DESIGN AND FABRICATION OF ENERGY-EFFICIENT INDUCTION MOTOR WITH ELECTRICAL OUTPUT

A PROJECT REPORT

Submitted by

V.KARTHIK BALAJI	-	**71204105026**
M.VIVEK	-	**71204105060**
A.KRISHNA KUMAR	-	**71204105303**

in partial fulfillment for the Award of the Degree
of

BACHELOR OF ENGINEERING

in

ELECTRICAL AND ELECTRONICS ENGINEERING

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

KUMARAGURU COLLEGE OF TECHNOLOGY

COIMBATORE - 641 006

ANNA UNIVERSITY : CHENNAI - 600 025

APRIL - 2008

ANNA UNIVERSITY : CHENNAI - 600 025

BONAFIDE CERTIFICATE

Certified that this project report entitled **"DESIGN AND FABRICATION OF ENERGY EFFICIENT INDUCTION MOTOR WITH ELECTRICAL OUTPUT"** is the bonafide work of

V.KARTHIK BALAJI - Register No. 71204105026
M.VIVEK - Register No. 71204105060
A.KRISHNA KUMAR - Register No. 71204105303

who carried out the project work under my supervision.

16/4/2k8

Signature of the Head of the Department
Prof. K. Regupathy Subramaniam

Signature of the Guide
Mrs. K.Malarvizhi

Certified that the candidate with university Register No. 71204105026 71204105060 71204105303 was examined in project viva-voce Examination held on 21-04-2008

Internal Examiner

21/4/08
External Examiner

DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING
KUMARAGURU COLLEGE OF TECHNOLOGY,
COIMBATORE - 641006

CERTIFICATE

TO WHOMSOEVER IT MAY CONCERN

We certify that the below named B.E. (Electrical and Electronics Engineering) students of Kumaraguru College of Technology,

1. **Mr. V.Karthik Balaji (Reg.No.71204105026)**
2. **Mr. M.Vivek (Reg.No.71204105060)**
3. **Mr. A.Krishna Kumar (Reg.No.71204105303)**

have carried out an innovative project **"Design and Fabrication of Energy Efficient Induction Motor with Electrical Output"** in our industry and they have successfully completed the same.

For **Sharp Tools - Motor Division,**

K.R.Pandian,

Partner & C.E.O.

ABSTRACT

ABSTRACT

Electrical power demand of a country is the index of its growth. Expansion of power generating projects become necessary in our country. It is well known that around 60% of electricity generated is utilized by induction motor due to their wide usage. The induction motor has dominated industrial applications to almost 80% that it was predicted that the other motors would be absolute soon. Induction motors find universal applications in almost all industries. Nearly three-fourth of the motors that drive in the industrial gears are of induction type, in particular cage motors.

In this project, a novel design of three phase induction motor is developed in which energy conservation is more than that expected from the conventional design. The developed model is a dual stator winding induction machine, categorized as "split wound". It consists of a standard squirrel-cage rotor and a stator with two separate three phase windings wound for similar number of poles. One winding is used to meet the mechanical load working as an induction motor. The other winding develops three phase EMF and it works as a generator. Its output can be used to feed the lighting load, which need not depend on separate supply while the machine is in operation. Conventional mechanical loading and additional electrical loading are possible on the same machine leading to better efficiency and energy conservation.

The testing of this motor under mechanical loading condition establishes itself as a conventional induction motor. But when the electrical load is tapped out along-with mechanical load, there is no additional power absorbed from the supply and hence increase in the efficiency of the machine is considerable. This is due to the fact that both electrical and mechanical loads are catered by each of the three phase windings in the stator of a three phase induction motor. The usage of electrical power for lighting loads during the conventional motor operation paves a great way for energy conservation.

ACKNOWLEDGEMENT

ACKNOWLEDEGEMENT

The completion of our project can be attributed to the combined efforts made by us and the contribution made in one form or the other by the individuals and the industry people we hereby acknowledge.

We would like to express our deep sense of gratitude and profound thanks to our guide **Mrs. K.Malarvizhi**, M.E., Senior Lecturer, Electrical and Electronics Engineering Department, for her valuable guidance, support, constant encouragement and co-operation rendered throughout the project.

We are very grateful to **Mr. K.R.Pandian**, B.E., M.B.A., Managing Director, Sharp Tools, for encouraging and providing us the opportunity to work on this project in their industry and his staff members **Mr. P.Balamurugan** and **Mr. S.Ravindran** for their guidance and technical support at all stages of this project.

We express our heart felt gratitude and thanks to the Dean / HOD of Electrical & Electronics Engineering, **Prof. K.Regupathy Subramanian**, B.E.(Hons), M.Sc., for encouraging us and for being with us right from beginning of the project and guiding us at every step.

We are also thankful to all the teaching and non-teaching staffs of Electrical and Electronics Engineering department for their kind help and encouragement.

We extend our sincere thanks to all our parents and friends who have contributed their invaluable ideas and encouraged us for completing the project.

CONTENTS

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

S. NO.	SYMBOLS	ABBREVIATIONS
01	HP	Horse Power
02	KW	KiloWatt
03	mm	Millimetre
04	RPM	Rotations Per Minute
05	rps	Revolutions Per Second
06	EMF	Electromotive Force
07	LRC	Locked Rotor Current
08	LRT	Locked Rotor Torque
09	FLC	Full load Current
10	FLT	Full Load Torque
11	DOL	Direct-On-Line
12	TEFC	Totally Enclosed Forced air Cooled
13	V	Volt
14	A	Ampere
15	Hz	Hertz
16	S	Slip
17	N	Rotor Speed
18	N_s	Synchronous Speed
19	S_s	No. of Stator Slots
20	Y_{ss}	Stator Slot Pitch

CHAPTER 1

CHAPTER 1

INTRODUCTION

1.1 NEED FOR THE PROJECT

The induction motor has dominated industrial applications to almost 80% that it was predicted that the other motors would be absolute soon. Induction motors find universal applications in almost all industries. Nearly three-fourth of the motors that drive in the industrial gears are of induction type, in particular cage motors.

If it is possible to improve the efficiency of the induction motors even by a small percentage it provides a great contribution to the energy conservation. The emerging interest on energy conservation has brought some focus on energy efficient and energy conserving induction motors. In this project we present a method, which deals with the improvement of the efficiency of the cage rotor induction motor thus leading to energy conservation. The efficiency of induction motors range from 70% to 90% depending on the design and rating. If by some way the operating efficiency of the induction motor can be improved by even 1% would lead to significant energy conservation.

Industries all over the world are becoming aware of the problem of consuming too much energy and are making conscious effort to conserve it. By conserving energy we preserve the precious non-renewable fuel resources for the future. There is a growing need to bring about improvement in the efficiency of energy use in the industrial sector. The industrial sector consumes about 50% of the total commercial energy produced. In that most of the energy is consumed by induction motors. The efficiency of conventional induction motors can be improved by better design, utility of slot space factor and good thermal stability.

1.2 OBJECTIVE

- To design and fabricate an energy efficient induction motor with an additional identical (similar number of poles) stator winding (Double layer lap wound) which provides electrical output for lighting loads in addition to its conventional mechanical output.
- To conduct combined electrical and mechanical load test on this motor and to represent the increase in efficiency of the machine.

