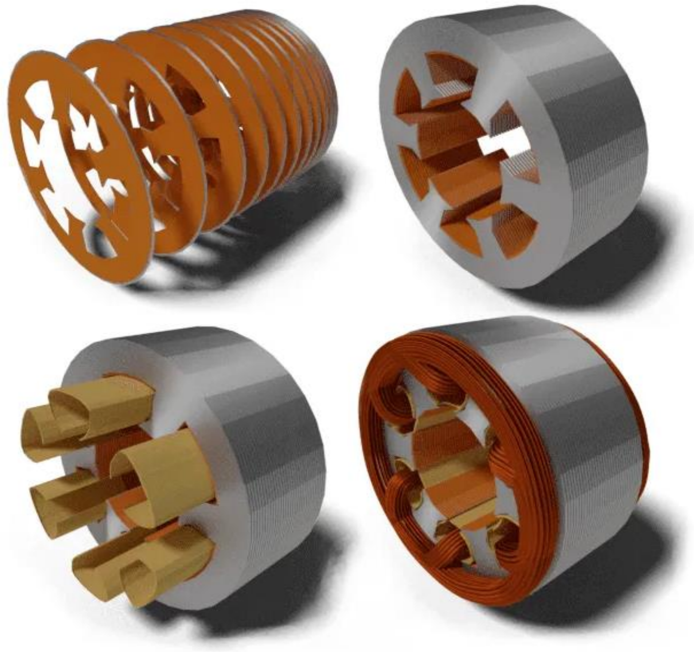


Figure I.13: 3D model of the 3 Phase Motor-Stator

b) Rotor

It is the part of the motor which will be in a rotation to give mechanical output for a given amount of electrical energy. The rated output of the motor is mentioned on the nameplate in horsepower. It consists of a shaft, short-circuited copper/aluminum bars, and a core [8].

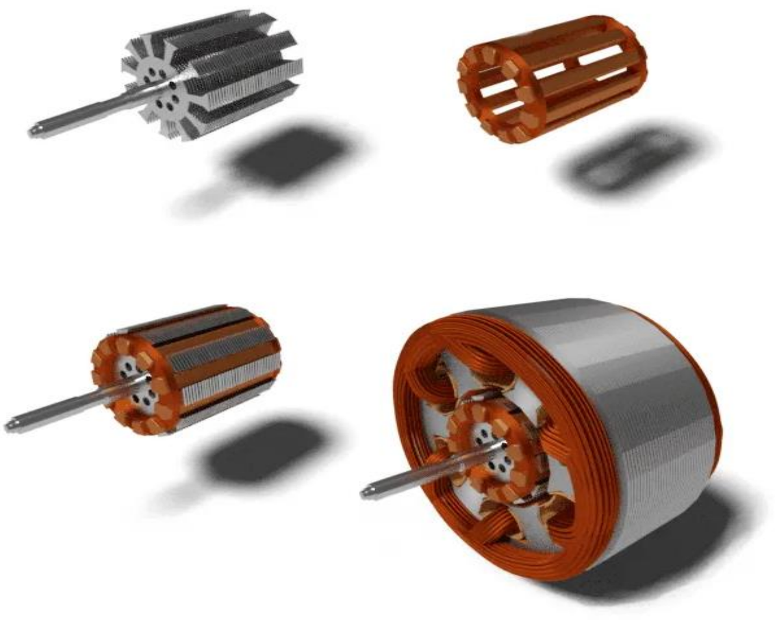


Figure I.14: 3D model of the 3 Phase Motor-Rotor

The rotor core is laminated to avoid power loss from eddy currents and hysteresis. Conductors are skewed to prevent cogging during starting operation and gives better transformation ratio between stator and rotor.

c) Fan

A fan is attached to the back side of the rotor to provide heat exchange, and hence it maintains the temperature of the motor under a limit.

d) Bearings

Bearings are provided as the base for rotor motion, and the bearings keep the smooth rotation of the motor.

- Application of Squirrel Cage Induction Motor

Squirrel Cage Induction Motor are commonly used in many industrial applications. They are particularly suited for applications where the motor must maintain a constant speed, be self-starting, or there is a desire for low maintenance [8].

These motors are commonly used in:

- Centrifugal pumps.

- Industrial drives (e.g., to run conveyor belts).
- Large blowers and fans.
- Machine Tools.
- Lathes and other Turing Equipment.

- Advantages of Squirrel Cage Induction Motor

Some advantages of Squirrel Cage Induction Motor are:

- They are low cost.
- Require less maintenance (as there are no slip rings or brushes).
- Good speed regulation (they are able to maintain a constant speed).
- High efficiency in converting electrical energy to mechanical energy (while running, not during startup).
- Have better heat regulation (i.e., don’t get as hot).
- Small and lightweight.
- Explosion proof (as there are no brushes which eliminate the risks of sparking) [8].

- Disadvantages of Squirrel Cage Induction Motor

Although squirrel cage motors are very popular and have many advantages – they also have some downsides. Somme disadvantages of squirrel cage Induction Motors are:

- Very poor speed control.
- Although they are energy efficient while running at full load current, they consume a lot of energy on startup.
- They are more sensitive to fluctuations in the supply voltage. When the supply voltage is reduced, induction motor draws more current. During voltage surges, increase in voltage saturates the magnetic components of the squirrel cage induction motor.
- They have high starting current and poor starting torque (the starting current can be 5-9 times the full load current; the starting torque can be 1.5-2 times the full load torque) [8].

I.7 Difference Between Squirrel Cage and Slip Ring Induction Motor

While slip ring Induction Motor (also known as wound-rotor motor) aren't as popular as squirrel cage induction motors, they do have a few advantages.

Below is a comparison table of squirrel cage vs wound rotor type motors:

S I,N0	Property	Squirrel Cage Motor	Slip Ring Motor
1	Rotor Construction	Bars are used in rotor. Squirrel cage motor is very simple, rugged and long lasting. No slip rings and brushes	Winding wire is to be used. Wound rotor required attention. Slip ring and brushes are needed also need frequent maintenance.
2	Starting	Can be started by D.O.L., star-delta, auto transformer starters	Rotor resistance starter is required
3	Starting Torque	Low	Very High
4	Starting current	High	Low
5	Speed Variation	Not easy, but could be varied in large steps by pole changing or through smaller incremental steps through thyristors or by frequency variation.	Easy to vary speed. Speed change is possible by inserting rotor resistance using frequency variation injecting emf in the rotor circuit cascading.
6	Maintenance	Almost ZERO maintenance	Requires frequent maintenance
7	Cost	Low	High

Table I.1: squirrel cage vs wound rotor type motors

I.8 PERFORMANCE IMPROVEMENT OF THREE PHASE INDUCTION MOTOR USING SUPER MAGNETIC MATERIAL

Electrical motors are extensively used in commercial and industrial applications. Electrical motors are an important part of any electrical system as they consume about 65% to 70% of all electricity generated. The increased interest in induction motors is because of its merits over the other types of industrial motors.

These merits are simplicity, ruggedness, less initial cost and ease of maintenance etc. It is very essential to increase efficiency of induction motor and improve the other performance parameters also to minimize the energy consumption and to contribute to environment friendly society. The performance improvement through better motor design becomes a major concern.

I.8.1 Hiperco 50

Hiperco 50 Alloy is an iron-cobalt-vanadium soft magnetic alloy which exhibits high magnetic saturation (24 kilogauss), high D.C. maximum permeability, low D.C. coercive force and low A.C. core loss. Produced in strip form only and contains a small niobium addition for grain refinement during mill processing and final heat treatment of strip. excel in applications where this attribute is needed. Hiperco 50 maintains its strength after heat treating making it the best choice for applications that experience high forces (e.g., rotating parts) [9].

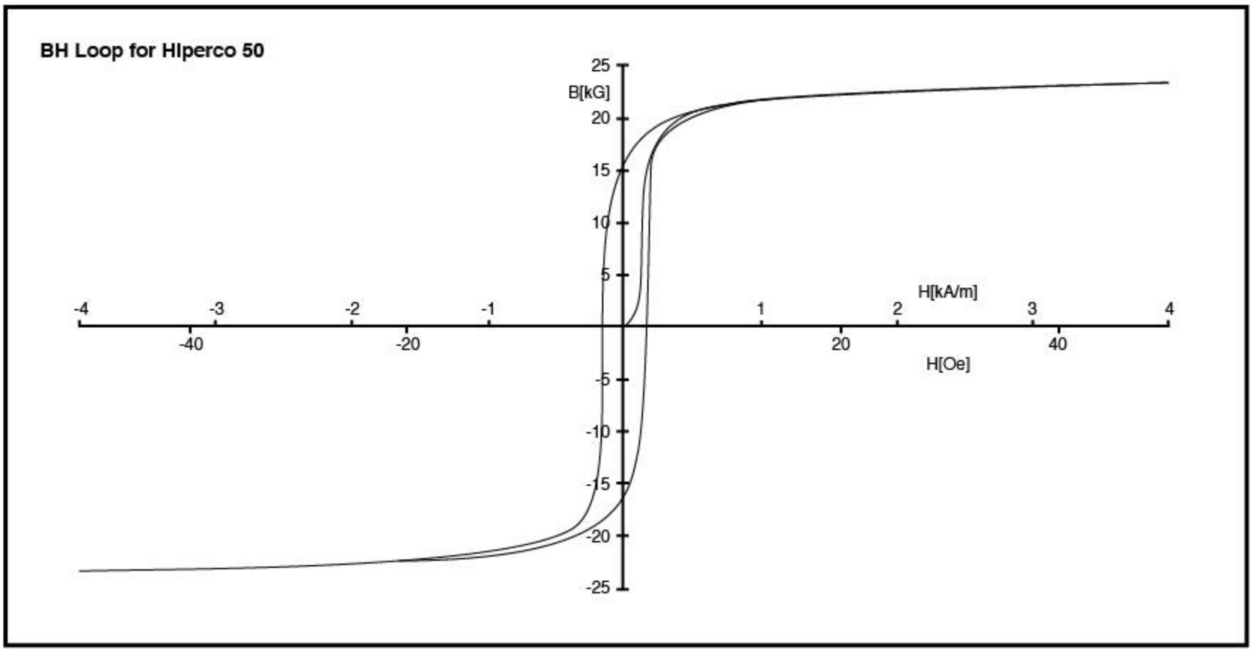


Figure I.15: BH Loop for Hiperco 50

Soft magnetic materials can be magnetized and demagnetized with a relatively low magnetic field. This makes them ideal for use in transformer cores where the electric and magnetic field is rapidly changing. It is also an important property for good electromagnets, which likewise need to be easily demagnetized [10].

The magnetic saturation of a material describes the upper limit to its magnetization. For materials which exhibit a high magnetic saturation, a high magnetic field can be achieved in the interior of the material.

Hiperco 50 exhibit the highest magnetic saturation (24 Kg or 2.4 T) of all soft-magnetic alloys. In addition, it exhibits low values of coercive force (72 A/m for Hiperco 50), meaning demagnetization can be easily achieved. In addition, it exhibits high DC maximum permeability and low AC core loss [10].

Hiperco 50 have greater mechanical strength than other soft magnetic alloys. This makes it ideal for applications containing parts which undergo significant mechanical stress such as electrical motors and generators.

I.8.2 APPLICATION OF SUPERIOR MAGNETIC MATERIAL HIPERCO50

Hiperco50 consist of an alloy of 49% Cobalt, 2% Vanadium and balance Iron. Hiperco50 has the highest flux density of all soft-magnetic alloys. Hiperco50 maintains its strength after heat treating making it best choice for applications that experience high rotational forces. The specific mass density of Hiperco50 is 8120 kg/m^3, modulus of elasticity 207 GPa, electric conductivity 2.5 × 106 S/m, thermal conductivity 29.8 W/ (m K), Curie temperature 940^{0}C, specific core loss about 76 W/kg at 2T, 400 Hz and thickness from 0.15 to 0.36 mm [9].

The below table shows the physical properties of Hiperco50

Sr. No	Property	Hiperco50
1	Saturation flux density, T	2.44
2	Relative permeability	10000
3	Curie temperature, ^{0}C	940
4	Electric conductivity, S/m	2.38
5	Core losses at 60 Hz and 1.5 T, W/kg	1.73
6	Core losses at 400 Hz and 1.5T, W/kg	17.47

Table I.2: The physical properties of Hiperco50

This makes them an important material in the aerospace industry where they are used for rotor and stator laminations for electric motors, specifically in the main generators, auxiliary power unit (APU) and the ram air turbine (RAT) of commercial airliners.

Other applications of the materials are in electromagnets for medical applications, for example for X-ray optics for radiation therapy and medical radiology, pole pieces for electromagnets, speciality transformers, high magnetic flux devices and instruments and magnetic bearings for the levitation of rotating parts [9].

I.9 STEEL MATERIAL OF INDUCTION MOTOR

Electrical steel has high demand as a core material for electromagnetic induction in transformers. Transformers convert alternating current (AC) of one voltage into AC of another voltage by means of electromagnetic induction at an invariable frequency. Electrical steel is mainly responsible for the efficiency of the transformer. Electrical steels are being chosen based on their magnetic losses at alternating frequency. Magnetic losses of electrical steel are divided into three parts: (1) quasi-static loss, (2) parasitic loss, and (3) anomalous loss. Silicon electrical steel was initially obtained in 1900 by alloying iron with silicon. Resistivity of alloy substantially increased, thus decreased the loss due to eddy currents and reduced hysteresis upon reversal magnetization.

Steel is an alloy made up of iron with typically a few tenths of a percent of carbon to improve its strength and fracture resistance compared to other forms of iron. Many other elements may be present or added. Stainless steels that are corrosion– and oxidation-resistant need typically an additional 11% chromium.

Because of its high tensile strength and low cost, steel is used in buildings, infrastructure, tools, ships, trains, cars, machines, electrical appliances, and weapons. Iron is the base metal of steel.

Steel is an alloy of iron and carbon containing less than 2% carbon and 1% manganese and small amounts of silicon, phosphorus, Sulphur, and oxygen. Steel is the world’s most important engineering material.

