

# INDUCTION MOTOR AND SELF-EXCITED INDUCTION GENERATOR

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## Summary

Since its invention by Nikola Tesla in 1888, the induction motor has been built in vast numbers and has become the most important workhorse in industry. This article introduces the basic construction, operating principle, and major performance characteristics of three-phase squirrel-cage and slip-ring induction motors. Operational aspects, such as starting, electric braking, and speed control will then be discussed. The operating principle of single-phase induction motors, which are used extensively for domestic applications, will also be explained.

When a suitable capacitance is connected across the stator winding of an induction machine, self-excitation may occur under favorable conditions, and a machine operating in this mode is called a self-excited induction generator (SEIG). It has found increasing applications in generation systems utilizing renewable energy. This article will briefly

describe the principle, characteristics, and operating limits of the SEIG when supplying isolated loads.

## 1. Introduction

The induction motor is an alternating current (ac) rotating machine. Invented in 1888 by Nikola Tesla, it is by far the most widely used type of rotating electrical machine. It is the major workhorse in industry, agriculture, transportation, and domestic electric appliances. Typical applications include rolling mills, machine tools, winders, crane hoists, electric lifts and escalators, compressors, water pumps, fans, traction drives, electric vehicles, food processing machines, and many others. Medium and large induction motors invariably operate on three-phase supplies, but many small induction motors, for example those for domestic use, operate on single-phase power supplies. It is estimated that about 60% of industrial power demand comes from induction motor loads.

The advantages of induction motors include simplicity of construction, low cost, robustness, high efficiency, and satisfactory drive characteristics for most applications. However, induction motors must operate at lagging power factors, meaning that they draw a considerable amount of reactive power from the power supply. Moreover, speed control is difficult and expensive to achieve. Before the advent of power electronics, induction motors were used mainly for constant-speed applications.

## 2. Basic Construction

The three-phase induction motor consists of the stator, the rotor, the air gap, and the auxiliaries. Figure 1 shows a cross-section through an induction motor, showing the essential components of the machine and the flux density distribution.

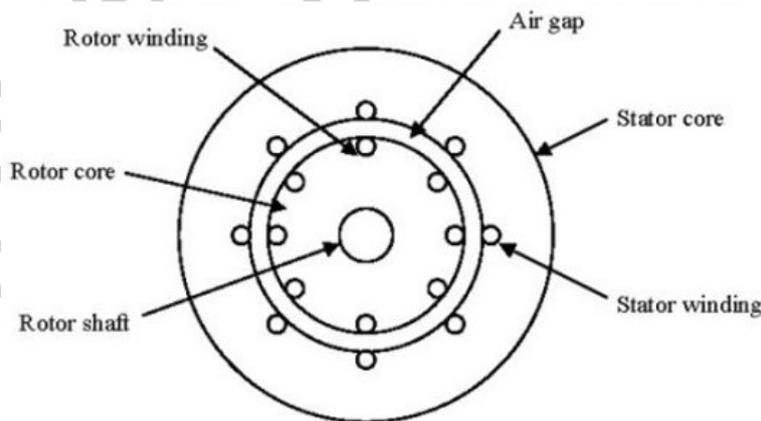


Figure 1. Cross section of induction motor

### 2.1. Stator

The stator core is built up of laminated silicon-steel punchings and assembled as a hollow cylinder in a steel frame. The punchings are insulated from one another in order

to minimize eddy-current loss. A three-phase stator winding, usually made up of a series of connected copper coils, is accommodated in slots cut at the inner circumference of the stator core. Closed or semi-closed slots are often used to reduce undesirable harmonics.

## 2.2. Rotor

The rotor core is a solid, laminated steel cylinder with slots on the outer surface to carry the rotor winding. The rotor winding may be (a) wound type, or (b) cage type.