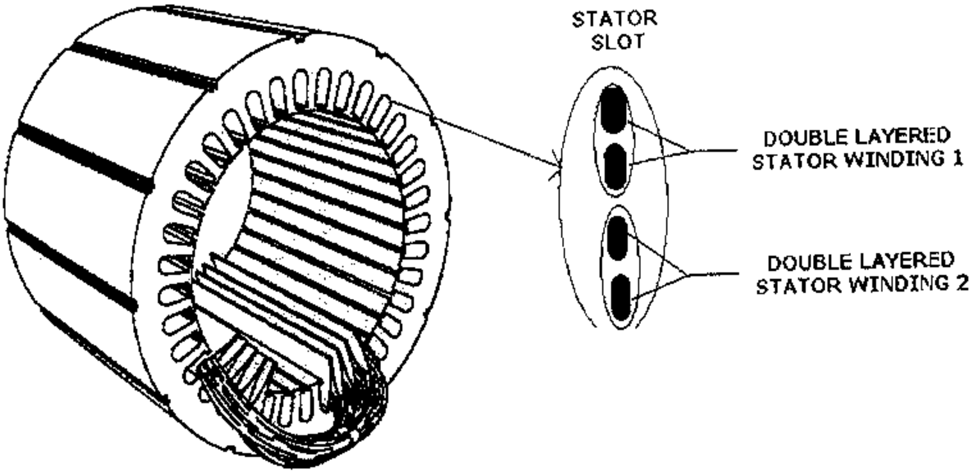


Fig.1 Stator and Stator slots (semi-enclosed) with Two Double-layered stator windings

1.3 ORGANISATION OF THE REPORT

Chapter 1 : Introduction to the project stating the need for this approach, Objective Methodology.

Chapter 2 : Induction Motor - An overview.

Chapter 3 : Design - Describes about the equivalent circuit, starting and running characteristics, stator and rotor design, insulation and bearing specifications.

Chapter 4 : Testing - Details of No load test, Blocked rotor test, Conventional Mechanical load test, Combined electrical and mechanical load test are provided.

Chapter 5 : Conclusion - The project work is done and the scope for improvements in the design based on the test results are discussed

1.4 METHODOLOGY

The sequence of work carried out have been listed below :

Stator Design - Design of stator slots and windings.
Rotor Design - Selection of rotor material, shaft and Bearings.
Frame - Selection of frame based on the stator and rotor.
Testing - Mechanical load test.
- Electrical load test.
- Combined electrical and mechanical load tests.
Analysis - Continual process to improve design based on the test results.
Verification - Measurement of voltage and current levels by connecting lighting loads.

CHAPTER 2

CHAPTER 2

INDUCTION MOTOR - AN OVERVIEW

2.1 AC MOTOR

An AC motor is an electric motor that is driven by an alternating current. An AC motor consists of two basic parts:

- An outside stationary stator having coils supplied with AC current to produce a rotating magnetic field, and;
- An inside rotor attached to the output shaft that is given a torque by the rotating field.

2.2 INDUCTION MOTOR

An induction motor (IM) is a type of AC motor where power is supplied to the rotating device by induction. 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. But in an AC motor this power is induced in the rotating device. An induction motor can be 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 widely used, especially polyphase induction motors, which are frequently used in industrial drives.

Induction motors are now the preferred choice for industrial motors due to their rugged construction, lack of brushes and thanks to modern power electronics the ability to control the speed of the motor.

2.2.1 PRINCIPLE OF OPERATION

The induction motor does not have any supply onto the rotor; instead, a secondary current is induced onto the rotor. Conductors in the rotor induce a current as the rotating magnetic field created by the stator windings sweep past them much in the same way as in a transformer. This current in the rotor conductors will therefore induce a magnetic field which will interact with the rotating magnetic field in the stator and the rotor will turn. For this to happen, the speed of the 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 current will be induced. If this happens, the rotor slows slightly until a current is re-induced 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 to the speed of the rotating field. Due to this an induction motor is sometimes referred to as an asynchronous machine.

2.2.2 HISTORY

In 1882 Serbian-American inventor Nikola Tesla identified the rotating magnetic induction field principle; and pioneered the use of this rotating and inducting electromagnetic field force to generate torque in rotating machines. He exploited this principle in the design of a poly-phase induction motor in 1883. In 1885, Galileo Ferraris independently researched the concept. In 1888, Ferraris published his research in a paper to the Royal Academy of Sciences in Turin.

Introduction of Tesla's motor from 1888 onwards initiated what is sometimes referred to as the Second Industrial Revolution, making possible both the efficient generation and long distance distribution of electrical energy using the alternating current transmission system, also of Tesla's invention (1888). Before widespread use of Tesla's principle of poly-phase induction for rotating machines, and all motors operated by continually passing a conductor through a stationary magnetic field.

Initially Tesla suggested that the commutators from a machine could be removed and the device could operate on a rotary field of electromagnetic force. Professor Poeschel, his teacher, stated that would be akin to building a perpetual motion machine. This was because Tesla's teacher had understood one half of Tesla's ideas. Professor Poeschel had realized that the once induced rotating magnetic field would start the rotor of the motor spinning, but he did not see that the counter electromotive force generated would gradually bring the machine to a stop. Tesla would later obtain U.S. Patent 0,416,194, Electric Motor (December 1889), which resembles the motor seen in many of Tesla's photos. This classic alternating current electro-magnetic motor was an induction motor. Michail Osipovich Dolivo-Dobrovolsky later invented a three-phase "cage-rotor" in 1890. This type of motor is now used for the vast majority of commercial applications.

2.3 THREE-PHASE INDUCTION MOTOR

Where a poly-phase electrical supply is available, the three-phase (or poly-phase) AC induction motor is commonly used, especially for higher-powered motors. The phase differences between the three phases of the poly-phase electrical supply create a rotating electromagnetic field in the motor.

Through electromagnetic induction, the time changing and reversing (alternating in direction poly-phase currents) rotating magnetic field induces a time changing and reversing (alternating in direction)current in the conductors in the rotor; this sets up a time changing and counterbalancing moving electromagnetic field that causes the rotor to turn in the direction the field is rotating. The rotor always moves (rotates) slightly behind the phase peak of the primary magnetic field of the stator and is thus always moving slower than the rotating magnetic field produced by the poly-phase electrical supply.

Induction motors are the workhorses of industry and motors up to about 500 kW (670 horsepower) in output are produced in highly standardized frame sizes, making them nearly completely interchangeable between manufacturers (although European and North American standard dimensions are different). Very large induction motors are capable of tens of thousands of kW in output, for pipeline compressors, wind-tunnel drives and overland conveyor systems.

2.4 DUAL STATOR WINDING INDUCTION MOTOR

The dual stator winding or "Split-wound" machine was introduced in the 1920's as a means of increasing the total power capability of large synchronous generators. Since then they have been used in many different applications ranging from synchronous machines with AC and DC outputs, as part of uninterrupted power supplies (UPS) and as current-source inverters to large pumps, compressors and rolling mills. But the dual stator winding motors are used for speed control by feeding variable frequency voltage to both the stator windings.

An innovative approach to create a novel design of this dual stator winding motor is made by changing the stator design. Instead of using dissimilar number of poles as in the design of speed control, when similar number of poles are used in both stator windings one of the windings can be used to supply mechanical power and the other is used to supply electrical power.