Steel has a number of properties, including hardness, toughness, tensile strength, yield strength, elongation, fatigue strength, corrosion, plasticity, malleability, and creep.

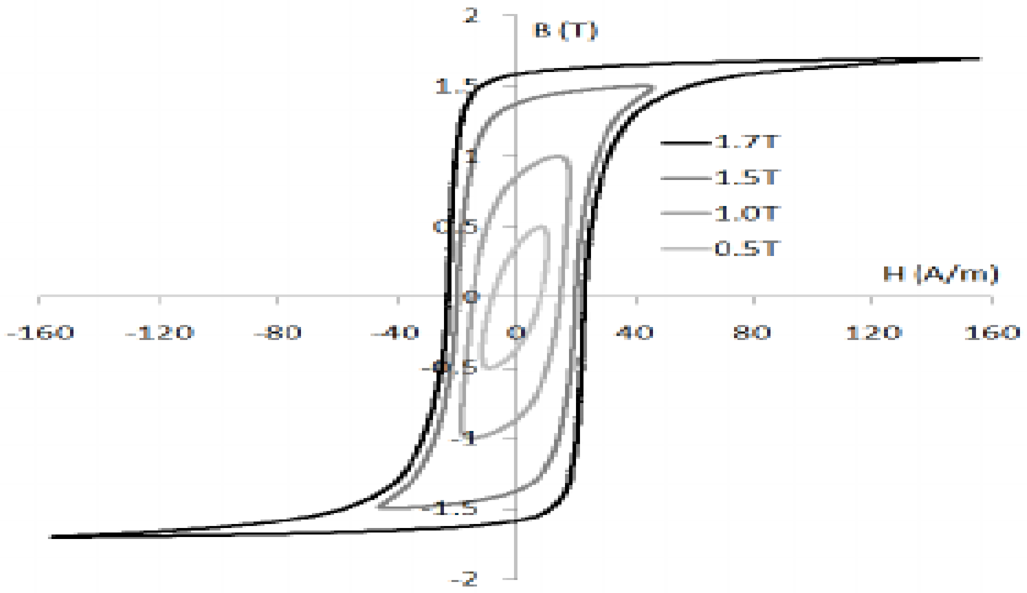


Figure I.16: BH Loop for Steel

According the figures (**Figure I.16, Figure I.15**) above we see that the hysteresis surface area is wider than hysteresis surface area of the super magnetic Hiperco 50 that means the hysteresis losses of Hiperco 50 is lesser than the steel hysteresis losses.

I.10 CONCLUSION

In this first chapter we presented the constitution of the induction machine and its various designs as well as its classifications. Then we exposed the different types of machine most used for rotating machines. And at the end of this chapter we briefly presented the materials we will use in the induction machine.

Chapter Ⅱ

Presentation of COMSOL Multiphysics

II.1 INTRODUCTION

COMSOL-Multiphysics is one of the most successful simulation programs used in design the induction motor and it's used in other applications. It has been used in this current work to analyze induction motor parameters. The "rotating machinery" interface in COMSOL-Multiphysics 5.6 has used to run a frequency domain and non-linear simulation of an induction machine's dynamic activity action. The two-dimensional FEM model is linked to electrical circuits by connecting the physics interfaces "rotating machinery" and "electrical circuit". Also, the COMSOL-Multiphysics has included the multi-time analysis in the same program like time-dependent, frequency-domain.

The two-dimensional model in the COMSOL program is a perfect method for studying induction motor behavior under different situations, speed, torque, and current values are depending on the precision of identification and calculation of induction motor parameters, geometry, and material properties. FE program, traditional analysis calculation, and actual measurement have been used to look into the flux density in the air gap, torque output of the dual 3-ph motor. The COMSOL AC/DC module's rotating machinery, the magnetic interface is used for stationery and time-domain modeling. The dependent variables in this physical interface, which satisfies Maxwell's equations, are the magnetic vector potential and magnetic scalar potential. The magnetic interface of the nodes ampere's law has used in the rotating machinery to solve the magnetic field in the motor. The main problem of the 3-phase induction motor is the beginning of the start operation torque and distribution of magnetic flux density. Therefore, this present paper suggested enhancing the performance design of a 3-phase induction motor squirrel cage by COMSOL-Multiphysics [11].

II.2 FINITE ELEMENT METHOD

The finite element method is often used for accurate modeling of electrical systems. This approach allows for a systematic approach that considers machine geometry and magnetic problems.

In addition, a coupling between the electrical, mechanical and magnetic quantities can be achieved [12].

The finite element method is one of the most widely used numerical methods today to efficiently solve partial differential equations of physical problems. This method is organized around these main steps:

- Definition of structure parameters.
- Creation of the parameters that define the geometry.
- Definition of areas and allocation of materials.
- Application of boundary conditions.
- Creation of the structure mesh.

II.2.1 Principle of finite element calculation

The principle of calculation by finite elements is to divide the structure of the studied machine into a large number of elements of finite dimensions then to solve Maxwell's equations on each of these elements. The boundary conditions of each element are fixed by the neighboring elements. The combination of all these calculation elements then makes it possible to know the magnetic state of the complete structure and therefore to perform calculations of flux, force, and inductance.

The advantage of this calculation method is that it allows, like any theoretical calculation, to have access to the three stages independently. The finite element method discretizes an integral formulation of the partial differential equation to lead to a system of algebraic equations which provides an approximate solution of the problem studied. The study domain is broken down into a finite number of polygonal elements which form the mesh. The value of the vector potential is determined on all the vertices of the polygons (the vertices are called the mesh nodes). By using appropriate interpolation functions, the solution at any point of the domain will be determined according to the values at the vertices of the element. To transform a system of partial differential equations by an integral formulation, the processes most often used are the method of weighted residuals or the variational method [12].

II.2.2 Main steps of the implementation of the finite element method

The implementation of the finite element method is based on three essential steps:

- Formulation of partial differential equations from physical laws.

- Transformation of the equations into an algebraic system that must be solved to obtain the solution of the problem posed.
- Running problems on computer from appropriate software.

II.2.3 Discretization and approximation

The fundamental idea of the finite element method is to subdivide the region to be studied into small sub-regions called finite element constituting the mesh. The unknown functions are approximated on each finite element by simple function called shape function which is continuous and defined on each element alone.

The shape of the elements is directly linked to the dimension of the problem (2D or 3D).

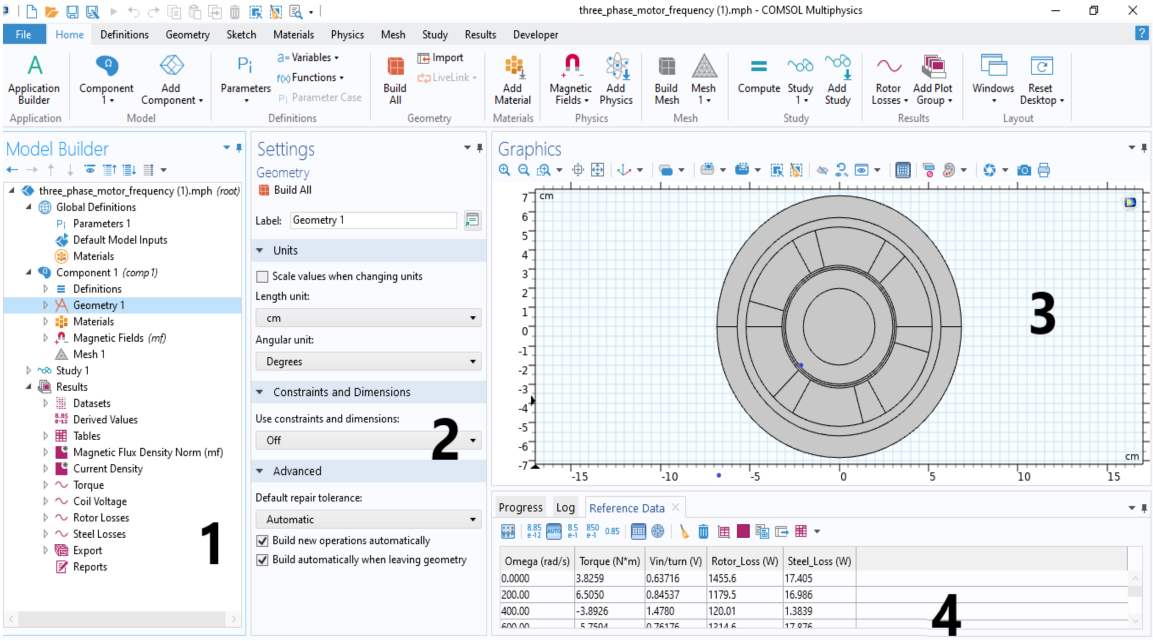
- For a (2D) geometry, we generally use triangles or quadrilaterals.
- For a (3D) geometry, we use tetrahedrons, prisms or the hexahedrons.

Discretization is an important step in finite element analysis because the precision of the results depends on the method of the discretization method and on the fineness of this subdivision into subdomains [12].

II.3 DESIGN ADVANTAGES WITH COMSOL-MULTIPHYSICS

The main purpose of the creation of COMSOL-Multiphysics is to have a software where scientists and engineers can formulate, using the user interface, any system of partial differential equations (EDP) based on the laws of physics and especially to be based on the most common areas in physics and engineering. This interface is based on an equation interpreter that formulates a finite element discretization by the fully coupled system. Predefined modeling interfaces for different areas of applied physics, including multi-physics couplings. Thanks to the underlying technology, properties, sources, sinks and boundary conditions can be functions of the modelled variables and their partial derivatives [13].

II.4 COMSOL MAIN MENU



Geometry
Build All
Label: Geometry 1
Units
☐ Scale values when changing units
Length unit: cm
Angular unit: Degrees
Constraints and Dimensions
Use constraints and dimensions: Off
Advanced
Default repair tolerance: Automatic
☑ Build new operations automatically
☑ Build automatically when leaving geometry

Omega (rad/s)	Torque (N*m)	Vin/turn (V)	Rotor_Loss (W)	Steel_Loss (W)
0.0000	3.8259	0.63716	1455.6	17.405
200.00	6.5050	0.84537	1179.5	16.986
400.00	-3.8926	1.4780	120.01	1.3839

Figure II.1: The interface of the COMSOL Multiphysics simulation software

On the left, we find the Model Builder (1) in which the problem to be studied is defined. In detail, the Global Definitions menu includes the variables and parameters of the problem. In the Component 1 menu are defined the default coordinate system, the Cartesian system, geometry, materials, physics (s) applied to problems and mesh. The following menu Study 1 allows you to define the resolution parameters, (stationary or time-dependent), as well as the options of the solver. Finally, the Result menu includes all the options for post-processing data.

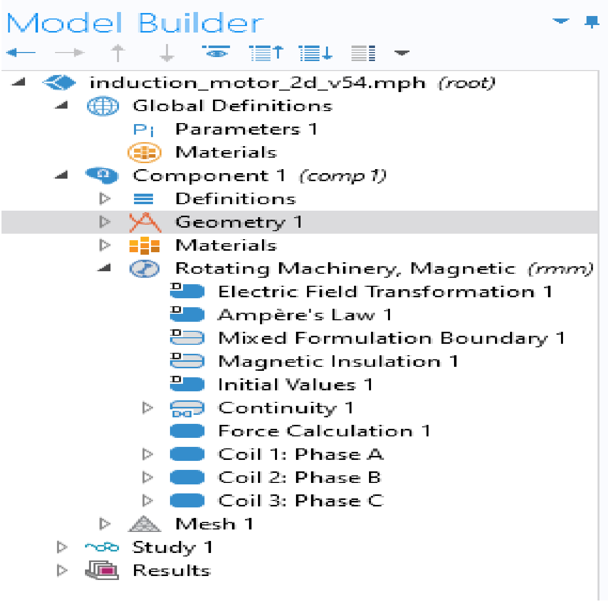
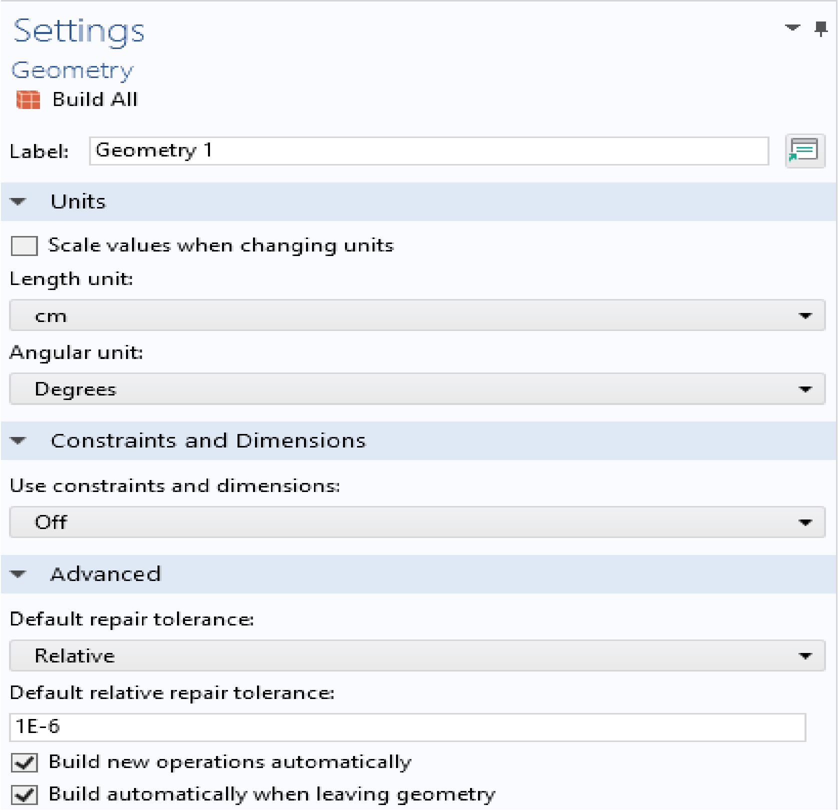


Figure II.2: Model Builder

The column directly to the right (2) (Setting) is used to enter data about the selected options in the Model Builder. For example, the dimensions of the object created in Geometry. It is also in this window that the initial values and boundary conditions of the simulation and the necessary physical models are chosen [13].