### 2.2.1. Wound-Rotor Type

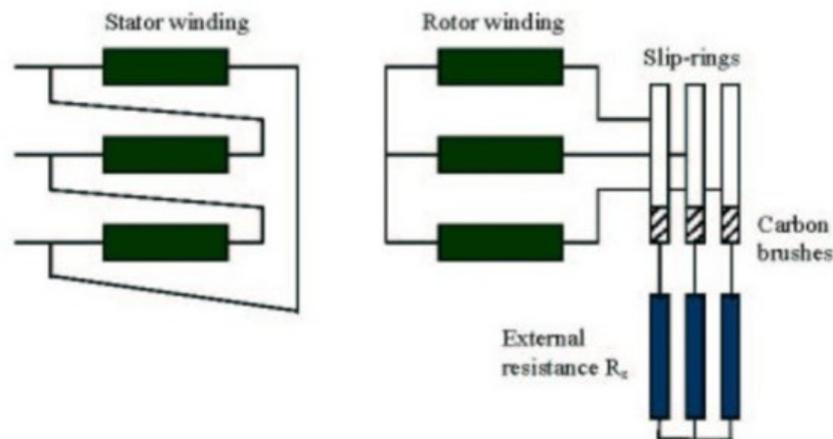


Figure 2. Circuit connection of a wound-rotor induction motor



Figure 3. A 1.8-kW wound-rotor induction motor

The rotor winding is a distributed polyphase winding similar to that of the stator and has the same number of poles. The phases are usually star-connected, with the lines brought out to insulated slip-rings that make contact with stationary carbon brushes. Under normal operating conditions, the slip-rings are short-circuited at the brushes, but external resistances can be connected to the carbon brushes for motor starting and speed control. An induction motor with a wound rotor is often called a wound-rotor induction

motor or slip-ring induction motor. Figure 2 shows the circuit arrangement of a wound-rotor induction motor with delta-connected stator and a star-connected rotor. Figure 3 shows a 1.8-kW, laboratory-sized wound-rotor induction motor; the slip-rings and brushgear can be seen clearly on the right-hand side of the motor.

### 2.2.2. Cage-Rotor Type

A cage rotor (or squirrel-cage rotor) winding consists of copper or aluminum bars housed in the rotor slots. All the bars are short-circuited at their ends by two end-rings. If aluminum is used, the cage winding may be manufactured in a single die-casting process. For a cage winding, the number of poles depends on the currents induced from the stator rotating field, hence a given cage rotor can operate satisfactorily for stators with different pole numbers. Figure 4 shows a 2.2-kW squirrel-cage induction motor.



Figure 4. A 2.2-kW squirrel-cage induction motor

### 2.2.3. Comparison between Cage-Rotor and Wound-Rotor Induction Motors

The cage motor is cheap, robust, and practically maintenance free due to the absence of moving contacts. It can operate in extremely adverse environments, for example contaminated and explosive atmospheres and even in submersible equipment. The major disadvantages of the cage motor are its low starting torque and large starting current.

The wound-rotor induction motor, on the other hand, can develop a very large starting torque at a low starting current, by simply introducing external resistance in each rotor phase via the slip-rings. Minor speed control can also be accomplished using this method. However, wound-rotor induction motors are more expensive than cage motors and frequent maintenance of the slip-rings and brushgear is required.

### 2.3. Air Gap

The rotor and stator cores are separated by a small air gap (usually ranging from 0.2 mm to 1 mm) necessary for mechanical clearance. Due to the presence of the air gap, the induction motor requires a fairly large magnetizing current for setting up the rotating

magnetic field. The magnetizing current lags behind the supply voltage by 90 electrical degrees, which means that the machine must operate at lagging power factors.

## 2.4. Auxiliaries

These include the frame, end-shields, bearings, terminal box, cooling fan, foot mounting, and so on. The frame encloses the stator and rotor, providing mechanical protection to the motor. There are two end-shields, one on each side of the stator frame, which accommodate the bearings for supporting the rotor shaft. A cooling fan is often fitted in the motor enclosure for ventilation purposes. The supply cable is connected to the stator phases at the terminal junction box, usually mounted on the motor frame.

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## Biographical Sketch

**Tze-Fun Chan** received the B.Sc.(Eng.) and M.Phil. degrees in electrical engineering from the University of Hong Kong in 1974 and 1980. Since 1978, Mr. Chan has been with the Department of Electrical Engineering of the Hong Kong Polytechnic University, where he is now an Associate Professor. His current research interests are self-excited ac generators and permanent-magnet machines. Mr. Chan is a Chartered Engineer, and a member of the UK Institution of Electrical Engineers, the US Institute of Electrical and Electronic Engineers, and the Hong Kong Institution of Engineers.