

2 The Rotating Magnetic Field

The principle of operation of the induction machine is based on the generation of a rotating magnetic field. Let us understand this idea better.

Click on the following steps in sequence to get a graphical picture. It is suggested that the reader read the text before clicking the link.

- Consider a cosine wave from 0 to 360°. This sine wave is plotted with unit amplitude.
- Now allow the amplitude of the sine wave to vary with respect to time in a sinusoidal fashion with a frequency of 50Hz. Let the maximum value of the amplitude is, say, 10 units. This waveform is a pulsating sine wave.

$$i_{apk} = I_m \cos 2\pi \cdot 50 \cdot t \quad (1)$$

- Now consider a [second sine wave](#), which is displaced by 120° from the first (lagging)...
- and allow its amplitude to [vary](#) in a similar manner, but with a 120° time lag.

$$i_{bpk} = I_m \cos(2\pi \cdot 50 \cdot t - 120^\circ) \quad (2)$$

- Similarly consider a [third sine wave](#), which is at 240° lag...
- and allow its amplitude [to change](#) as well with a 240° time lag. Now we have three pulsating sine waves.

$$i_{cpk} = I_m \cos(2\pi \cdot 50 \cdot t - 240^\circ) \quad (3)$$

Let us see what happens if we [sum up](#) the values of these three sine waves at every angle. The result really speaks about Tesla's genius. What we get is a constant amplitude travelling sine wave!

In a three phase induction machine, there are three sets of windings — phase A winding, phase B and phase C windings. These are excited by a balanced three-phase voltage supply. This would result in a balanced three phase current. Equations 1 — 3 represent the currents that flow in the three phase windings. Note that they have a 120° *time* lag between them.

Further, in an induction machine, the windings are not all located in the same place. They are distributed in the machine 120° away from each other (more about this in the section on alternators). The correct terminology would be to say that the windings have

their axes separated in space by 120° . This is the reason for using the phase A, B and C since waves separated in *space* as well by 120° .

When currents flow through the coils, they generate mmfs. Since mmf is proportional to current, these waveforms also represent the mmf generated by the coils and the total mmf. Further, due to magnetic material in the machine (iron), these mmfs generate magnetic flux, which is proportional to the mmf (we may assume that iron is infinitely permeable and non-linear effects such as hysteresis are neglected). Thus the waveforms seen above would also represent the flux generated within the machine. The net result as we have seen is a travelling flux wave. The x-axis would represent the space angle in the machine as one travels around the air gap. The first pulsating waveform seen earlier would then represent the a-phase flux, the second represents the b-phase flux and the third represents the c-phase.

This may be better visualized in a [polar plot](#). The angles of the polar plot represent the *space* angle in the machine, i.e., angle as one travels around the stator bore of the machine. Click on the links below to see the development on a polar axes.

- This plot shows the pulsating wave at the zero degree axes. The amplitude is maximum at zero degree axes and is zero at 90° axis. Positive parts of the waveform are shown in red while negative in blue. Note that the waveform is pulsating at the $0 - 180^\circ$ axis and red and blue alternate in any given side. This corresponds to the sinewave current changing polarity. Note that the maximum amplitude of the sinewave is reached only along the $0 - 180^\circ$ axis. At all other angles, the amplitude does not reach a maximum of this value. It however reaches a maximum value which is less than that of the peak occurring at the $0 - 180^\circ$ axis. More exactly, the maximum reached at any space angle θ would be equal to $\cos\theta$ times the peak at the $0 - 180^\circ$ axis. Further, at any space angle θ , the time variation is sinusoidal with the frequency and phase lag being that of the excitation, and amplitude being that corresponding to the *space* angle.
- This plot shows the pulsating waveforms of [all three cosines](#). Note that the first is pulsating about the $0 - 180^\circ$ axis, the second about the $120^\circ - 300^\circ$ axis and the third at $240^\circ - 360^\circ$ axis.
- This plot shows the travelling wave in a [circular trajectory](#). Note that while individual pulsating waves have maximum amplitude of 10, the resultant has amplitude of 15.

If f_1 is the amplitude of the flux waveform in each phase, the travelling wave can then

be represented as

$$\begin{aligned} f(t) &= f_1 \cos \omega t \cos \theta + f_1 \cos\left(\omega t - \frac{2\pi}{3}\right) \cos\left(\theta - \frac{2\pi}{3}\right) + f_1 \cos\left(\omega t - \frac{4\pi}{3}\right) \cos\left(\theta - \frac{4\pi}{3}\right) \\ &= \frac{3}{2} f_1 \cos(\omega t - \theta) \end{aligned} \quad (4)$$

It is worthwhile pondering over the following points.

1. what is the interpretation of the pulsating plots of the animation? If one wants to know the 'a' phase flux at a particular angle for all instants of time, how can it be obtained?
2. What will this time variation look like? It is obviously periodic. What will be the amplitude and frequency?
3. Why does eqn. 4 represent a travelling wave?