Settings

Geometry

Build All

Label: Geometry 1

Units

☐ Scale values when changing units

Length unit: cm

Angular unit: Degrees

Constraints and Dimensions

Use constraints and dimensions: Off

Advanced

Default repair tolerance: Relative

Default relative repair tolerance: 1E-6

☑ Build new operations automatically

☑ Build automatically when leaving geometry

Figure II.3: Settings

At the top right, the Graphics (3) graphical display interface allows you to view the geometry, mesh or results. At the top of this window are the options to change the magnification of the display, the orientation of a three-dimensional object, hide certain elements, etc.

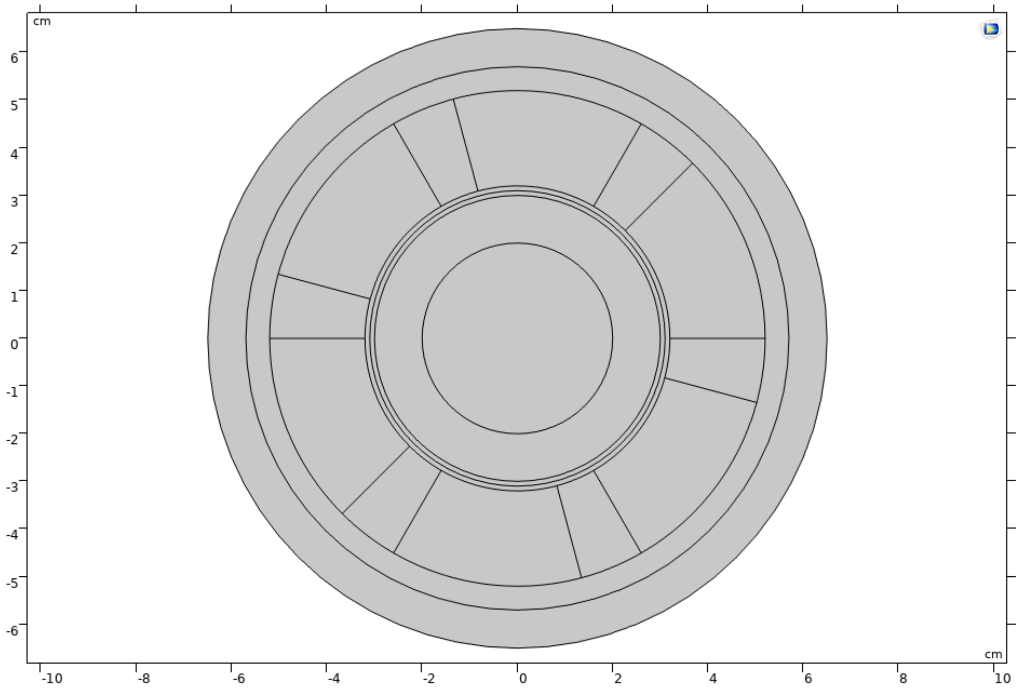
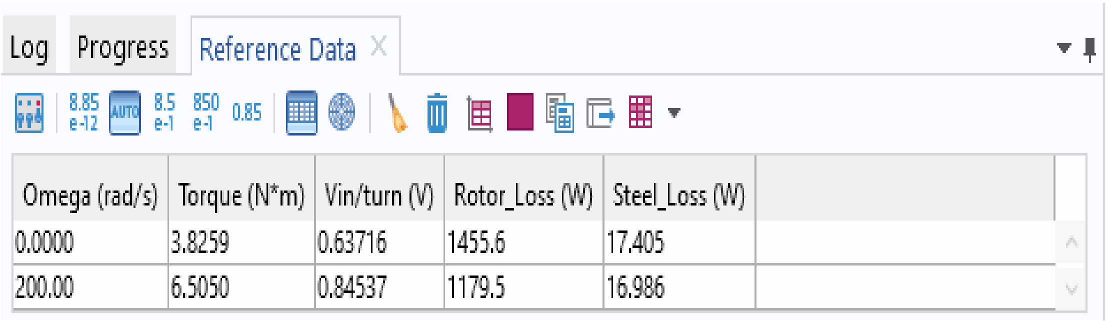


Figure II.4: Graphics

The options for selecting objects, domains, boundaries or points are also found at the top of this window.

Finally, directly below the graphical display window, a window (4) allows you to view any error messages, the progress of the simulations, the list of operations performed during the calculation of the solution as well as the numerical results calculated once the simulation is complete [13].



Omega (rad/s)	Torque (N*m)	Vin/turn (V)	Rotor_Loss (W)	Steel_Loss (W)
0.0000	3.8259	0.63716	1455.6	17.405
200.00	6.5050	0.84537	1179.5	16.986

Figure II.5: The numerical results calculated

II.5 MODELING AND SIMULATION BY COMSOL-MULTIPHYSICS

II.5.1 Creating the simulation model

① Open a new COMSOL simulation, select Model Wizard. This option allows you to define step by step the modalities of the problem.

② Then choose a 2D spatial model.

③ You must then choose the appropriate physical model. Select the Heat Transfer in Solids (ht) and Kat Transfer in Pipes (htp) model in the Chemical Species Transport category. Click Add and then click ➔ Study

④ After selecting the model, you need to select the desired study type. Under Preset Studies, choose the Stationary case study, and then click ☑ Done

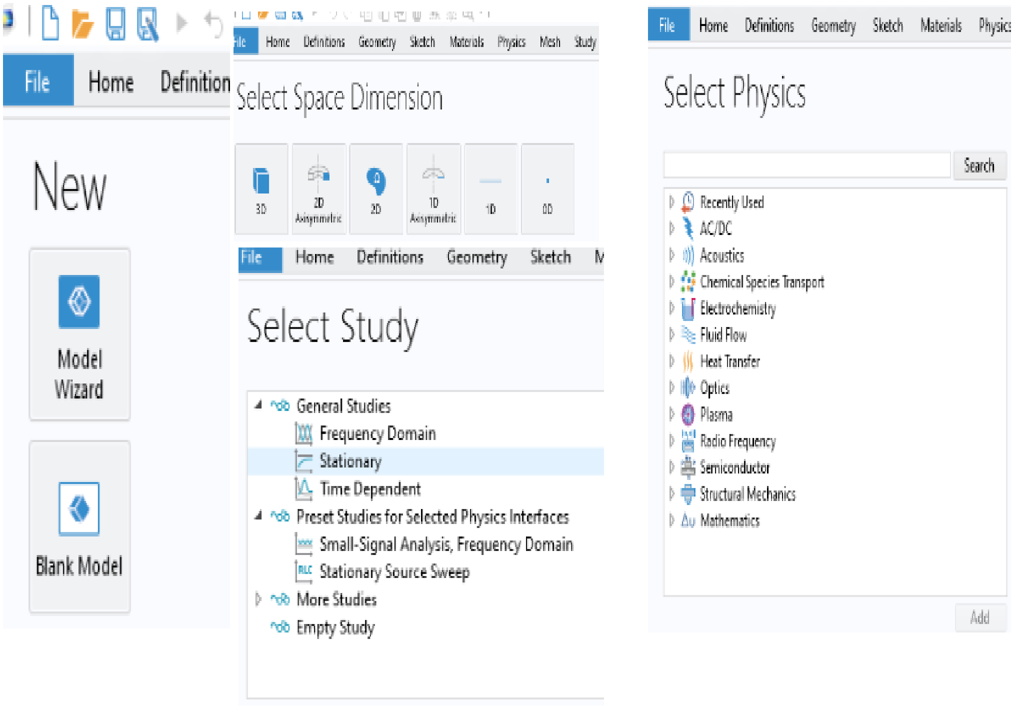
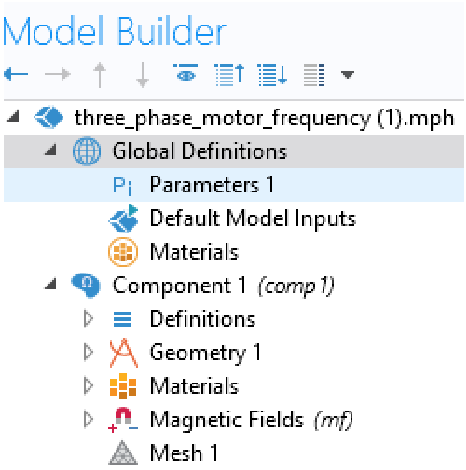


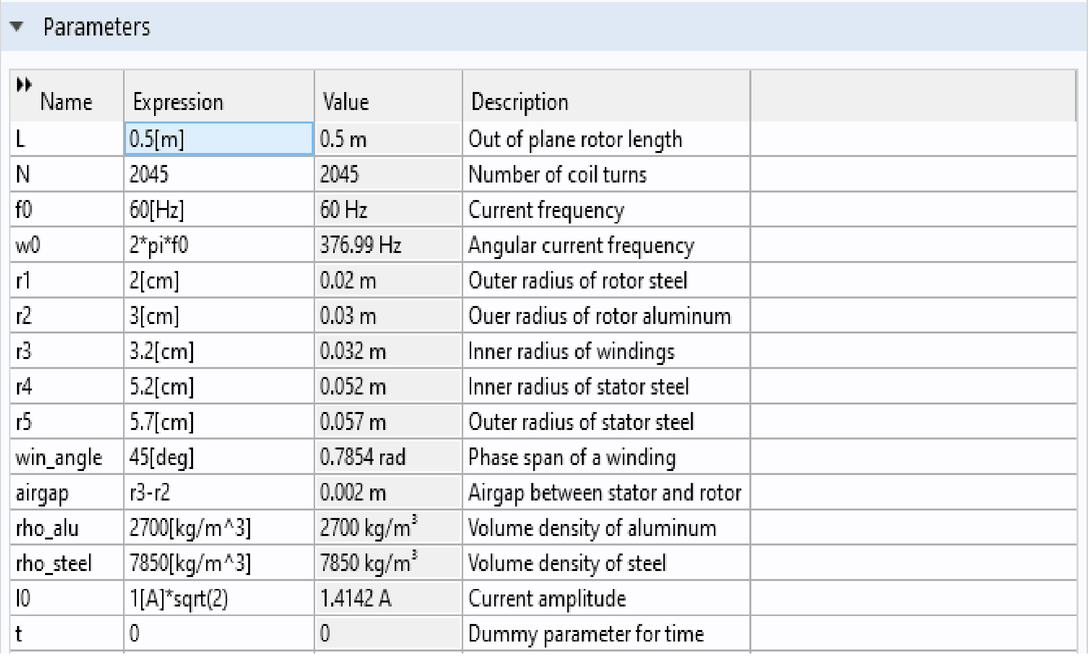
Figure II.6: The steps to create a simulation model

- Setting global definitions


Model Builder

- three_phase_motor_frequency (1).mph
  - Global Definitions
    - Parameters 1
    - Default Model Inputs
    - Materials
  - Component 1 *(comp 1)*
    - Definitions
    - Geometry 1
    - Materials
    - Magnetic Fields *(mf)*
    - Mesh 1

Figure II.7: Parameters add to the template



Parameters

Name	Expression	Value	Description
L	0.5[m]	0.5 m	Out of plane rotor length
N	2045	2045	Number of coil turns
f0	60[Hz]	60 Hz	Current frequency
w0	2*pi*f0	376.99 Hz	Angular current frequency
r1	2[cm]	0.02 m	Outer radius of rotor steel
r2	3[cm]	0.03 m	Ouer radius of rotor aluminum
r3	3.2[cm]	0.032 m	Inner radius of windings
r4	5.2[cm]	0.052 m	Inner radius of stator steel
r5	5.7[cm]	0.057 m	Outer radius of stator steel
win_angle	45[deg]	0.7854 rad	Phase span of a winding
airgap	r3-r2	0.002 m	Airgap between stator and rotor
rho_alu	2700[kg/m^3]	2700 kg/m³	Volume density of aluminum
rho_steel	7850[kg/m^3]	7850 kg/m³	Volume density of steel
I0	1[A]*sqrt(2)	1.4142 A	Current amplitude
t	0	0	Dummy parameter for time

Figure II.8: Table of Simulation model parameters

II.5.3 Creating the geometry of the problem

When we construct the geometry of the induction motor in COMSOL-Multiphysics, we create two unions. One is for the stator domains and the other is for the rotor domains. We finalize the geometry using the Form Assembly operation, so that the identity pair is automatically between the rotor and the stator [11].

