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11. Induction motors

11.1 Principle and design of induction motor

11.2 Characteristics and parameters of three-phase induction motors

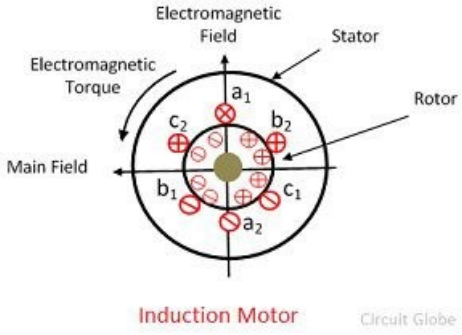
11.3 Starting three-phase induction motors

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11.1 Principle and design of induction motor

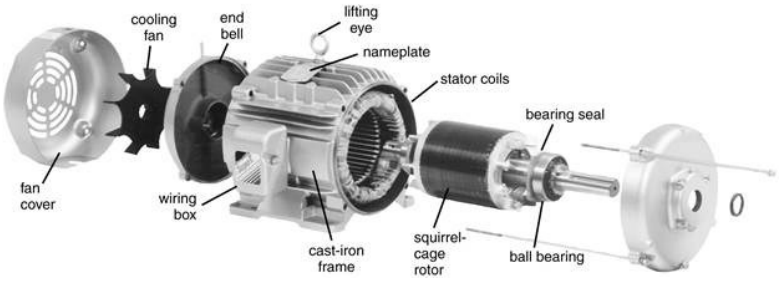
11.1.1. Principle of operation



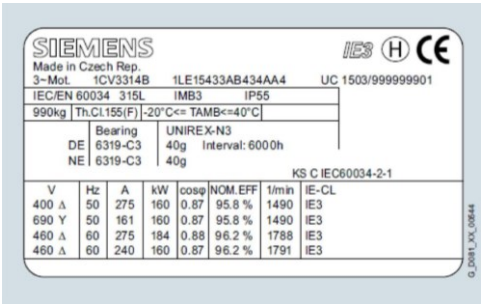
Induction motors (also called as asynchronous motors) are the most common types of motors. Their construction is rather simple and so it costs relatively little to manufacture. The principle of induction motors operation is similar to the induction between the primary and secondary windings of the transformer in many ways. The currents flowing through the three-phase stator windings form a three-phase rotating magnetic field. The speed of this magnetic field is called synchronous speed. It is determined by the number of magnetic field pole pairs p (which is the half of the number of its magnetic poles $2p$) and the frequency f of the input voltage. The stator rotating magnetic field induces voltages and currents into the rotor windings or cage, so the rotor windings or cage are affected by a force. So an electromagnetic torque is generated and motor starts rotating. The rotor is never able to reach synchronous speed. If it is did, there would be no voltage induced in the rotor winding. No torque would be developed and the motor would not operate. So from this reason this type of motor is also called asynchronous (G. Rizzoni: Fundamentals of electrical engineering).

11.1.2. Design of induction motor

Induction motor has two mechanical parts: a rotor and a stator. The rotor is the part that rotates and the stator is the part that remains stationary. The stator consists of a laminated iron core with windings (single-phase or three-phase) wounded from a copper wire and embedded in slots of this core. The winding is isolated from the core with an insulating paper. The magnetic core is secured to a stator frame. The stator winding is connected to voltage of a source and it is connected into star or delta. The rotor is made up of laminated cylinder with slots in its surface that is fixed on a machine shaft. The winding in these slots is one of two types. The most common is the squirrel-cage winding. This entire winding is made up from heavy aluminum (rarely copper) bars connected together at each end by an aluminum ring. The other type of winding contains actual coils placed in the rotor slots (in its magnetic circuit respectively). The rotor is then called a wound rotor. This winding is made up of a copper wire and it is connected into the star for three-phase motors. One ends of this winding are connected to three metal rings also fixed on the shaft. Carbon-graphite brushes fasten upon the stator frame are slipping on the rings and which an external rotor-resistance starter is connected to (G. Rizzoni: Fundamentals of electrical engineering).



11.2. Characteristics and parameters of three-phase induction motors



Motor parameters are listed in motor catalogue issued by its manufacturer. However, some important parameters are placed on a motor metal nameplate fixed on the motor iron frame as seen in the picture. Some next parameters can be calculated from formulas, see below.

Synchronous speed is given by the formula:

$$n_{S1} = \frac{60 \cdot f}{p} \quad \left(\text{min}^{-1}, \text{Hz}, -\right)$$

where f is frequency of the input voltage, p is the number of magnetic field pole pairs.

