4.3 Synchronous speed

Consider the stator of a 2-pole machine having two phase winding represented by the concentric coils a-a’ and b-b’ respectively as shown in Fig. 4.

Let a 2-phase supply having wave diagram shown in Fig. 5(a) is applied to the stator winding. Phase-1 is connected to coil a-a’ and phase-2 is connected to coil b-b’. Alternating currents having the same wave shape as that of supply voltage start flowing through the coils and produce their own magnetic field Im (each).

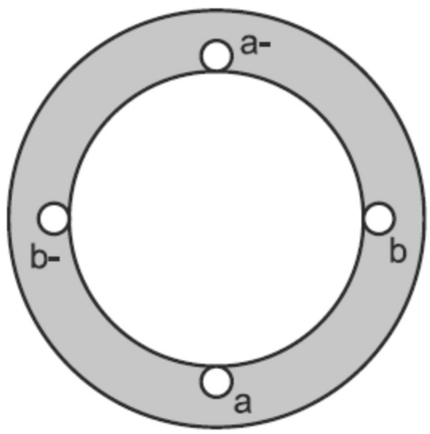

Fig. 4

The phasor diagram of the fields at an instant is shown in Fig. 5(b). The positive half cycle of the alternating current is considered as inward flow of current [cross in a circle ³] and negative half cycle as outward flow of current (dot in a circle ±). This abbreviation is marked in the start terminals of the two coils i.e., a and b, respectively. Whereas, the direction of flow of current is opposite in the other two ends of the coils.

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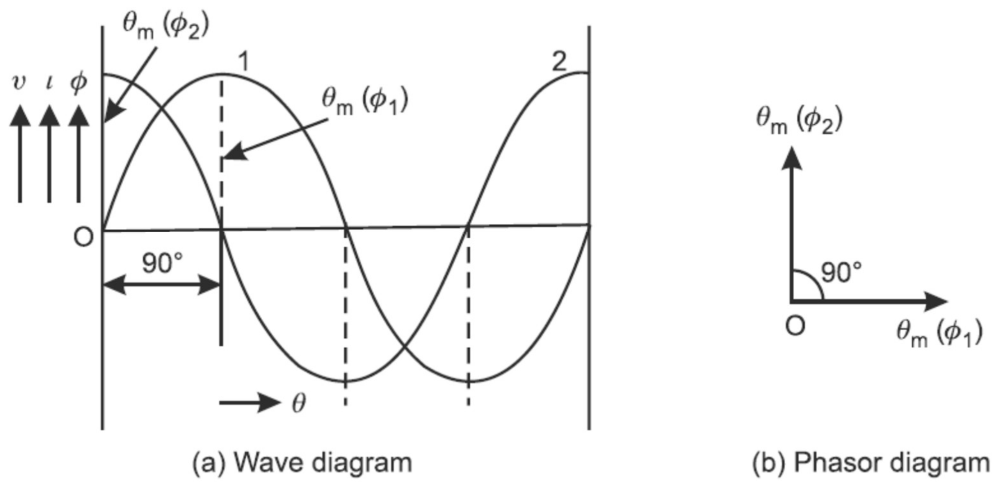