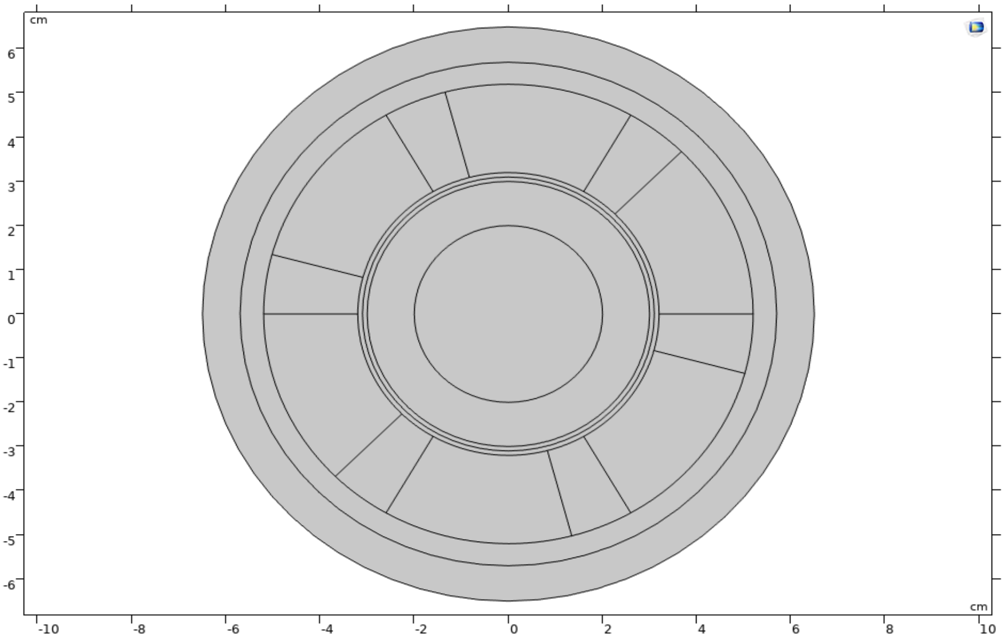


Figure II.9: Construction of 2D geometry

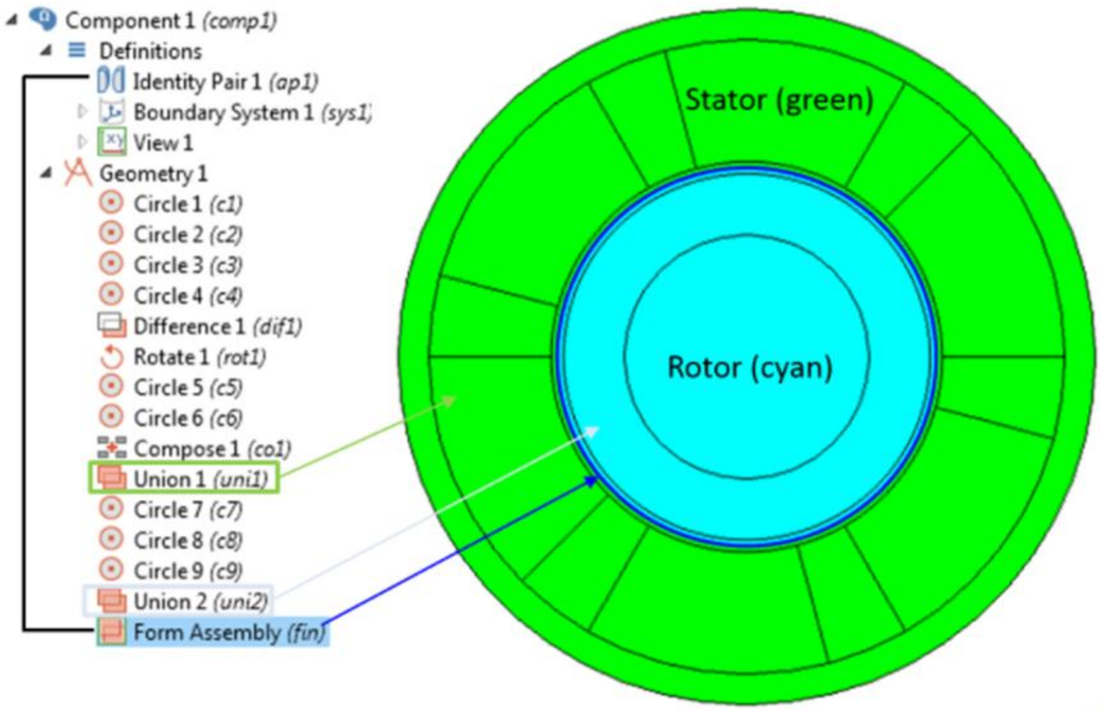


Figure II.10: Assembly between the two unions of rotor and stator

The material properties used in this model are listed in the following table. The density of the material is not given in the original TEAM document, therefore, we assume the density of the rotor steel and aluminum to be 7850 kg/m^3 and 2700 kg/m^3, respectively, to compute the rotor inertia.

We use the Rotating Machinery, Magnetic interface to simulate the electromagnetic fields in this three-phase induction motor. Since all of the electrical and magnetic material properties are linear, the default Ampère’s *Law* node works without any modification.

We model the three phases using the *Homogenized* and *Multi-turn Coil* features. The number of turns for each winding is n_0 = 2045. Each stranded wire carries 1[A] current with 120° out of phase between the three phases. The currents through the three phases are described as:

1. I_A = 1[A]*cos(w0*t)*sqrt(2) (II.1)
2. I_B = 1[A]*cos(w0*t+120[deg])*sqrt(2) (II.2)
3. I_C = 1[A]*cos(w0*t-120[deg])*sqrt(2) (II.3)

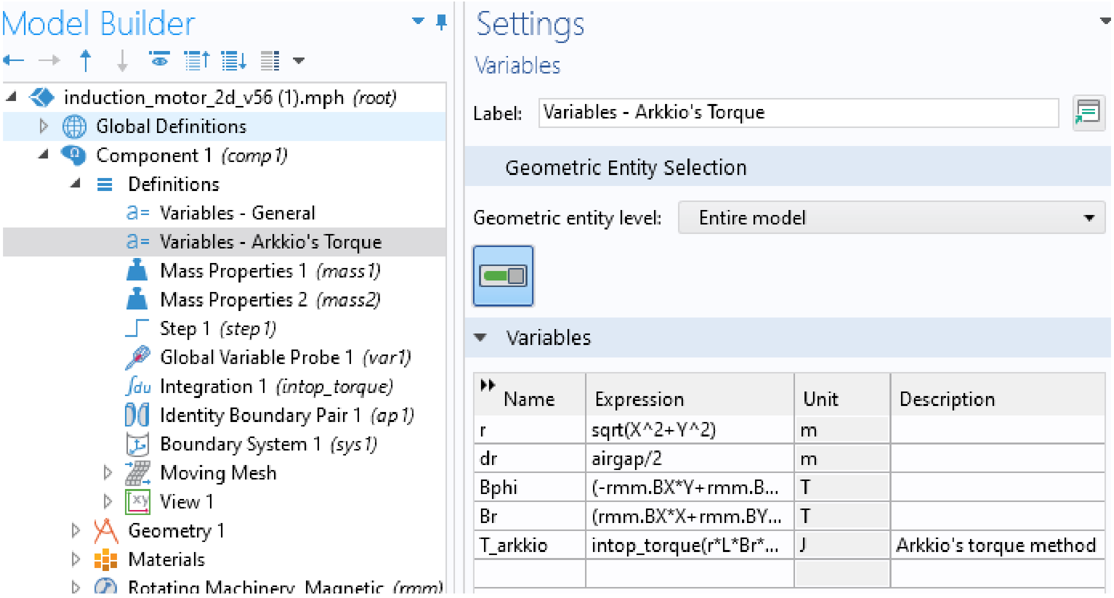
Here, 1[A] is the RMS value of the input current so we need to multiply it with sqrt (2) to make it a peak value.

We can obtain the electromagnetic torque in the rotor directly by using the *Force Calculation* feature in the *Rotating Machinery, Magnetic* interface. By adding this feature, the spatial component of the magnetic forces (rmm.Forcex_0, rmm.Forcey_0, rmm.Forcez_0) and the axial torque (rmm.Tax_0) in this interface can be obtained when postprocessing. The Force Calculation feature simply integrates the Maxwell stresses over the entire outer boundary of the domain selection. Since this method is based on surface integration, the computed force is sensitive to mesh size. When using this method, it is important to always perform a mesh refinement study to correctly compute the force or torque.

The alternative approach would be to use Arkkio's method of torque calculation, a volume integration of the product of the magnetic flux densities. In this method, the electromagnetic torque in 2D models of electrical rotating machines can be calculated using the following expression:

$$\mathrm{T_e} = \frac{1}{\mu_0(\mathrm{r_0}-\mathrm{r_1})}\int_{\mathrm{S_{ag}}} \mathrm{rB_rB_\emptyset ds} \tag{II.4}$$

where r_0 is the outer radius, r_1 is the inner radius, and S_{ag} is the cross-sectional area of the air gap, The magnetic flux density in the radial and azimuthal directions is B_r and $B_\emptyset$, respectively. Refer to the following screenshots for more details on implementing Arkkio's method in COMSOL-Multiphysics.



Label: Variables - Arkkio's Torque

Geometric entity level: Entire model

Name	Expression	Unit	Description
r	sqrt(X^2+Y^2)	m	
dr	airgap/2	m	
Bphi	(-rmm.BX*Y+rmm.B...	T	
Br	(rmm.BX*X+rmm.BY...	T	
T_arkkio	intop_torque(r*L*Br*...	J	Arkkio's torque method

Figure II.11: Implementation of Arkkio's method of torque calculation for an Induction Motor

II.5.4 Mesh

The mesh that you choose for your COMSOL-Multiphysics simulation strongly affects your modeling requirements. In fact, meshing is one of the most memory-intensive steps when it comes to setting up and solving a finite element problem. Mesh generation is a very important phase in the work given its influence on the calculated solution in terms of precision and calculation time.

The Figure below contains a structured mesh created by COMSOL-Multiphysics.

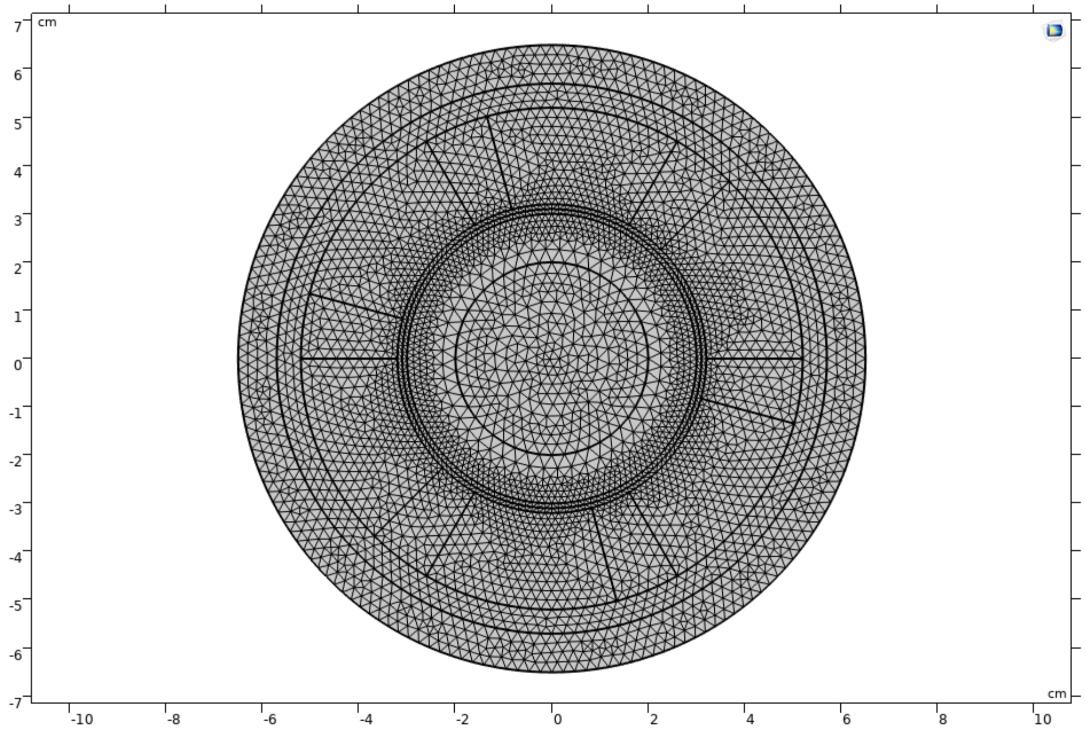


Figure II.12: Induction motor mesh

As we have demonstrated here, modifying meshing sequences is a powerful tool for greatly reducing mesh elements and thus minimizing computational time — all while still delivering accurate results for the key areas of a geometry [11].

II.6 CONCLUSION

The main part of this chapter, the software used in this study is COMSOL-Multiphysics version 5.6. contains a guide to write our thesis simulation program and how to model the potential and intensity of the stationary electric field in the Induction Motor.

Chapter III

Simulation, Results and Interpretation

III.1 INTRODUCTION

Simulation is a modeling technique widely used in the performance evaluation of electrical systems.

It is very interesting to have a simulation environment that includes the possibility of adding different physical phenomena to the model studied, which has allowed the evolution of the field of robotics and electrical machines.

It is in this philosophy that COMSOL-Multiphysics was developed. It is a modular finite element numerical calculation software for modeling a wide variety of physical phenomena characterizing a real problem. It will also be a design tool thanks to its ability to manage complex 3D geometries.

Different physical modules exist in COMSOL-Multiphysics, among which we find fluid mechanics, heat transfer, electricity, electromagnetism, chemistry, structural mechanics... It is possible to combine several physical phenomena during the same simulation digital: this is one of the strengths of this software.

III.2 GETTING STARTED WITH THE SOFTWARE

The modeling and numerical simulation process under COMSOL-Multiphysics involves several steps:

- The global definition of parameters and variables related to the model.

  The definition of its geometry.

- Taking into account the different physical phenomena that may exist in the problem under consideration.
- Solving the problem using one of the different solvers.
- Visualization of the results.

III.3 POTENTIAL OF COMSOL-MULTIPHYSICS

The potential of COMSOL-Multiphysics is numerous and it depends on the number of applications that can be solved thanks to its complete environment for scientific computing. He is able to couple and solve equations in different fields such as fluid mechanics and heat transfer, electromagnetism, fluid dynamics and chemistry, MEMS and Structural Mechanics. It also offers several solvers very high level of performance capable of dealing with problems with optimal resolution times. This and other features make COMSOL-Multiphysics an unparalleled modeling environment for industrial design, research & development, and education.

COMSOL was used during this study to model and simulate the magnetic field in the Induction machine.

III.4 DEFINING IM PARAMETERS

The first task allows the layout of the geometry of the machine and affects the different materials as well as the boundary conditions in the various regions of the study domain.