2.4.1 CONSTRUCTION

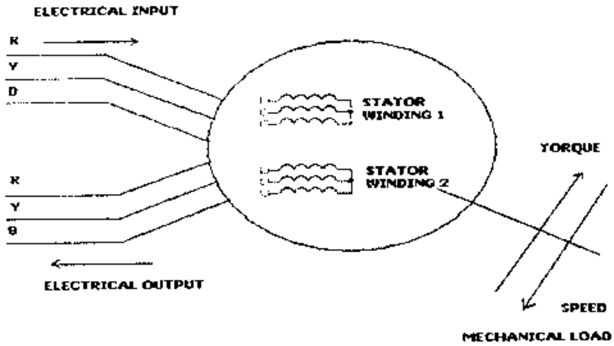


Fig.2 Representation of Dual stator winding Induction Motor

In this scheme two identical (similar number of poles) three phase windings are provided in the stator. These two windings are double layer lap wound. There is no space and phase shift between two windings. The terminals of these two windings are tapped out to the terminal box which contains 8 terminals. These two windings can be either star or delta connected.

2.4.2 OPERATING MECHANISM

When the three phase power is fed to the stator winding 1, a magnetic flux of constant magnitude but rotating at synchronous speed is set up. The flux passes through the air gap, sweeps past the rotor surface and so cuts the rotor conductors which, as yet, are stationary. Due to this the rotor starts rotating with 4% slip. Also due to the relative speed between the rotating flux and the stationary rotor conductors an EMF is induced in the stator winding 2, according to Faraday's law of electromagnetic induction. The frequency of the induced EMF is same as the supply frequency. Its magnitude is proportional to the relative velocity between the flux and the conductors and it's direction is given by Fleming's right hand rule.

Since the rotor bars are conductors from a closed circuit, rotor current is produced, whose direction is given by Lenz's law, is such as to oppose the very cause producing it. Hence to reduce the relative speed the rotors starts running in the same direction as that of the flux and tries to catch up with rotating flux. When the magnetic flux revolves in the air gap it induces EMF in the stator winding 2.Since the stator winding 2 is wound for three phase, power is obtained from which lighting loads are fed.

CHAPTER 3

CHAPTER 3

DESIGN CONSIDERATIONS

3.1 EQUIVALENT CIRCUIT

The induction motor can be treated essentially as a transformer for analysis. The induction motor has stator leakage reactance, stator copper loss elements as series components, and iron loss and magnetising inductance as shunt elements. The rotor circuit likewise has rotor leakage reactance. Rotor copper (aluminium) loss and shaft power as series elements.

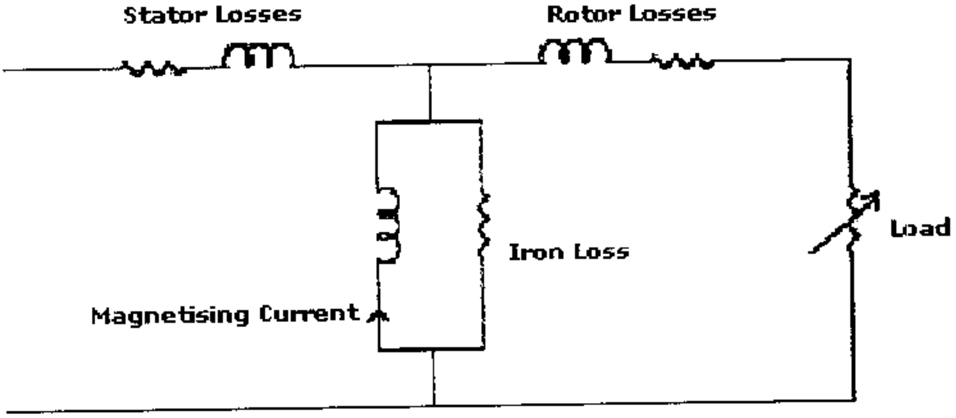


Fig. 3. Equivalent circuit of induction motor

The transformer in the centre of the equivalent circuit can be eliminated by adjusting the values of the rotor components in accordance with the effective turns ratio of the transformer.

From the equivalent circuit and a basic knowledge of the operation of the induction motor, it can be seen that the magnetising current component and the iron loss of the motor are voltage dependant, and not load dependant. Additionally, the full voltage starting current of a particular motor is voltage and speed dependant, but not load dependant.

The magnetising current varies depending on the design of the motor. For small motors, the magnetising current may be as high as 60%, but for large two pole motors, the magnetising current is more typically 20 - 25%. At the design voltage, the iron is typically near saturation, so the iron loss and magnetising current do not vary linearly with voltage with small increases in voltage resulting in a high increase in magnetising current and iron loss.

3.2 CHARACTERISTICS

The characteristics of an induction motor is based on current, speed and torque. It can be classified into two types:

1.Starting Characteristics

2.Running Characteristics

3.2.1 STARTING CHARACTERISTICS

In order to perform useful work, the induction motor must be started from rest and both the motor and load accelerated up to full speed. Typically, this is done by relying on the high slip characteristics of the motor and enabling it to provide the acceleration torque. Induction motors at rest, appear just like a short circuited transformer, and if connected to the full supply voltage, draw a very high current known as the "Locked Rotor Current". They also produce torque which is known as the "Locked Rotor Torque". The Locked Rotor Torque (LRT) and the Locked Rotor Current (LRC) are a function of the terminal voltage to the motor, and the motor design. As the motor accelerates, both the torque and the current will tend to alter with rotor speed if the voltage is maintained constant.The starting current of a motor, with a fixed voltage, will drop very slowly as the motor accelerates and will only begin to fall significantly when the motor has reached at least 80% full speed. The actual curves for induction motors can vary considerably between designs, but the general trend is for a high current until the motor has almost reached full speed. FLC.

The starting torque of an induction motor starting with a fixed voltage, will drop a little to the minimum torque known as the pull up torque as the motor accelerates, and then rise to a maximum torque known as the breakdown or pull out torque at almost full speed and then drop to zero at synchronous speed. The curve of start torque against rotor speed is dependant on the terminal voltage and the motor/rotor design.

The power factor of the motor at start is typically 0.1 - 0.25, rising to a maximum as the motor accelerates, and then falling again as the motor approaches full speed. A motor which exhibits a high starting current will generally produce a low starting torque, whereas a motor which exhibits a low starting current, will usually produce a high starting torque. This is the reverse of what is generally expected.

The induction motor operates due to the torque developed by the interaction of the stator field and the rotor field. Both of these fields are due to currents which have resistive or in phase components and reactive or out of phase components. The torque developed is dependant on the interaction of the in phase components and consequently is related to the I^2R of the rotor. A low rotor resistance will result in the current being controlled by the inductive component of the circuit, yielding a high out of phase current and a low torque.

Figures for the locked rotor current and locked rotor torque are almost always quoted in motor data, and certainly are readily available for induction motors. Some manufactures have been known to include this information on the motor name plate. One additional parameter which would be of tremendous use in data sheets for those who are engineering motor starting applications, is the starting efficiency of the motor. By the starting efficiency of the motor, I refer to the ability of the motor to convert amps into newton meters. This is a concept not generally recognised within the trade, but one which is extremely useful when comparing induction motors. The easiest means of developing a meaningful figure of merit, is to take the locked rotor torque of the motor (as a percentage of the full load torque) and divide it by the locked rotor current of the motor (as a percentage of the full load current).

If the terminal voltage to the motor is reduced while it is starting, the current drawn by the motor will be reduced proportionally. The torque developed by the motor is proportional to the current squared, and so a reduction in starting voltage will result in a reduction in starting current and a greater reduction in starting torque. If the start voltage applied to a motor is halved, the start torque will be a quarter, likewise a start voltage of one third will result in a start torque of one ninth.