Fig. 5

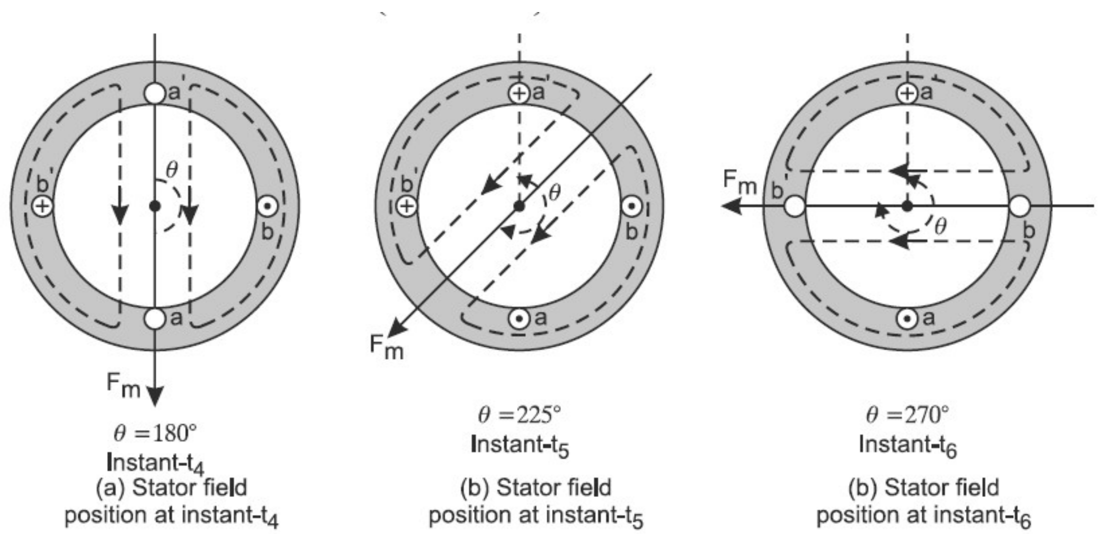


Fig. 4

When a 2-phase AC supply is given to a 2-phase wound stator of a machine, a resultant field of magnitude ϕm is produced which rotates in the space of the stator at synchronous speed

$$N_s = \frac{120\,f}{P}\ ,\ N_s\ in\ rpm \tag{1}$$

4.4 Slip

In practice, the rotor never succeeds in 'catching up' with the stator field. If it really did so, then there would be no relative speed between the two, hence no rotor e.m.f., no rotor current and so no torque to maintain rotation. That is why the rotor runs at a speed which is always less than the speed of the stator field. The difference in speeds depends upon the load on the motor.

The difference between the synchronous speed N_s and the actual speed N of the rotor is known as ***slip***. Though it may be expressed in so many revolutions/second, yet it is usual to express it as a percentage of the synchronous speed. Actually, the term '***slip***' is descriptive of the way in which the rotor 'slips back' from synchronism.

$$s = \frac{N_s - N}{N_s} \times 100\% \tag{2}$$

Sometimes, $N_s - N$ is called the ***slip speed.***

Obviously, rotor (or motor) speed is $N = N_s\ (1 - s)$.

It may be kept in mind that revolving flux is rotating synchronously, relative to the stator (*i.e*. Stationary space) but at slip speed relative to the rotor.

4.5 Frequency of Rotor Current

When the rotor is stationary, the frequency of rotor current is *the same as the supply frequency.* But when the rotor starts revolving, then the frequency depends upon the relative speed or on slip-speed. Let at any slip-speed, the frequency of the rotor current be f' Then:

$$N_s - N = \frac{120\,f'}{P} \tag{3}$$

$$f' = sf \tag{4}$$

Example1: A 4-pole, 1-phase induction motor operates from a supply whose frequency is 50 Hz. Calculate:

(i) The speed at which the magnetic field of the stator is rotating.

(ii) The speed of the rotor when the slip is 0.04.

(iii) The frequency of the rotor currents when the slip is 0.03.

(iv) The frequency of the rotor currents at standstill.

Solution

(i) Stator field revolves at synchronous speed, given by

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = \mathbf{1500\ rpm}$$

(ii) $N = N_s(1 - 0.04) = \mathbf{1440\ rpm}$

(iii) $f' = sf = 0.03 \times 50 = \mathbf{1.5\ Hz}$

(iv) $s = 1, \quad f' = sf = \mathbf{50\ Hz}$

5 Equivalent Circuit of Single-phase Induction Motor

The equivalent circuit of a single-phase induction motor may be drawn on the basis of two revolving field theory. Accordingly, each of the field is producing emf in the rotor by induction. Therefore, a single-phase induction motor may be imagined to have common stator but two rotors revolving in opposite directions. Where, each rotor has resistance and reactance half the actual rotor values

Let R_1 be the resistance of stator winding.

X_1 be the leakage reactance of stator winding.

X_m be the total magnetizing reactance.

R_m be the total magnetizing resistance.

R_2' be the resistance of rotor referred to stator.

X_2' be the reactance of rotor referred to stator.

Considering the case when the rotor is stationary and only the main winding is excited. The motor behaves as a single-phase transformer with its secondary short circuit. The equivalent circuit diagram of the single-phase motor with only its main winding energized is shown below:

While developing the equivalent circuit, it is considered that the stator is having only one winding. The equivalent circuit can be developed under stand-still (at start) and running (operating) conditions.