- **Three Phase Induction Motor:**

  Current amplitude: I_0= 1.4142 A

  Angular current frequency: w_0= 376.99 Hz

  Number of coils turns: N= 2045

  Volume density of aluminum: rho_alu= 2700 kg/m^3

  Volume density of steel: rho_steel= 7850 kg/m^3

  Volume density of Hiperco 50: rho_Hiperco= 8120 kg/m^3

  Out of plane rotor length: L= 0.5 m

  Phase span of a winding: win_angle= 0.7854 rad

  Airgap between stator and rotor: airgap= r_3-r_2= 0.002 m

  Outer radius of rotor: r_1= 0.02 m

  Outer radius of rotor aluminum: r_2= 0.03 m

  Inner radius of windings: r_3= 0.032 m

  Inner radius of stator: r_4= 0.052 m

  Outer radius of stator: r_5= 0.057 m

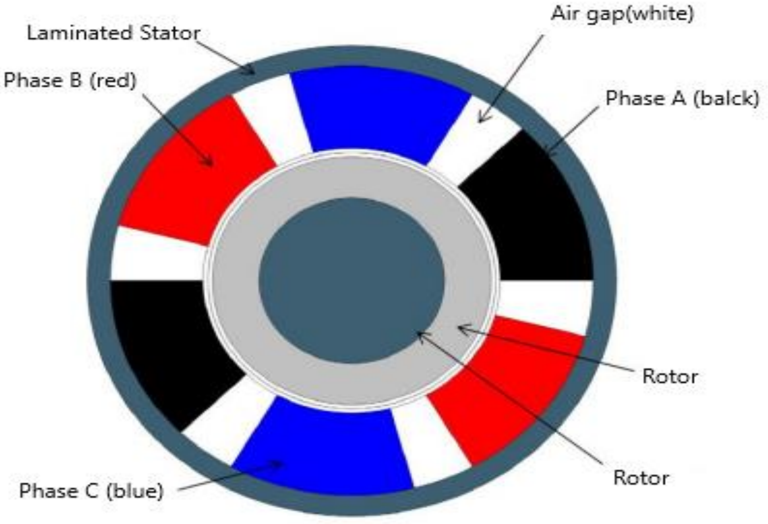
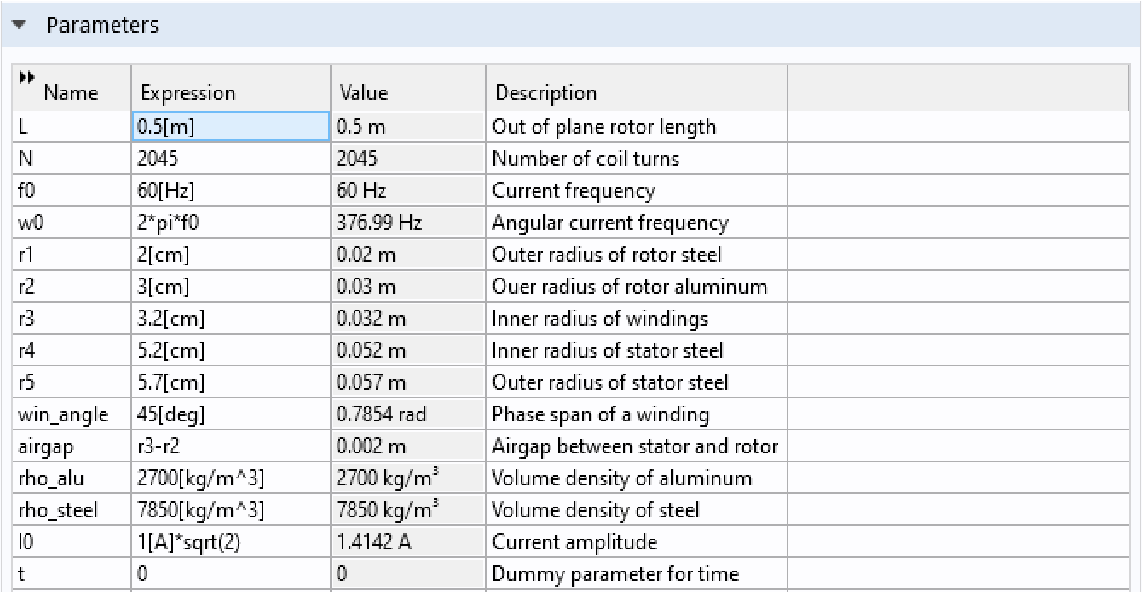


Figure III.1: 2D section of the Induction Motor



Name	Expression	Value	Description	
L	0.5[m]	0.5 m	Out of plane rotor length	
N	2045	2045	Number of coil turns	
f0	60[Hz]	60 Hz	Current frequency	
w0	2*pi*f0	376.99 Hz	Angular current frequency	
r1	2[cm]	0.02 m	Outer radius of rotor steel	
r2	3[cm]	0.03 m	Ouer radius of rotor aluminum	
r3	3.2[cm]	0.032 m	Inner radius of windings	
r4	5.2[cm]	0.052 m	Inner radius of stator steel	
r5	5.7[cm]	0.057 m	Outer radius of stator steel	
win_angle	45[deg]	0.7854 rad	Phase span of a winding	
airgap	r3-r2	0.002 m	Airgap between stator and rotor	
rho_alu	2700[kg/m^3]	2700 kg/m³	Volume density of aluminum	
rho_steel	7850[kg/m^3]	7850 kg/m³	Volume density of steel	
I0	1[A]*sqrt(2)	1.4142 A	Current amplitude	
t	0	0	Dummy parameter for time	

Figure III.2: Parameter of IM

III.5 PHYSICS

For modeling our induction motor, we used two physics (**The Rotating Machinery, Magnetic Interface** and **The Magnetic Fields Interface**) will be giving a preface about the two physics.

III.5.1 Rotating Machinery, Magnetic Interface

The Rotating Machinery, Magnetic (rmm) interface ( ), found under the AC/DC>Electromagnetics and Mechanics branch when adding a physics interface, is used for design and analysis of electric motors and generators. Stationery and time-domain modeling is supported in 2D and 3D.

The physics interface solves Maxwell's equations formulated using a combination of magnetic vector potential and magnetic scalar potential as the dependent variables.

When this physics interface is added, these default nodes are also added to the Model Builder — Electric Field Transformation, Ampère’s Law, Mixed Formulation Boundary, Magnetic Insulation (the default boundary condition), and Initial Values. Then, from the Physics toolbar, add other nodes that implement, for example, boundary conditions and point conditions. You can also right-click Rotating Machinery, Magnetic to select physics features from the context menu.

III.5.2 Magnetic Fields Interface

The Magnetic Fields (mf) interface, found under the AC/DC>Electromagnetic Fields branch when adding a physics interface, is used to compute magnetic field and induced current distributions in and around coils, conductors, and magnets. Depending on the licensed products, stationary, frequency-domain, small-signal analysis, and time-domain modeling are supported in 2D and 3D. Note that the frequency and time-domain formulations become ill-posed when approaching the static limit. You can extend the useful frequency range downward by adding a low conductivity.

The physics interface solves Maxwell’s equations, which are formulated using the magnetic vector potential and, optionally for coils, the scalar electric potential as the dependent variables.

The main node is Ampère’s law, which adds the equation for the magnetic vector potential and provides an interface for defining the constitutive relations and its associated properties, such as the relative permeability.

When this physics interface is added, these default nodes are also added to the Model Builder — Magnetic Fields, Ampère’s Law, Magnetic Insulation (the default boundary condition), and Initial Values. Then, from the Physics toolbar, add other nodes that implement boundary conditions and external currents. You can also right-click Magnetic Fields to select physics features from the context menu.

At the end of studying the influence of materials on engine performance, we choose to work with two different materials, namely Hiperco 50 and steel.

III.6 MATERIALS

The below table shows both of the physical properties of Hiperco50 and Steel material

Sr. No	Property	Hiperco50	Steel
1	Saturation flux density, T	2.44	1.7
2	Relative permeability	10000	30
3	Curie temperature, ^{0}C	940	770
4	Electric conductivity, S/m	2.38	1
5	Core losses at 60 Hz and 1.5 T, W/kg	1.73	1.5
6	Core losses at 400 Hz and 1.5 T, W/kg	17.47	10

Table III.1: The physical properties of Steel and Hiperco 50

III.7 RESULTS AND INTERPRETATION

III.7.1 Number of mesh and Time Dependent

Mesh generation is a very important phase in the work given its influence on the calculated solution in terms of precision and calculation time.

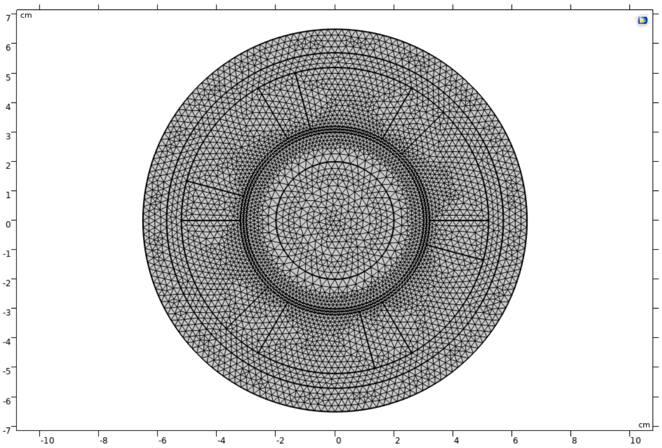
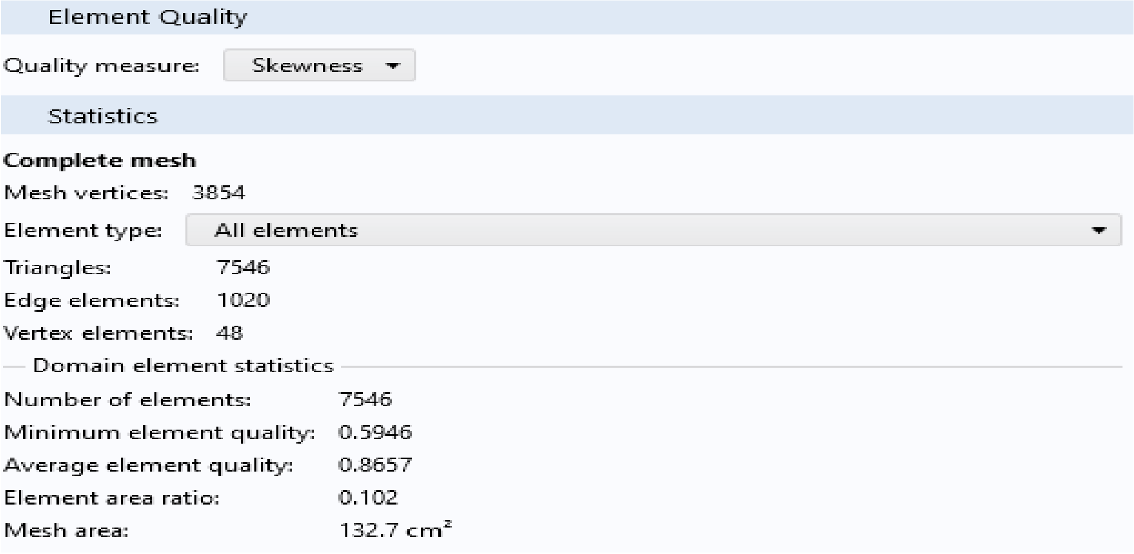


Figure III.3: State of the model after meshing



Element Quality

Quality measure: Skewness

Statistics

Complete mesh

Mesh vertices: 3854

Element type: All elements

Triangles: 7546

Edge elements: 1020

Vertex elements: 48

Domain element statistics

Number of elements: 7546

Minimum element quality: 0.5946

Average element quality: 0.8657

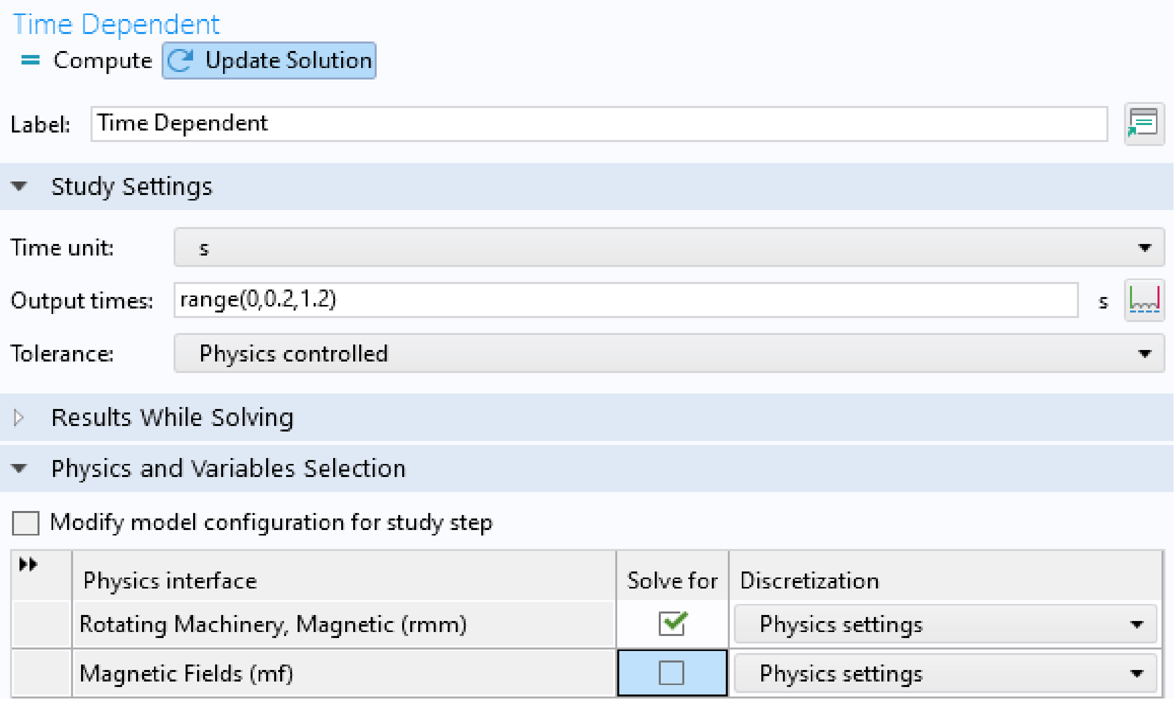
Element area ratio: 0.102

Mesh area: 132.7 cm^2

Figure III.4: Number of meshing

Time-dependent simulations, check that the initial conditions and the boundary conditions match at the start time. If they do not match, the model setup is likely unphysical, and the time-dependent solver can take very small-time steps trying to reconcile inconsistent initial values.