3.2.2RUNNING CHARACTERISTICS

Once the motor is up to speed, it operates at low slip, at a speed determined by the number of stator poles.The frequency of the current flowing in the rotor is very low. Typically, the full load slip for a standard cage induction motor is less than 5%. The actual full load slip of a particular motor is dependant on the motor design with typical full load speeds of four pole induction motor varying between 1420 and 1480 RPM at 50 Hz. The synchronous speed of a four pole machine at 50 Hz is 1500 RPM and at 60 Hz a four pole machine has a synchronous speed of 1800 RPM.

The induction motor draws a magnetising current while it is operating. The magnetising current is independent of the load on the machine, but is dependant on the design of the stator and the stator voltage. The actual magnetising current of an induction motor can vary from as low as 20% FLC for large two pole machines to as high as 60% for small eight pole machines. The tendency is for large machines and high speed machines to exhibit a low magnetising current, while low speed machines and small machines exhibit a high magnetising current. A typical medium sized four pole machine has a magnetising current of about 33% FLC.

A low magnetising current indicates a low iron loss, while a high magnetising current indicates an increase in iron loss and a resultant reduction in operating efficiency. The resistive component of the current drawn by the motor while operating, changes with load, being primarily load current with a small current for losses. If the motor is operated at minimum load, i.e. open shaft, the current drawn by the motor is primarily magnetising current and is almost purely inductive. Being an inductive current, the power factor is very low, typically as low as 0.1. As the shaft load on the motor is increased, the resistive component of the current begins to rise. The average current will noticeably begin to rise when the load current approaches the magnetising current in magnitude. As the load current increases, the magnetising current remains the same and so the power factor of the motor will improve. The full load power factor of an induction motor can vary from 0.5 for a small low speed motor up to 0.9 for a large high speed machine. The losses of an induction motor comprise: iron loss, copper loss, windage loss and frictional loss. The iron loss, windage loss and frictional losses are all essentially load independent, but the copper loss is proportional to the square of the stator current.

Typically the efficiency of an induction motor is highest at 3/4 load and varies from less than 60% for small low speed motors to greater than 92% for large high speed motors. Operating power factor and efficiencies are generally quoted on the motor data sheets.

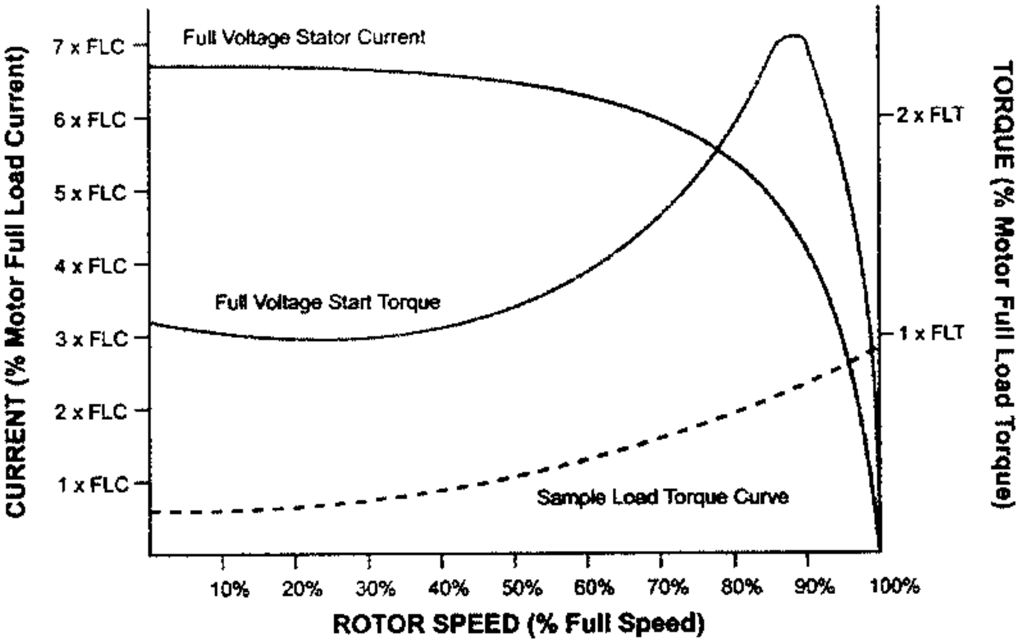


Fig. 4. Characteristics of induction motor

3.3 DESIGN PROCEDURE

It has a major effect on the behaviour and performance of an induction motor. Very often the details or class of design of a motor are not well understood or promoted.

3.3.1 STATOR DESIGN

The stator is the outer body of the motor which houses the driven windings on an iron core. In a single speed three phase motor design, the standard stator has three windings, while a single phase motor typically has two windings.

The stator core is made up of a stack of round pre-punched laminations pressed into a frame which may be made of aluminium or cast iron. The laminations are basically round with a round hole inside through which the rotor is positioned. The inner surface of the stator is made up of a number of deep slots or grooves right around the stator. It is into these slots that the windings are positioned. The arrangement of the windings or coils within the stator determines the number of poles that the motor has. A standard bar magnet has two poles, generally known as North and South. Likewise, an electromagnet also has a North and a South pole. As the induction motor Stator is essentially like one or more electromagnets depending on the stator windings, it also has poles in multiples of two. i.e. 2 pole, 4 pole, 6 pole etc.

The winding configuration, slot configuration and lamination steel all have an effect on the performance of the motor. The voltage rating of the motor is determined by the number of turns on the stator and the power rating of the motor is determined by the losses which comprise copper loss and iron loss, and the ability of the motor to dissipate the heat generated by these losses.

The stator design determines the rated speed of the motor and most of the full load, full speed characteristics.

3.3.2 ROTOR DESIGN

The Rotor comprises a cylinder made up of round laminations pressed onto the motor shaft, and a number of short-circuited windings. The rotor windings are made up of rotor bars passed through the rotor, from one end to the other, around the surface of the rotor. The bars protrude beyond the rotor and are connected together by a shorting ring at each end. The bars are usually made of aluminium or copper, but sometimes made of brass. The position relative to the surface of the rotor, shape, cross sectional area and material of the bars determine the rotor characteristics. Essentially, the rotor windings exhibit inductance and resistance, and these characteristics can effectively be dependant on the frequency of the current flowing in the rotor.

A bar with a large cross sectional area will exhibit a low resistance, while a bar of a small cross sectional area will exhibit a high resistance. Likewise a copper bar will have a low resistance compared to a brass bar of equal proportions.

Positioning the bar deeper into the rotor, increases the amount of iron around the bar, and consequently increases the inductance exhibited by the rotor. The impedance of the bar is made up of both resistance and inductance, and so two bars of equal dimensions will exhibit a different A.C. impedance depending on their position relative to the surface of the rotor. A thin bar which is inserted radialy into the rotor, with one edge near the surface of the rotor and the other edge towards the shaft, will effectively change in resistance as the frequency of the current changes. This is because the A.C. impedance of the outer portion of the bar is lower than the inner impedance at high frequencies lifting the effective impedance of the bar relative to the impedance of the bar at low frequencies where the impedance of both edges of the bar will be lower and almost equal. The rotor design determines the starting characteristics. There are two types of rotors used in induction motors: squirrel cage rotors and wound rotors.