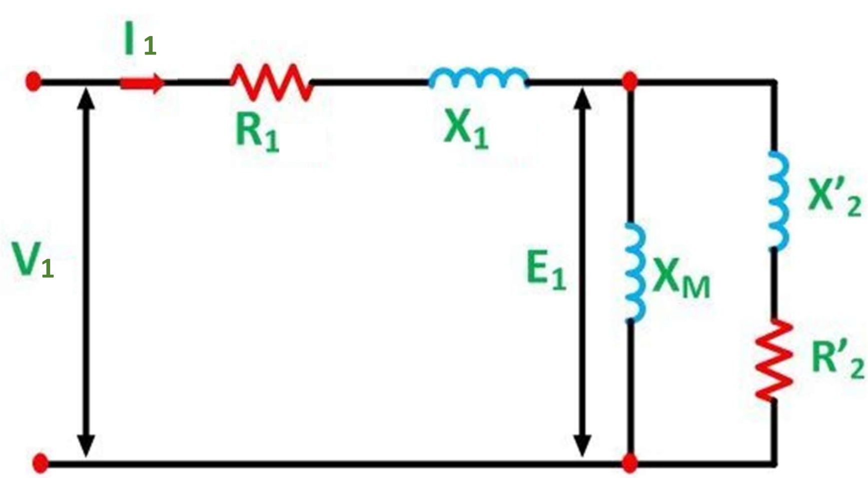


Fig. 5

The core loss will be assumed to be lumped with the mechanical and stray losses as a part of the rotational losses of the rotor. The pulsating air gap flux in the motor at the standstill is resolved into two equal and opposite fluxes with the motor. The standstill impedance of each of the rotors referred to as the main stator winding is given as:

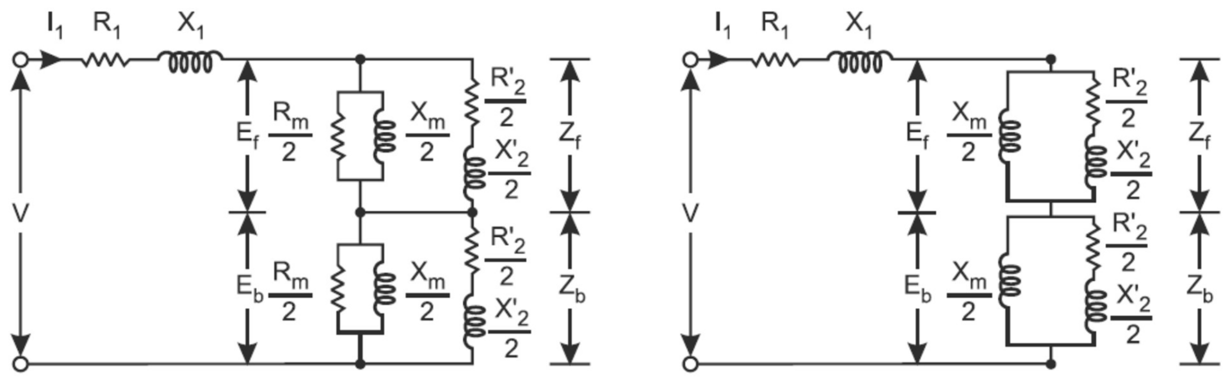
$$\frac{R_2'}{2} + j\frac{X_2'}{2} \qquad (5)$$

The equivalent circuit of a single-phase single winding induction motor with the standstill rotor is shown below. The forward and the backward flux induces a voltage E_{mf} and E_{mb} respectively in the main stator winding. E_m is the resultant induced voltage in the main winding.

$$E_m = E_{mf} + E_{mb} \qquad (6)$$

At Standstill Conditions

At standstill, the motor is considered simply as a transformer with its secondary short-circuited. The only difference is that in this case, two fields are considered revolving in opposite direction. Therefore, for each field rotor resistance and reactance is considered to be half the value, i.e., $R_2'/2$ and $X_2'/2$. Moreover, each rotor is associated with half the total magnetizing reactance and resistance i.e., $X_m/2$ and $R_m/2$ respectively.



(a) Equivalent circuit of 1-ϕ induction motor at standstill

(b) Simplified equivalent circuit neglecting core loss component R_m

Fig. 6

The equivalent circuit of a single-phase induction motor at standstill is shown in Fig. 6(a), Its simplified circuit is shown in Fig. 6(b) where core loss component Rm has been neglected.