For example, in electromagnetics, it is used to compute transient electromagnetic fields, including electromagnetic wave propagation in the time domain.



Time Dependent

Label: Time Dependent

Study Settings

Time unit: s

Output times: range(0,0.2,1.2) s

Tolerance: Physics controlled

Results While Solving

Physics and Variables Selection

☐ Modify model configuration for study step

Physics interface	Solve for	Discretization
Rotating Machinery, Magnetic (rmm)	☑	Physics settings
Magnetic Fields (mf)	☐	Physics settings

Figure III.5: Time-dependent simulations

III.7.2 Current of Induction Motor

In the following figure we represent the current waveforms from the three phases of Induction Motor (A, B, C) as a function of time (s).

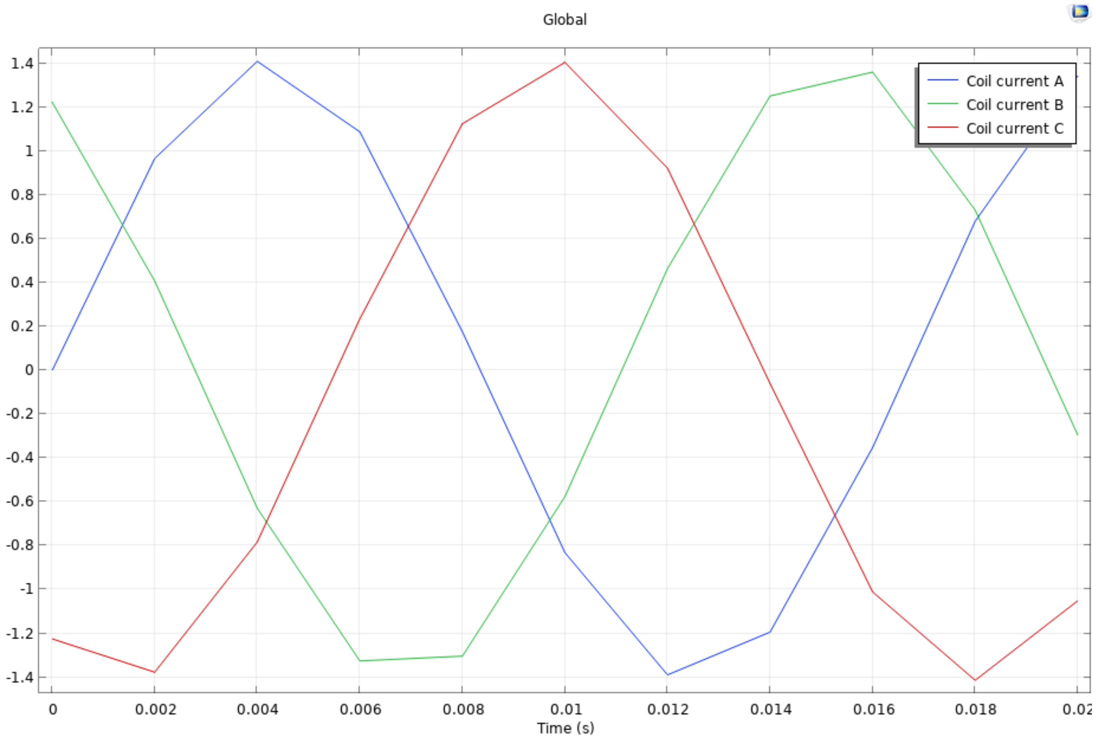


Figure III.6: The currents waveform from Induction Motor

According to **Figure III.6** we note that the currents is three-phase, then we are in the right direction to the desired results that means that the program is working fine.

III.7.3 Flux calculation in IM

The COMSOL Multiphysics Software allows us to calculate the flux in the three coils (A, B, C) by introducing the equation (III.1) in the parameters of the induction machine (IM):

$$\boldsymbol{\varphi} = \iint \boldsymbol{B}\, \boldsymbol{ds} \qquad \text{(III.1)}$$

B : induction magnétique.

$\boldsymbol{ds}$ **:** surface area

$\boldsymbol{\varphi}$: magnetic flux

In the following figure we represent the coil concatenated flux (Wb) as a function of time (s).

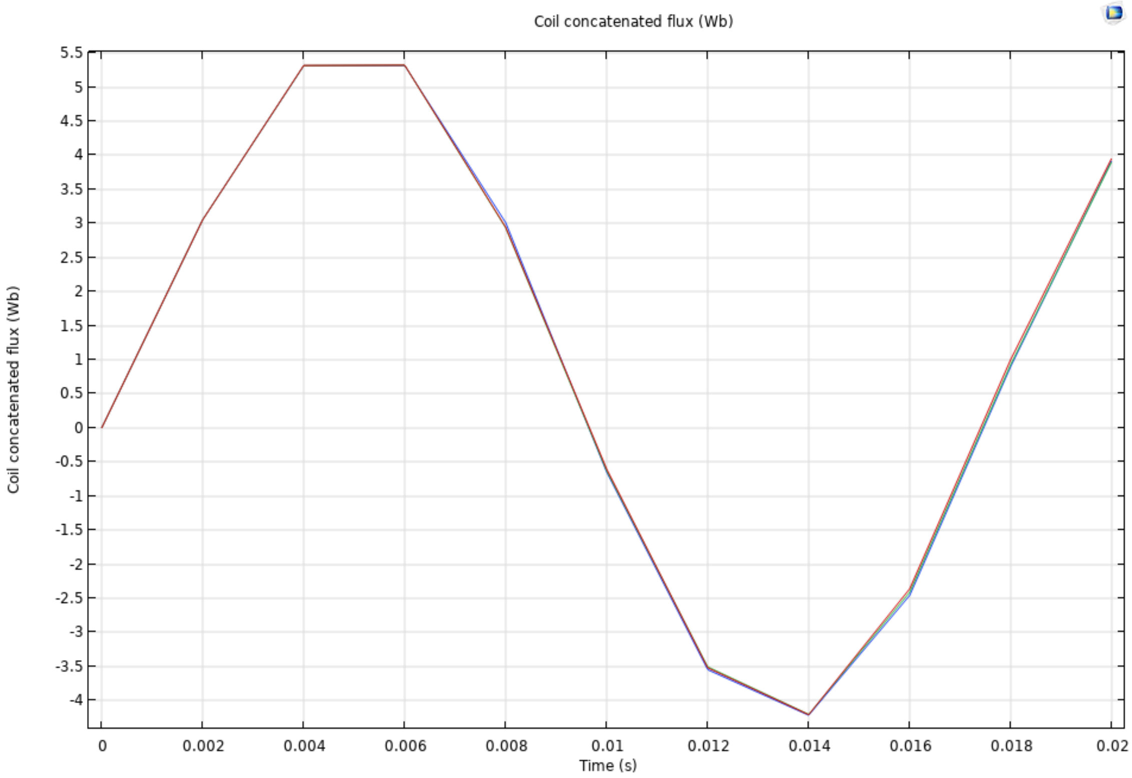


Figure III.7: The coil concatenated flux (Wb)

We note that the curve of the flux is periodic (the current curve is periodic). The flux reaches a maximum value of 5.2 Wb and where its minimum value of the flux is -4.3Wb.

III.7.4 Joule losses

Joule losses in electrical networks are not only a degradation factor, but also a shortfall for electricity companies. The standards require that these losses cannot exceed 3% of the power consumed in the electrical transmission networks and 5% in the electrical distribution networks.

As we have:

$$P= RI^2 \tag{III.2}$$

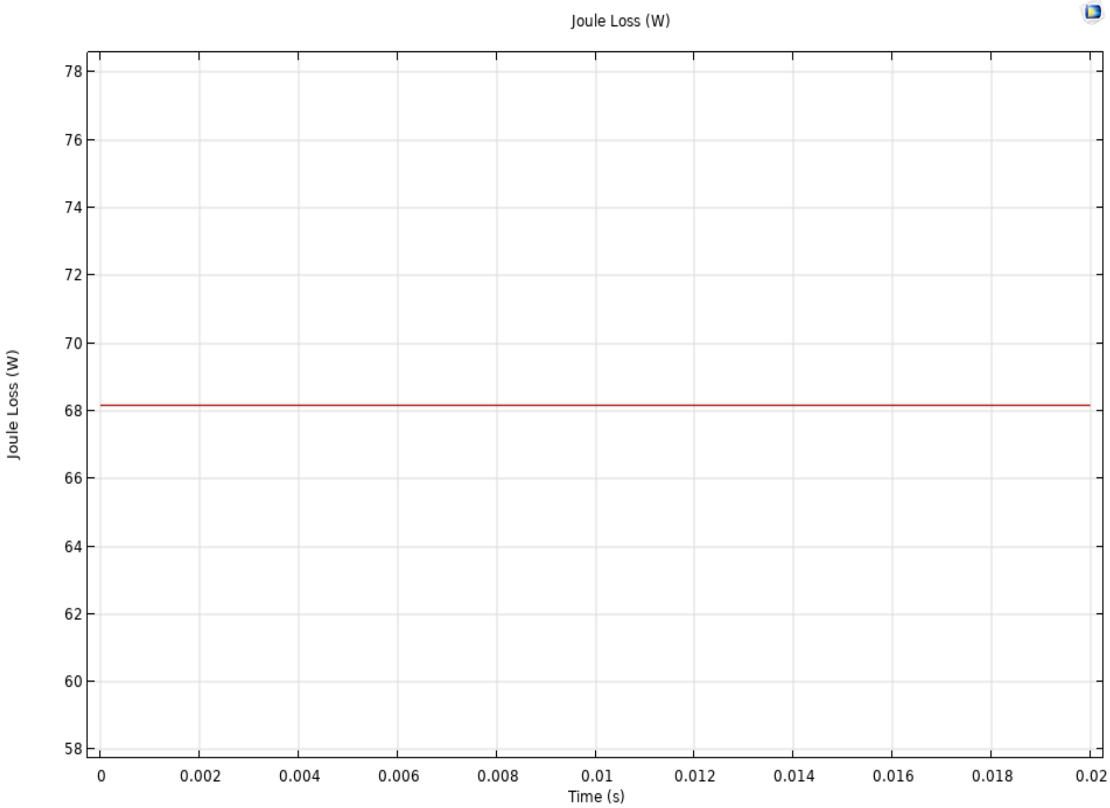


Figure III.8: Coil joule losses for the two materials

As we can see in the figure above, that the coil joule losses are fixed in approximately 68 J for both the Steel and super-magnetic Hiperco 50 materials.

III.7.5 Simulation result using steel

III.7.5.a Calculation of magnetic induction B in the IM

Among the results that can be calculated with the COMSOL Multiphysics Software are the equipotential lines of the vector potential A as well as the distribution of the magnetic induction in 2D.

The following figure shows the distribution of the magnetic field in the machine in the case of the material steel.

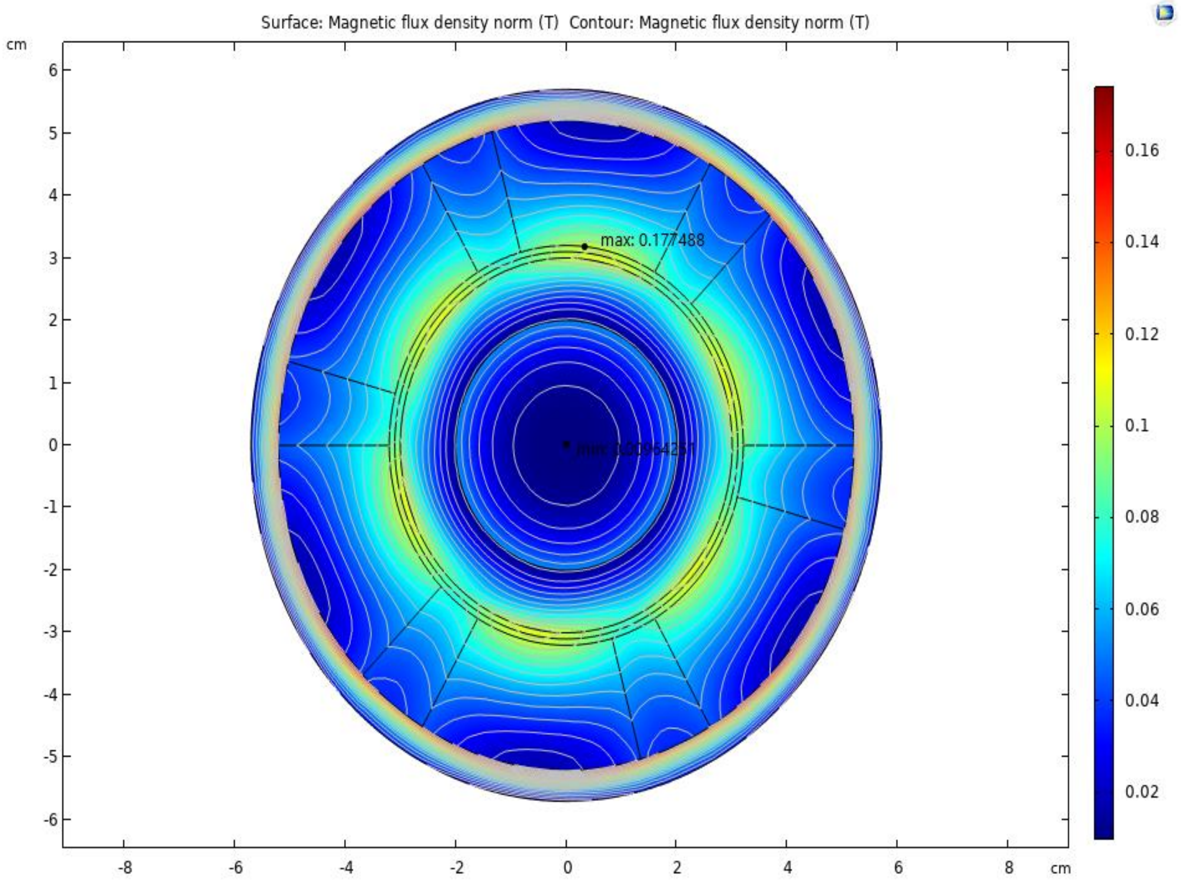


Figure III.9: magnetic field distribution when using steel material for the 2D model in COMSOL Multiphysics

we note that the lines of the magnetic field are concentrated in the air-gap where the maximum value of the field is 0.17T, in addition to the minimum value of the induction field is 0.0096T.