Squirrel-cage rotor

Most common AC motors use the squirrel cage rotor, which will be found in virtually all domestic and light industrial alternating current motors. The squirrel cage takes its name from its shape - a ring at either end of the rotor, with bars connecting the rings running the length of the rotor. It is typically cast aluminum or copper poured between the iron laminates of the rotor, and usually only the end rings will be visible. The vast majority of the rotor currents will flow through the bars rather than the higher-resistance and usually varnished laminates. Very low voltages at very high currents are typical in the bars and end rings; high efficiency motors will often use cast copper in order to reduce the resistance in the rotor.

In operation, the squirrel cage motor may be viewed as a transformer with a rotating secondary - when the rotor is not rotating in sync with the magnetic field, large rotor currents are induced; the large rotor currents magnetize the rotor and interact with the stator's magnetic fields to bring the rotor into synchronization with the stator's field. An unloaded squirrel cage motor at synchronous speed will consume electrical power only to maintain rotor speed against friction and resistance losses; as the mechanical load increases, so will the electrical load - the electrical load is inherently related to the mechanical load. This is similar to a transformer, where the primary's electrical load is related to the secondary's electrical load.

This is why, as an example, a squirrel cage blower motor may cause the lights in a home to dim as it starts, but doesn't dim the lights when its fan belt (and therefore mechanical load) is removed. Furthermore, a stalled squirrel cage motor (overloaded or with a jammed shaft) will consume current limited only by circuit resistance as it attempts to start. Unless something else limits the current (or cuts it off completely) overheating and destruction of the winding insulation is the likely outcome.

In order to prevent the currents induced in the squirrel cage from superimposing itself back onto the supply, the squirrel cage is generally constructed with a prime number of bars, or at least a small multiple of a prime number (rarely more than 2). There is an optimum number of bars in any design, and increasing the number of bars beyond that point merely serves to increase the losses of the motor particularly when starting.

Virtually every washing machine, dishwasher, standalone fan, record player, etc. uses some variant of a squirrel cage motor.

Wound Rotor

An alternate design, called the wound rotor, is used when variable speed is required. In this case, the rotor has the same number of poles as the stator and the windings are made of wire, connected to slip rings on the shaft. Carbon brushes connect the slip rings to an external controller such as a variable resistor that allows changing the motor's slip rate. In certain high-power variable speed wound-rotor drives, the slip-frequency energy is captured, rectified and returned to the power supply through an inverter.

Compared to squirrel cage rotors, wound rotor motors are expensive and require maintenance of the slip rings and brushes, but they were the standard form for variable speed control before the advent of compact power electronic devices. Transistorized inverters with variable-frequency drive can now be used for speed control, and wound rotor motors are becoming less common.

Several methods of starting a polyphase motor are used. Where the large inrush current and high starting torque can be permitted, the motor can be started across the line, by applying full line voltage to the terminals (Direct-on-line, DOL). Where it is necessary to limit the starting inrush current (where the motor is large compared with the short-circuit capacity of the supply), reduced voltage starting using either series inductors, an autotransformer, thyristors, or other devices are used. A technique sometimes used is (Star-Delta, YΔ) starting, where the motor coils are initially connected in wye for acceleration of the load, then switched to delta when the load is up to speed. This technique is more common in Europe than in North America. Transistorized drives can directly vary the applied voltage as required by the starting characteristics of the motor and load.

This type of motor is becoming more common in traction applications such as locomotives, where it is known as the asynchronous traction motor.

3.3.3 MOTOR DESIGN CLASSIFICATION

There are a number of design/performance classifications which are somewhat uniformly accepted by different standards organisations. These design classifications apply particularly to the rotor design and hence affect the starting characteristics of the motors. The two major classifications of relevance here are design A, and design B.

Design A motors have a shallow bar rotor, and are characterised by a very high starting current and a low starting torque. Shallow bar motors usually have a low slip, i.e. 1480 RPM.

Design B motors have a deeper bar rotor and are characterised by medium start current and medium starting torque. The slip exhibited by design B motors is usually greater than the equivalent design A motors. i.e. 1440 RPM.

Design F motors are often known as Fan motors having a high rotor resistance and high slip characteristics. The high rotor resistance enables the fan motor to be used in a variable speed application where the speed is reduced by reducing the voltage. Design F motors are used primarily in fan control applications with the motor mounted in the air flow. These are often rated as AOM or Air Over Motor machines.

3.3.4 FRAME CLASSIFICATION

Induction motors come in two major frame types, these being Totally Enclosed Forced air Cooled (TEFC), and Drip proof.

The TEFC motor is totally enclosed in either an aluminium or cast iron frame with cooling fins running longitudinally on the frame. A fan is fitted externally with a cover to blow air along the fins and provide the cooling. These motors are often installed outside in the elements with no additional protection and so are typically designed to IP55 or better.

Drip proof motors use internal cooling with the cooling air drawn through the windings. They are normally vented at both ends with an internal fan. This can lead to more efficient cooling, but requires that the environment is clean and dry to prevent insulation degradation from dust, dirt and moisture. Drip proof motors are typically IP22 or IP23.

3.3.5 TEMPERATURE CLASSIFICATION

There are two main temperature classifications applied to induction motors. These being Class B and Class F. The temperature class refers to the maximum allowable temperature rise of the motor windings at a specified maximum coolant temperature. Class B motors are rated to operate with a maximum coolant temperature of 40 degrees C and a maximum winding temperature rise of 80 degrees C. This leads to a maximum winding temperature of 120 degrees C.

Class F motors are typically rated to operate with a maximum coolant temperature of 40 degrees C and a maximum temperature rise of 100 degrees C resulting in a potential maximum winding temperature of 140 degrees C.

Operating at rated load, but reduced cooling temperatures gives an improved safety margin and increased tolerance for operation under an overload condition. If the coolant temperature is elevated above 40 degrees C then the motor must be derated to avoid premature failure. Some Class F motors are designed for a maximum coolant temperature of 60 degrees C, and so there is no derating necessary up to this temperature.

Operating a motor beyond its maximum will not cause an immediate failure, rather a decrease in the life expectancy of that motor. A common rule of thumb applied to insulation degradation, is that for every ten degree C rise in temperature, the expected life span is halved. The power dissipated in the windings is the copper loss which is proportional to the square of the current, so an increase of 10% in the current drawn, will give an increase of 21% in the copper loss, and therefore an increase of 21% in the temperature rise which is 16.8 degrees C for a Class B motor, and 21 degrees C for a Class F motor. This approximates to the life being reduced to a quarter of that expected if the coolant is at 40 degrees C. Likewise operating the motor in an environment of 50 degrees C at rated load will elevate the insulation temperature by 10 degrees C and halve the life expectancy of the motor.

3.3.6 POWER FACTOR CORRECTION

Power factor correction is achieved by the addition of capacitors across the supply to neutralise the inductive component of the current. The power factor correction may be applied either as automatic bank correction at the main plant switchboard, or as static correction installed and controlled at each starter in such a fashion that it is only in circuit when the motor is on line.

Automatic bank correction consists of a number of banks of power factor correction capacitors, each controlled by a contactor which in turn is controlled by a power factor controller. The power factor controller monitors the supply coming into the switchboard and adds sufficient capacitance to neutralise the inductive current. These controllers are usually set to adjust the power factor to 0.9 - 0.95 lagging. (inductive).