At standstill, therefore, $E_f = E_b$

At Running Condition

At running condition, if the rotor is rotating in the direction of the forward revolving field with the slip s, the rotor current produced by the forward field will have a frequency s*f*. At the same time the rotor current produced by the backward field will have a frequency (2-s) *f*. Accordingly, the equivalent circuit of single-phase induction motor at running condition is drawn and shown in Fig. Methods to make Single-phase Induction Motor Self-starting

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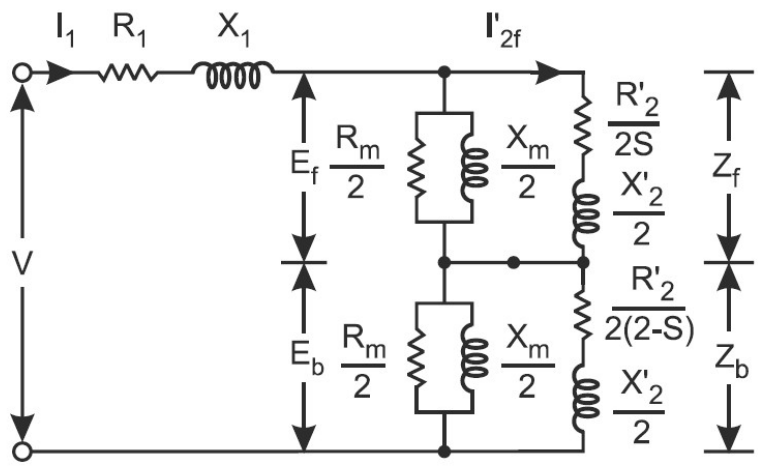

Fig. 7

When both forward and backward slips are taken into account, the equivalent circuit shown below is formed. In this condition, the motor is running on the main winding alone.

$$\frac{R_2'}{2\ s} + j\frac{1}{2}X_2' \text{ parallel with } j\frac{X_M}{2} \tag{7}$$

The rotor impedance of a single-phase induction motor representing the effect of the backward field referred to the stator winding m is given by an impedance shown below:

$$\frac{R_2'}{2(2-s)} + j\frac{1}{2}X_2' \text{ parallel with } j\frac{1}{2}X_M \tag{7}$$

Therefore,

$$Z_f = \frac{\left(\frac{R_2'}{2s} + j\frac{1}{2}X_2'\right)\left(j\frac{1}{2}X_M\right)}{\frac{R_2'}{2s} + j\frac{1}{2}X_2' + j\frac{1}{2}X_M} \tag{8}$$

$$Z_b = \frac{\left(\frac{R_2'}{2(2-s)} + j\frac{1}{2}X_2'\right)\left(j\frac{1}{2}X_M\right)}{\frac{R_2'}{2(2-s)} + j\frac{1}{2}X_2' + j\frac{1}{2}X_M} \quad (9)$$

The simplified equivalent circuit of a single-phase induction motor with only its main winding energized is shown in the figure below:

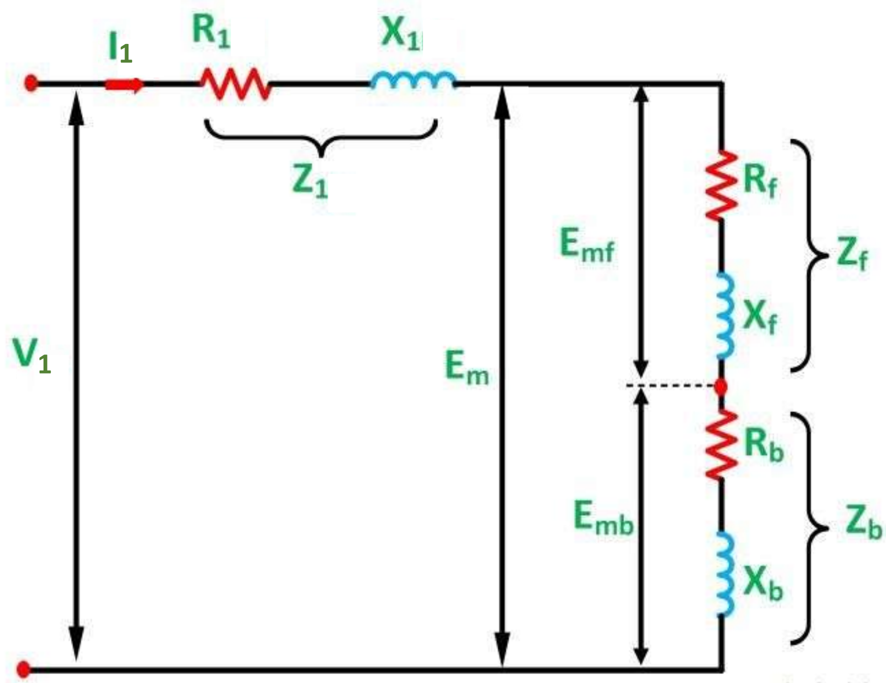

Fig. 8

$$I_m = \frac{V_m}{Z_{1m} + Z_f + Z_b} \quad (10)$$

Here,

The above equation (10) is the equation of the current in the stator winding.

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