The following graph below represent the distribution of the magnetic field as a function of the radius of our motor using Steel material.

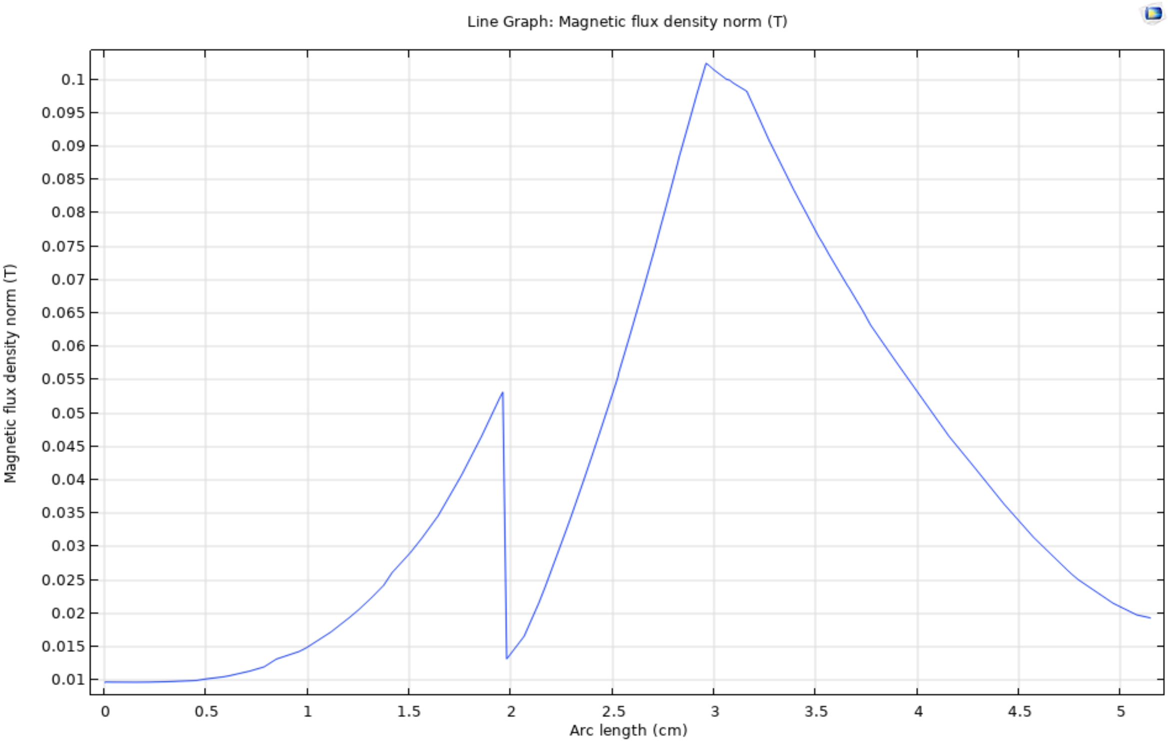


Figure III.10: Magnetic field as a function of Outer radius of stator steel

According to the figure above we note that it starts from 0.01T then reach first a maximum value of 0.054T then it diminishes to 0.014 and for a second time it reaches a maximum value 0.1T which corresponds the Airgap area.

III.7.5.b Total magnetic energy using steel

The presence of a magnetic field is globally expressed by an energy, called “magnetic energy”. It is expressed by:

$$W_m = \frac{B^2}{2\mu} \qquad \text{(III.3)}$$

B: magnetic field

μ : Permeability of material

The following graphs below represent the Total magnetic energy using Steel material.

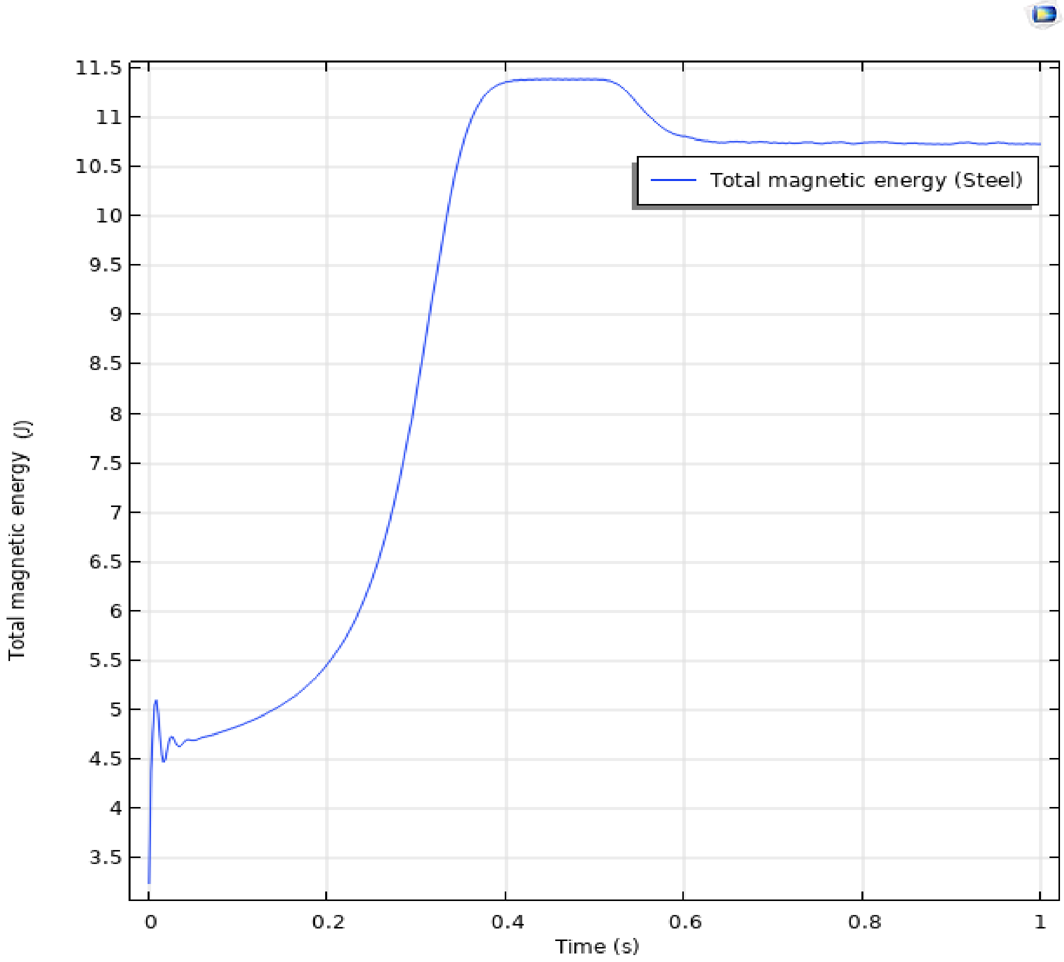


Figure III.11: Total magnetic energy of Steel

We note from the figure above that the total magnetic energy of the Induction Motor (IM) when using Steel material, it starts from 0 then reach approximately a maximum value 11.3 J then stabilize at 10.7J.

III.7.5.c SIMULATED TORQUE

The following figure shows the torque of the Induction Motor when using the steel material.

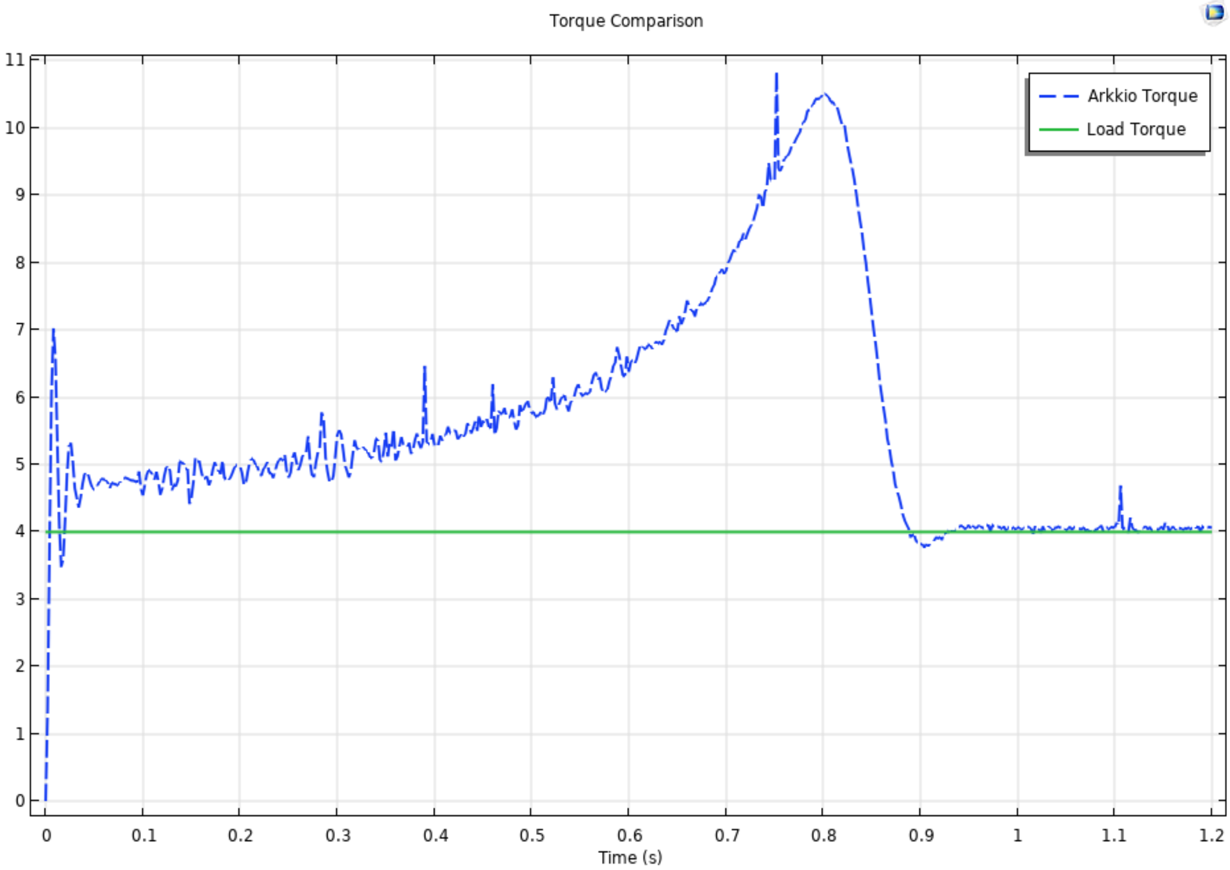


Figure III.12: Torque as a function of time -Steel

According to the results of the simulation we note that the Arkkio torque at the beginning of the motor operation is increasing during the transitional regime, we see large fluctuations in this phase. Then the torque reaches its peak approximately 10.5 N.m and then begins to decrease we notice a small trough before reaching the permanent regime from the moments 0.9s until it matches the value of the nominal torque 4 N.m. We also see a small fluctuation in this phase.

III.7.6 Simulation result using Hiperco 50

III.7.5.a Calculation of magnetic induction B in the IM

The following figure shows the distribution of the magnetic field when using the super magnetic material Hiperco 50.

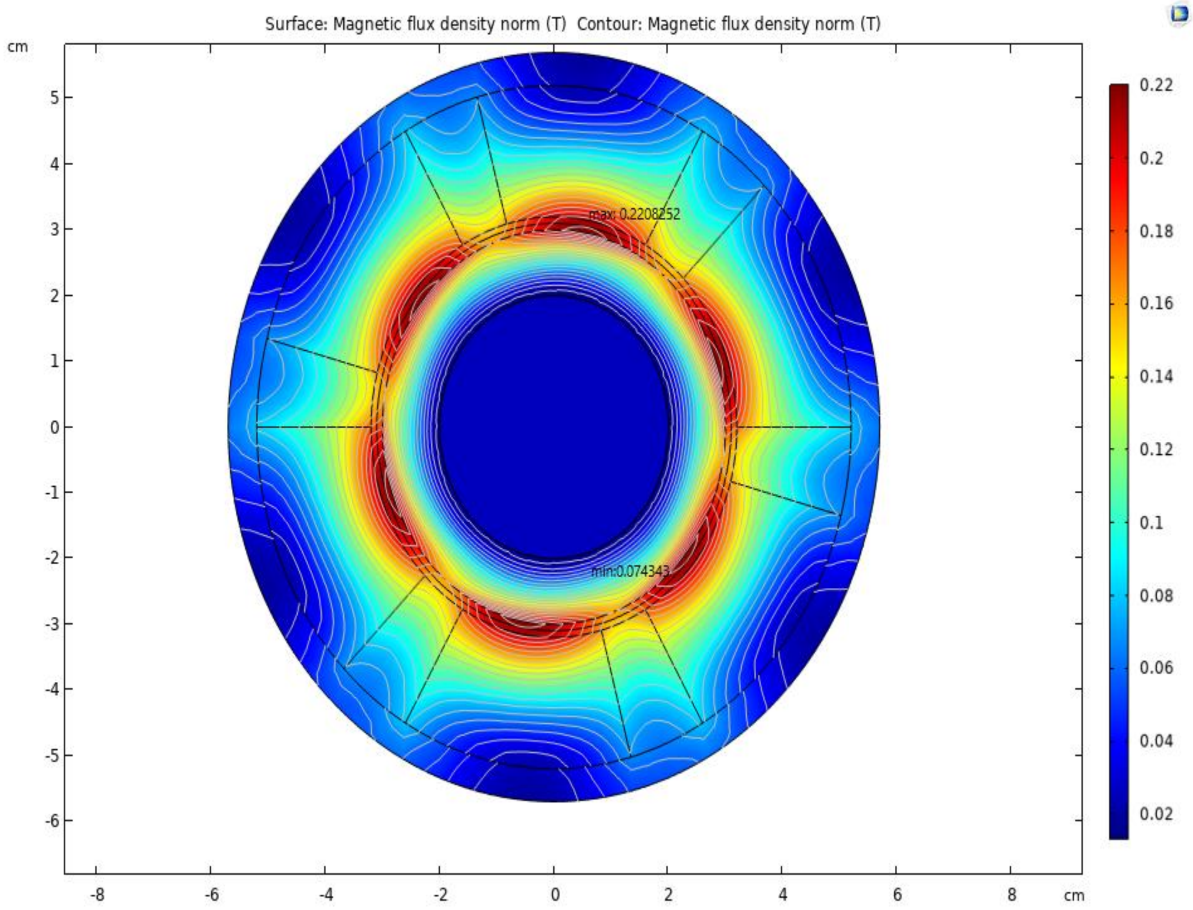


Figure III.13: Magnetic field distribution when using Hiperco 50 for the 2D model in COMSOL Multiphysics

We note that the lines of the magnetic field are concentrated in the air-gap where the maximum value of the induction field is 0. 22T, in addition to the minimum value of the induction field is 0.074T.