Static correction is controlled by a contactor when the motor is started and when the motor is stopped. In the case of a Direct On Line starter, the capacitors are often controlled by the main DOL contactor which is also controlling the motor. With static correction, it is important that the motor is under corrected rather than over corrected. This is because the capacitance and the inductance of the motor form a resonant circuit. While the motor is connected to the supply, there is no problem. Once the motor is disconnected from the supply, it begins to decelerate. As it decelerates, it generates voltage at the frequency at which it is rotating.

If the capacitive reactance equals the inductive reactance, i.e. unity power factor, we have resonance. If the motor is critically corrected (pf = 1) or over corrected, then as the motor slows, the voltage it is generating will pass through the resonant frequency set up between the motor and the capacitors. If this happens, major problems can occur. There will be very high voltages developed across the motor terminals and capacitors causing insulation damage, high resonant currents can flow, and transient torque's generated can cause mechanical equipment failure.

The correct method for sizing static correction capacitors, is to determine the magnetising current of the motor being corrected, and connect sufficient capacitance to give 80% current neutralisation. Charts and formula based on motor size alone can be totally erroneous and should be avoided if possible. There are some power authorities who specify a fixed amount of KVAR per kilowatt, independent of the size or speed. This is a dangerous practice.

3.3.7 BEARING SELECTION

A bearing arrangement does not only consist of rolling bearings but includes the components associated with the bearings such as the shaft and housing. The lubricant is also a very important component of the bearing arrangement because it has to prevent wear and protect against corrosion so that the bearing can deploy its full performance. Beside these, the seal is also a very important component, the performance of which is of vital importance to the cleanliness of the lubricant. Cleanliness has a profound effect on bearing service life.

To design a rolling bearing arrangement it is necessary

- To select a suitable bearing type
- To determine a suitable bearing size

but this is not all. Several other aspects have to be considered, such as

- a suitable form and design of other components of the arrangement
- appropriate fits and bearing internal clearance or preload
- holding devices
- adequate seals
- the type and quantity of lubricant
- installation and removal methods, etc.

Each individual decision affects the performance, reliability and economy of the bearing arrangement.

The amount of work entailed depends on whether experience is already available about similar arrangements. When experience is lacking, when extraordinary demands are made or, when the costs of the bearing arrangement and any subsequent outline have to be given special consideration, then much more work is needed including, for example, more accurate calculations and/or testing.

3.3.8 INSULATION SYSTEMS

Five specialized elements are used, which together constitute the motor's INSULATION SYSTEM. The following are typical in an AC motor:

1. TURN-TO-TURN INSULATION between separate wires in each coil. (Usually enamel on random wound coils of smaller motors - tape on "form wound" coils of larger motors.)

2. PHASE-TO-PHASE INSULATION between adjacent coils in different phase groups. (A separate sheet material on smaller motors - not required on form wound coils because the tape also performs this function.)

3. PHASE-TO-GROUND INSULATION between windings as a whole and the "ground" or metal part of the motor. (A sheet material, such as the liner used in stator slots, provides both di-electric and mechanical protection.)

4. SLOT WEDGE to hold conductors firmly in the slot.

5. IMPREGNATION to bind all the other components together and fill in the air spaces. (A total impregnation, applied in a fluid form and hardened, provides protection against contaminants.

3.3.9 INSULATION CLASS

Since there are various ambient temperature conditions a motor might see and different temperature ranges within which motors run and insulation is sensitive to temperature; motor insulation is classified by the temperature ranges at which it can operate for a sustained period of time.

There are four common classes:

TABLE 1 – INSULATION CLASS

Class	Temperature rating
A	105° C
B	130° C
F	F 155°
H	180° C

When a motor insulation class is labeled on the nameplate the total insulation system is capable of sustained operation at the above temperature.

3.3.10 SPEED OF AN INDUCTION MOTOR

The speed of the AC motor is determined primarily by the frequency of the AC supply and the number of poles in the stator winding, according to the relation:

$N_s = 120f / p$

where

N_s = Synchronous speed, in revolutions per minute
f = AC power frequency
p = Number of poles per phase winding

Actual RPM for an induction motor will be less than this calculated synchronous speed by an amount known as slip, that increases with the torque produced. With no load, the speed will be very close to synchronous. When loaded, standard motors have between 2-3% slip, special motors may have up to 7% slip, and a class of motors known as torque motors are rated to operate at 100% slip (0 RPM/full stall).

3.3.11 SLIP OF AN INDUCTION MOTOR

The slip of the AC motor is calculated by:

$S = (N_s - N_r) / N_s$

where

N_r = Rotational speed, in revolutions per minute.
Ns = Speed of rotating flux.
S = Normalised Slip, 0 to 1.

As an example, a typical four-pole motor running on 50 Hz might have a name plate rating of 1440 RPM at full load (4% slip), while its calculated speed is 1500 RPM.

3.4 DESIGN DATA

The three phase dual stator winding induction motor developed has the following specifications and design details.

3.4.1 MATERIAL SPECIFICATIONS

Core Material - Iron
Frame type - 100L
Frame - Totally Enclosed Forced air Cooled type (TEFC) IP55
Phase insulation - Class 'F'
Phase separator - Class 'F'
Temperature rise limited to Class 'B' (120°C)

3.4.2 DESIGN DETAILS

Power = 1 HP/0.746 KW
Voltage = 415 volts
Rated Current = 2A
Frequency f = 50 Hz
Speed N = 1500 RPM
Synchronous speed $N_s = 1500/60 = 25$rps
No. of poles $P = (2Xf) / N_s = (2X50) / 25 = 4$ poles
Let no. of Slots/pole/phase = 3
No. of stator slots S_s = (No. of Slots/pole/phase) x P x No.of phase
= 3 x 4 x 3
= 36
Stator slot pitch $Y_{ss} = 12$ mm
Coil pitch = 0-9
Stator conductors per slot = 190
Stator current per phase = 2 A

3.4.3 SLOT AREA UTILISATION FACTOR

The stator windings of this dual winding induction motor are double layered Lap wound.

Stator Winding 1 :

Conductor Size = 25 swg (0.51 mm)
No. of turns = 90 Turns
Conductor area = 18.38 mm^2

Stator Winding 2 :

Conductor Size = 28 swg (0.38 mm)
No. of turns = 100 Turns
Conductor area = 11.34 mm^2

Total slot area = 76.85 mm^2
Total conductor area = 18.38+11.34 = 29.72 mm^2
Percentage of slot area utilized = 29.72 / 76.85 = **38.7 %**

CHAPTER 4

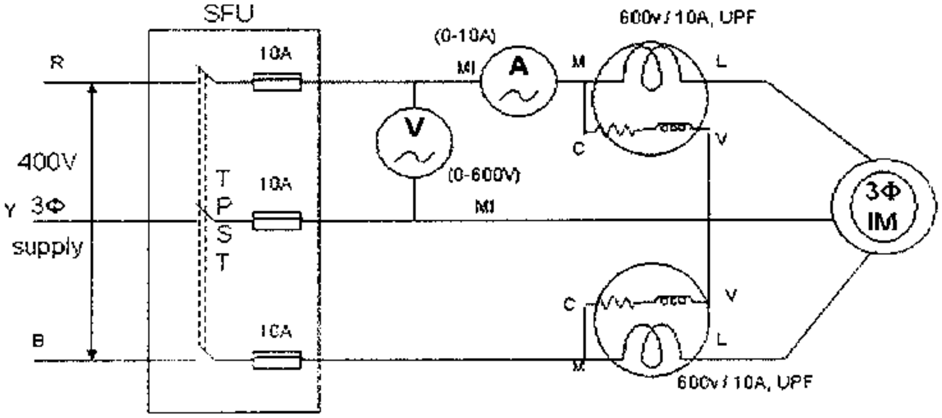
CHAPTER 4

TESTING AND APPLICATIONS OF DUAL STATOR WINDING INDUCTION MOTOR

4.1 NO LOAD TEST

In this test, the motor is made to run without any external mechanical load. The speed of the rotor would not be synchronous, but very much near to it. The rated voltage is applied to the motor and the corresponding input current, power and speed are measured. The power is measured using two wattmeter method.