The difference between rotor speed (mechanical speed of induction motor) n and synchronous speed n_{S1} of stator rotating magnetic field is called slip and it is determined in the percentage of synchronous speed according the formula:

$$s = \frac{n_{S1} - n}{n_{S1}} \cdot 100 \ (\%)$$

Mechanical speed can be calculated as:

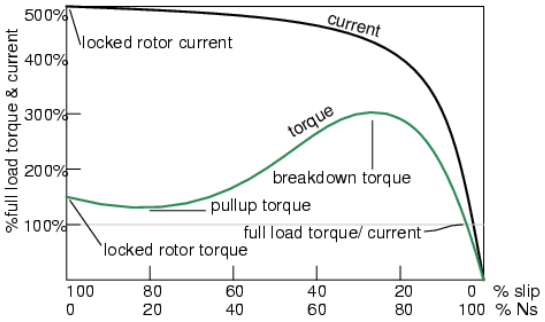
$$n = n_{S1} \cdot (1 - s) = \frac{60 \cdot f}{p} \cdot (1 - s)$$

With respect to the fact that the induction motor is used for driving of various mechanisms, its torque on motor shaft is important and its nominal value is determined by the formula as follows:

$$M_N = \frac{P_N}{\Omega_N} = \frac{P_N}{\frac{2\pi \cdot n_N}{60}} = 9{,}55 \cdot \frac{P_N}{n_N} \ (\mathrm{N \cdot m, W, min^{-1}})$$

where P_N is motor nominal mechanical power and n_N motor nominal mechanical speed (motor shaft speed).

Two fundamental characteristics of induction motor are in figure, namely torque-speed curve and current-speed curve, which some important levels are marked in. As seen the starting motor is accompanied by large starting torque and especially by large starting current which can cause problems in the network (G. Rizzoni: Fundamentals of electrical engineering).



11.3. Starting three-phase induction motors

Starting induction motor is a transient process from the motor standstill to its operating speed, during which the motor speed, currents in stator and rotor and torque change. The direct on-line start-up has advantages of the simple equipment, low costs, high starting torque and eventually fast start. The limitation of this starting method is the high starting current causes a voltage drop in the power line. The starting torque, often higher than the driven machines need, can result in mechanical stresses in couplings and driven machines. So these requirements for motor starting are required:

- Biggish starting torque to break the motor load at the standstill and during starting
- Small starting current

These starting methods are used:

- Direct on-line start-up: for motors of rated power below 3kW, or below 4-5 kW, respectively
- Reduce voltage resistor/reactor starter: with resistor starter for lower powers, with reactor starter for higher powers (a reduction of power losses is necessary)
- Autotransformer starter: during starting the voltage on motor is regulated
- Star/Delta starter: the stator winding is connected into star during motor starting, after reaching the operating speed (or near to it) the winding is switched into delta. The starting current in the network and starting torque is reduced to one third in comparison to the starting with winding connection into delta. A disadvantage is a current and torque surge at the switching, used for power up to c. 10 kW
- Soft starter: a semiconductor AC voltage controller for soft starting enables substantial limitation of starting current and torque. The start control is provided by adjusting time ramp of the supply voltage with adjusted surge voltage at the switch on, or by adjusting current limit or by “kickstart” using impulse starting torque.
- Variable frequency drive starting: a semiconductor frequency converter enables besides the speed control also soft starting and soft braking

11.4. Speed control of induction motors

11.4.1. The possibilities of speed control

Induction motors are used in various drives where its speed and the speed of a driven mechanism are constant. But there are a lot of technical applications where it is necessary to control the mechanisms speed. So induction motors are the part of drives called AC adjustable speed drives.

The mechanical speed of induction motor is determined by the formula:

$$n = n_{S1} \cdot (1 - s) = \frac{60 \cdot f}{p} \cdot (1 - s)$$

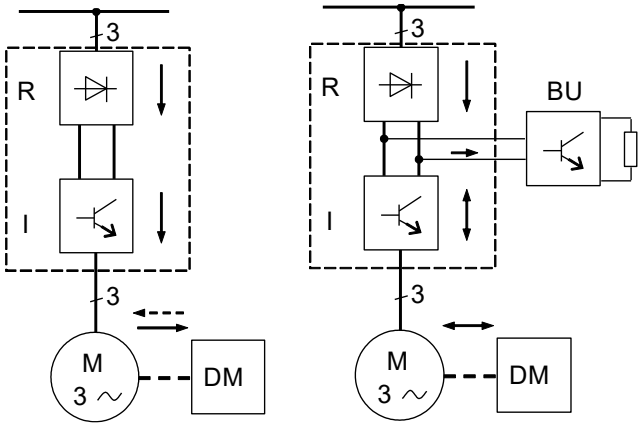
So the speed of induction motor is possible to control with these modes as follows (G. Rizzoni: Fundamentals of electrical engineering):

- alternation of the motor slip (at induction motors with wounded rotor with the change of resistance value of external rotor-resistance starter)
- alternation of supply frequency (at induction motors with squirrel-cage rotor with a frequency converter connected between the supply mains and the motor): the most efficient
- alternation of poles number (with a special mechanical switch of connection mode of the stator winding)

It is possible to change the motor speed by supply voltage change that is in principle the change of the motor slip.

11.4.2. Frequency control: adjustable speed drives

Very often a braking unit is necessary to use to absorb energy flowing from driven mechanism across motor into the converter.



A basic scalar and vector control strategy is used for speed control. The scalar control strategy is seen from the figures. For the range of output frequencies 0-50 Hz is used the control at a constant ratio of voltage and frequency, i.e. at constant magnetic flux and maximum torque in motor. This condition is difficult to achieve at motor start-up and at very low frequencies, in which cases the voltage must be raised above the constant voltage/frequency ratio. In the range above 50 Hz the control is at the constant rated voltage, i.e. at constant power, and at flux and max torque weakening.