The following graph below represent the distribution of the magnetic field as a function of the radius of our motor using super-magnetic Hiperco 50.

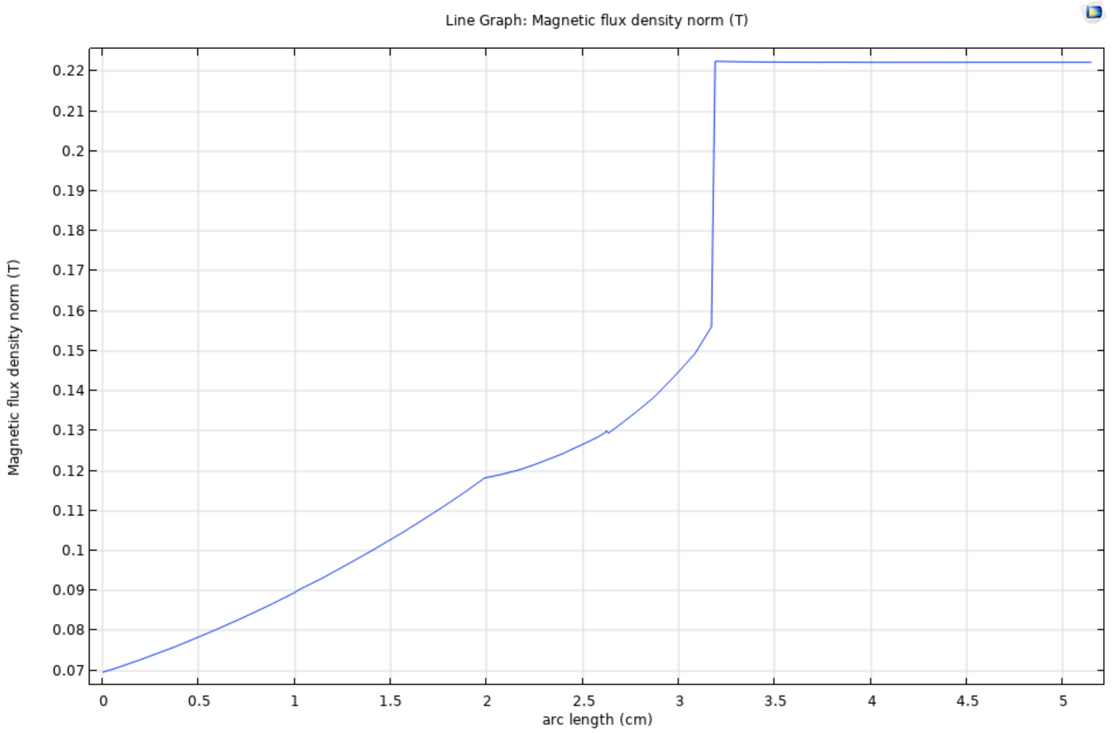


Figure III.14: Magnetic field as a function of the Outer radius of stator of the super magnetic material Hiperco 50

According to the figure above we note that it starts from 0.07T then reach a maximum value of 0.221T which corresponds the Airgap area

III.7.5.b Total magnetic energy using Hiperco 50

The following graphs below represent the Total magnetic energy using the super-magnetic material Hiperco 50.

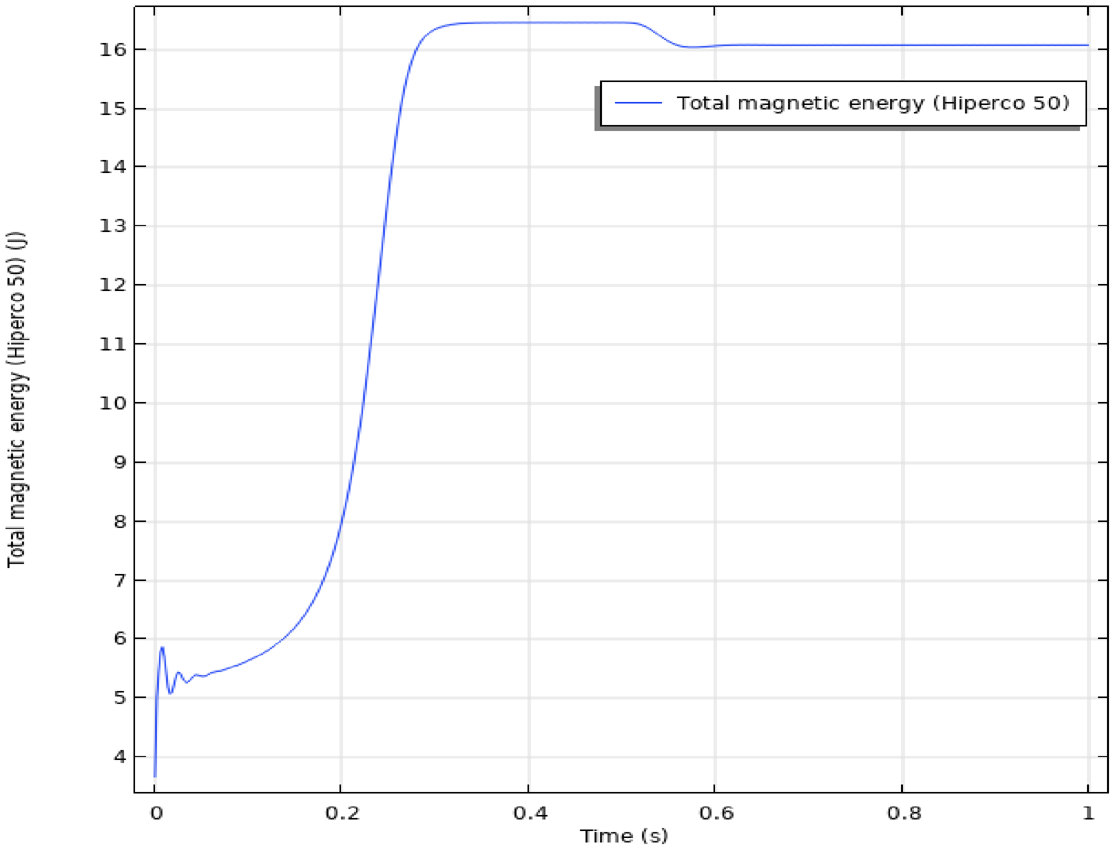


Figure III.15: Total magnetic energy of Super-magnetic Hiperco 50

We note from the figure above that the total magnetic energy of the Induction Motor (IM) when using Hiperco 50 material it starts from 0 then reach approximately a maximum 16.5J then stabilize at 16J.

III.7.5.c SIMULATED TORQUE

The following figure shows the torque of the Induction Motor when using the Super-magnetic material Hiperco 50.

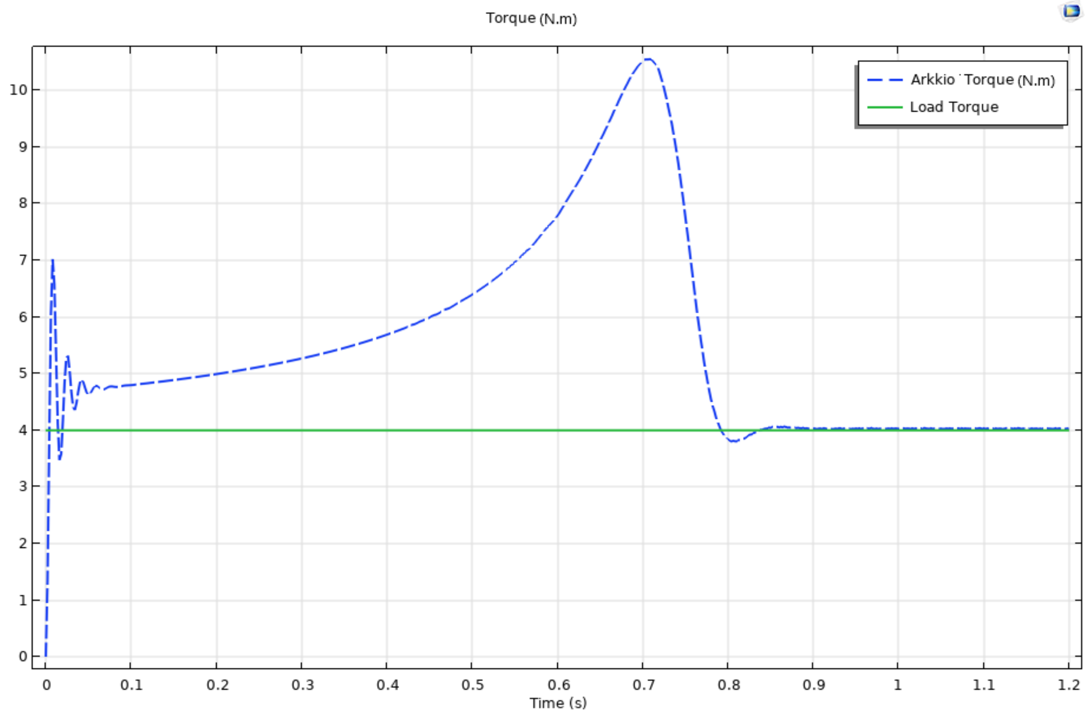


Figure III.16: Torque as a function of time -Hiperco 50

According to the results of the simulation we note that the Arkkio torque at the beginning of the motor operation is increasing during the transitional regime, it reaches its peak approximately 10.8 N.m and then begins to decrease we notice a small trough before reaching the permanent regime from the moments 0.8s until it matches the value of the nominal torque 4 N.m.

III.8 CONCLUSION

Hiperco 50 provide the highest magnetic induction than Steel material it also exhibits high permeability and low core loss.

From the results we got from COMSOL Multiphysics we see that Hiperco 50 is far better than steel it has high magnetic induction and the magnetic energy is higher than steel.

Hiperco 50 produces a fast and better Torque output than Steel for the same load.

In general, Hiperco 50 super magnetic alloy has better magnetization properties and produces faster torque than steel.

GENERAL CONCLUSION

The work presented concerns the simulation of the Induction Machine IM by COMSOL-Multiphysics software, this simulation software calculates its results using the Finite Element method.

In the modern design of electric machines, the finite element method has gained considerable momentum with the advent of computing means. This method allows the physical equations to be solved directly with minimal assumptions, and also allows coupling of the physical equations to the equations of the circuits that make up the static converter.

- ➢ In the first chapter we presented generalities on the Induction Motor IM; its operating principle, its constituents and its construction, the types of the Induction Motor IM and its advantages and disadvantages, its fields of application, brief definition about the super magnetic alloy Hiperco 50.
- ➢ In the second chapter we showed a preface of the COMSOL-Multiphysics as well as the geometric parameters and the modulation steps of our model, and we also presented the finite element method.
- ➢ In the third chapter, we presented the studied and the simulation results obtained by the COMSOL software.
we compared the results of the two materials (Torque, Magnetic field, Joule losses...etc.). This allowed us to show the influence of the two materials (steel and the super magnetic alloy Hiperco 50) on the IM.

The starting point in the near future could be the manufacture of this induction motor, so that it is presented in motorcycles engines for racing to give them more torque or in the engines of robots in factories to speed up their work and increase the life and efficiency of the robot and reduce its weight.

In general, it’s better to replace Steel with better material due to its intolerance for a long time due to humidity or phenomena that occurs on it, which leads to its corrosion and expensive maintenance.

In this work we have improved the performance of the induction motor by changing its magnetic material Steel with Hiperco 50, but we didn't take in consideration the economical part. So, in the future we are planning to realize economical study about its cost.

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Abstract

In this research, we are interested in studying the induction motor, where we aspire to improve the way, it works by changing its materials with other new materials. Which in turn contributes to raising the efficiency of the induction motor in several ways.

In order to Modulate and simulate, we used the COMSOL-MultiPhysics Software. This program studies physical phenomena such as mechanical force and magnetic saturation in solid media.

ملخص

في هذه البحث نحن مهتمون بدراسة المحرك الحثي, حيث نطمح الى ان نحسن من طريقة عمله عن طريق تغير مواده الداخلية بمواد اخرى. و التي بدورها تساهم برفع كفاءة المحرك الحثي بعدة طرق.

من اجل تنفيذ عملنا استعملنا برنامج COMSOL-Multiphysics. و يعمل هذا البرنامج على دراسة الظواهر الفيزيائية مثل القوة الميكانيكية و التشبع المغناطيسي في الوسائط الصلبة.