4.1.1 CIRCUIT DIAGRAM



Name plate Details

Power - 1 HP/0.746 KW
Current - 2A
Speed - 1500 Rpm
Frequency - 50 Hz
Voltage - 415V

Fig.5 No Load test on Dual stator winding induction motor

4.1.2 TABULATION

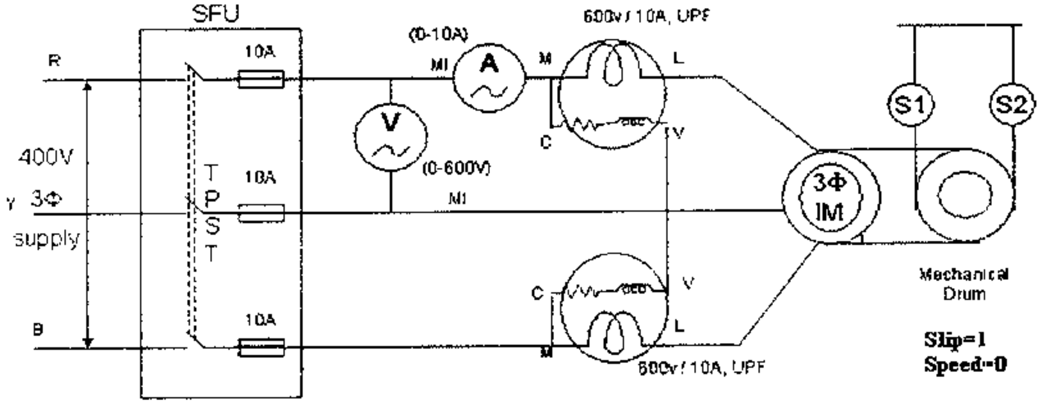
TABLE 2 - NO LOAD TEST

S. No.	Input Voltage (Volts)	Input Current (Amperes)	Wattmeter readings		Input Power (Watts)	Speed (RPM)
			W1 (Watts)	W2 (Watts)		
1	415	0.38	-165	420	255	1476

4.2 BLOCKED ROTOR TEST

It is also known as Locked rotor or short-circuit test. In this test a reduced voltage is applied to the stator terminals and is so adjusted that full load current flows in the stator. As in the case (Slip = 1), the equivalent circuit of a motor is exactly like a transformer, having a short circuited secondary. The values of current, voltage and input power are measured by the ammeter, voltmeter and wattmeter connected in the circuit shown below.

4.2.1 CIRCUIT DIAGRAM



Name plate Details

Power - 1 HP/0.746 KW
Current - 2A
Speed - 1500 Rpm
Frequency - 50 Hz
Voltage - 415V

Fig.6 Blocked rotor test on Dual stator winding induction motor

4.2.2 TABULATION

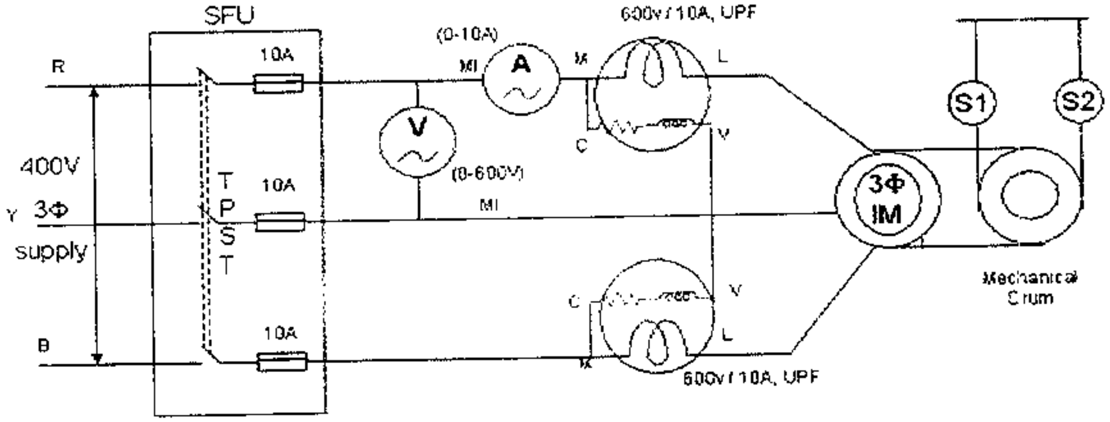
TABLE 3 - BLOCKED ROTOR TEST

S. No.	Input Voltage (Volts)	Input Current (Amperes)	Wattmeter readings		Input Power (Watts)
			W1 (Watts)	W2 (Watts)	
1	253	1.9	490	251	741

4.3 CONVENTIONAL MECHANICAL LOAD TEST

In this test, the rated voltage is applied to the stator initially without applying any external load. Now the mechanical load is applied with the help of brake drum and the corresponding voltage, current and power at the input and output are measured. This test is continued by increasing the mechanical load and measuring the values. As the load increases, the speed of the motor will decrease.

4.3.1 CIRCUIT DIAGRAM



Name plate Details

Power - 1 HP/0.746 KW
Current - 2A
Speed - 1500 Rpm
Frequency - 50 Hz
Voltage - 415V

Fig.7 Conventional Mechanical load test on Dual stator winding induction motor

4.3.2 TABULATION

TABLE 4 - MECHANICAL LOAD TEST

S. No.	Input Voltage (Volts)	Input Current (Amperes)	Input Power (Watts)	Output Power (Watts)	Speed (RPM)	Efficiency (%)
1	415	0.9	386.6	283.16	1456	73.3
2	415	1.3	640	508.8	1430	79.5
3	415	1.7	933.33	695.66	1402	74.53
4	415	1.9	1040	769.76	1389	74

4.4 COMBINED MECHANICAL AND ELECTRICAL LOAD TEST

In this test, the rated voltage is applied to the stator initially without applying any external load. Now the mechanical load with the help of brake drum and electrical lighting load are applied as shown in the figure below. The corresponding voltage, current, input power, electrical and mechanical output powers are measured. This test is continued by increasing the mechanical load while maintaining the electrical load as constant. As the load increases, the speed of the motor will decrease.

4.4.1 CIRCUIT DIAGRAM

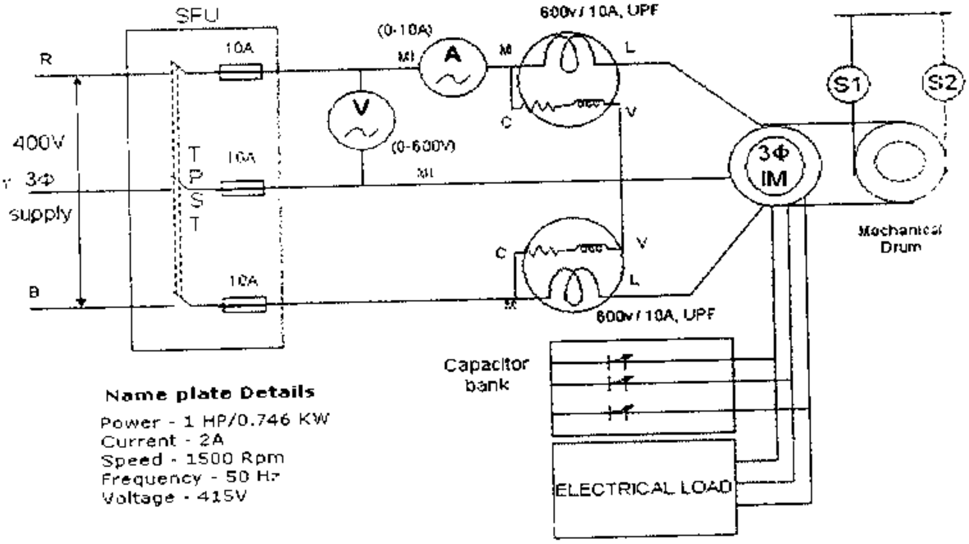


Fig.8 Combined mechanical and electrical load test on Dual stator winding induction motor

TABLE 5 –MECHANICAL LOADING WITH 0.5 A ELECTRICAL LOADING RESULTS

S. No.	Input Voltage (Volts)	Input Current (Amperes)	Input Power (Watts)	Output Electrical Power (Watts)	Output Mechanical Power (Watts)	Total Output Power (Watts)	Output Voltage (Volts)	Efficiency (%)
1	415	1.7	960	480	312.66	792.6	380	82.5
2	415	1.8	1173.3	533.3	441.76	975.06	379	83.1
3	415	1.8	1266.6	520	561.59	1081.59	374	85.3
4	415	1.9	1413	550	638.36	1188.36	376	84.1

SIMULTANEOUS ELECTRICAL AND MECHANICAL LOADING :

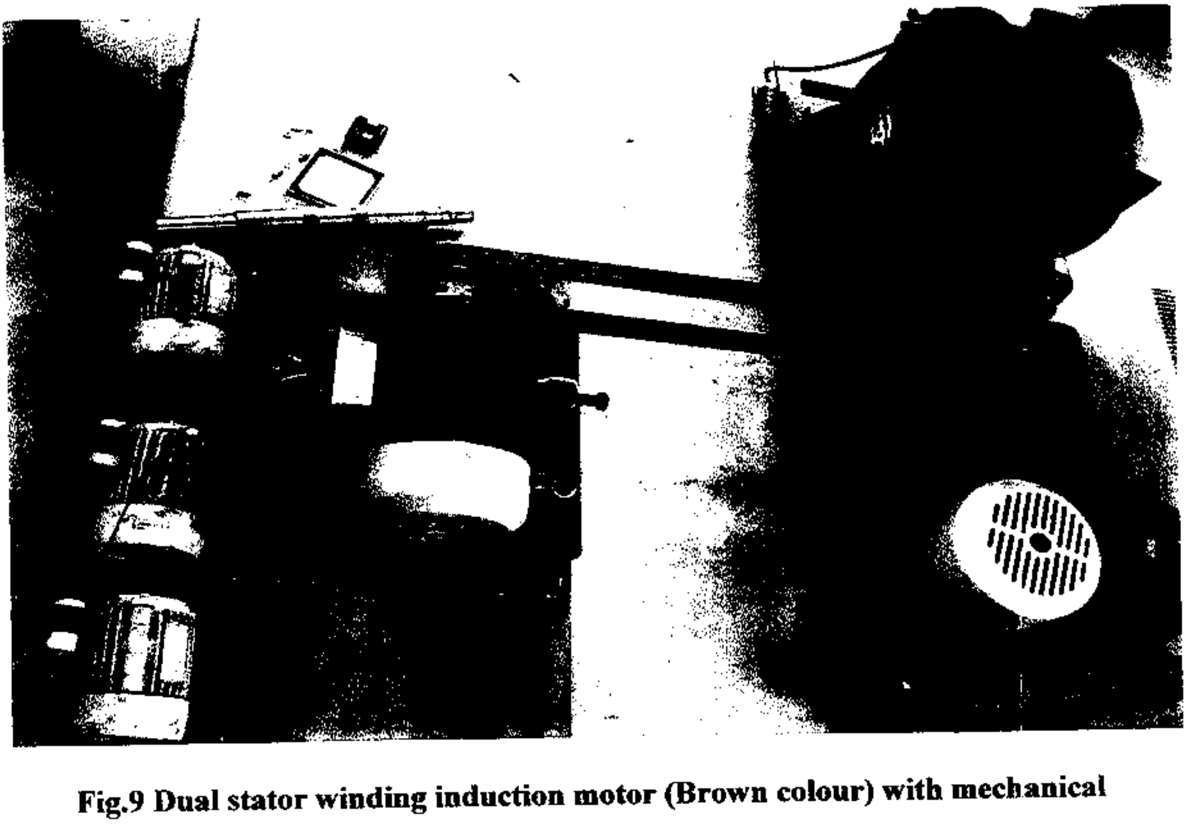


Fig.9 Dual stator winding induction motor (Brown colour) with mechanical (Electrodynamometer) and electrical load (Three 0.25 HP motors)

4.5 APPLICATIONS

The various applications where the induction motor runs continuously, to supply lighting loads are as follows,

- Textile industries
- Uninterrupted Power Supply (UPS) Systems
- Fertiliser Industries
- Steel and Power plants
- Compressors
- Machine Tools
- Cement Factories
- Wind mills
- Oil, Gas and Petrochemicals
- Air conditioning Units and Cooling plants
- Tea and Sugar Factories
- Crushers

CHAPTER 5

CHAPTER 5

CONCLUSION

A 1 HP, 3 phase, 4 pole, 415 V, 1500 rpm double winding induction motor has been designed, fabricated and successfully tested. The experimental results illustrate the improvement in efficiency over the conventional induction motors.

The experimental results are produced with conventional mechanical loading and 0.5 A electrical loading,

Output voltage = 380 V
Output power = 260 W

Energy saved (for 0.5 A electrical loading)

Total KWH/day = 20 Hrs x 260 W = 5.2 KWH/day for 20 hours of operation

This amount of energy is utilized for lighting loads for which no extra amount shall be paid.

Thus in one day, for a 1HP motor, 5.2 KWH of energy is saved by utilizing the electrical output from the motor. This energy in turn is obtained without any extra power from the supply. Hence the application oriented industry's dependency on EB for lighting loads is reduced.

REFERENCES

1.) Alfredo R.Munoz, (Sep-Oct 2000), "Dual Stator Winding Induction Machine Drive", IEEE transactions on industrial applications, Vol.36, No.5, PP 1369-1379.

2.) K.Murugesh Kumar (2000),"Induction and Synchronous machines", Vikas Publishing house.

3.) I.J.Nagrath and D.P.Kothari, (2001), "Electric Machines", Tata McGraw Hill Publishing Co. Ltd., New Delhi.

4.) A.K Sawhney , (2004), "A course in Electrical Machine Design", Dhanpat Rai and Co., New Delhi.

5.) M.G. Say, (1983), "The performance and design of Alternating Current Machines", CBS Publishers.

6.) B.L.Theraja and A.K.Theraja, (2006), "A Textbook of Electrical Technology", S.Chand & Company Limited.

7.) www.lmphotonics.com

8.) www.wikipedia.com