2nd August 2021

Torque-Speed Characteristics of the Induction Motor

(Reference : Section 7.5)

- Relationship among the torque ($\tau_{ind.}$); speed (n_m) and power.
- Primarily we would like to find the answers of the following questions :

✓ (i) How does the induced torque depend on the variation in mechanical load ?

(ii) what is the starting torque on the I.M. ?

(iii) How the speed of I.M. drop as its shaft load increases ?

Approach-I : We look at the Motor's Magnetic fields under the following conditions :

(i) No-load ; (ii) With-load .

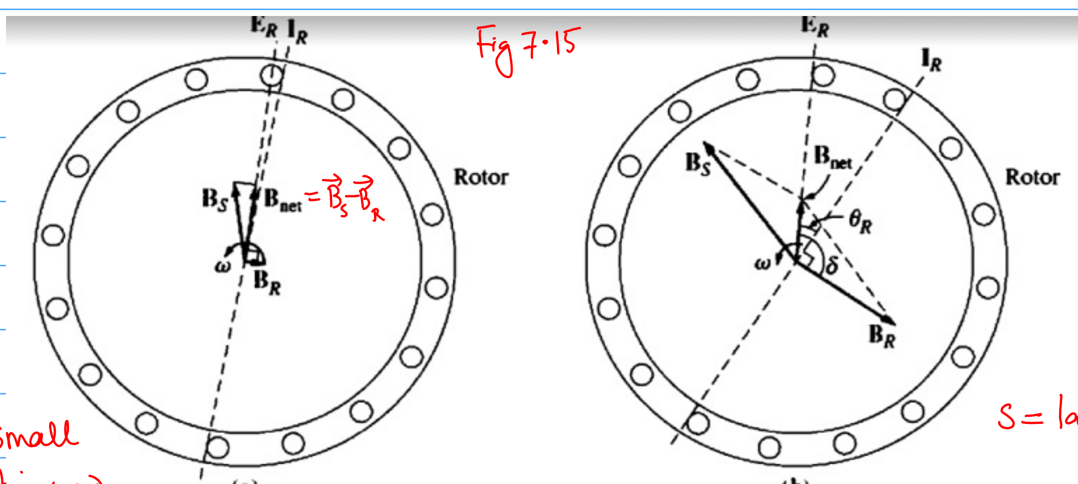


Fig 7.15

S = small (Relative speed is small) No-Load is connected

S = large (Relative Speed is also large) Heavy-load is connected

We know that the magnitude of the induced torque in the IM. is given as

$$\boxed{\tau_{ind.} = k \cdot |\vec{B}_R| \cdot |\vec{B}_{net}| \cdot \sin\delta}$$

where, $\vec{B}_{net} = \vec{B}_s - \vec{B}_R$

k = machine constant

δ = torque angle (ie, angle b/w $\vec{B}_R$ and $\vec{B}_{net}$.

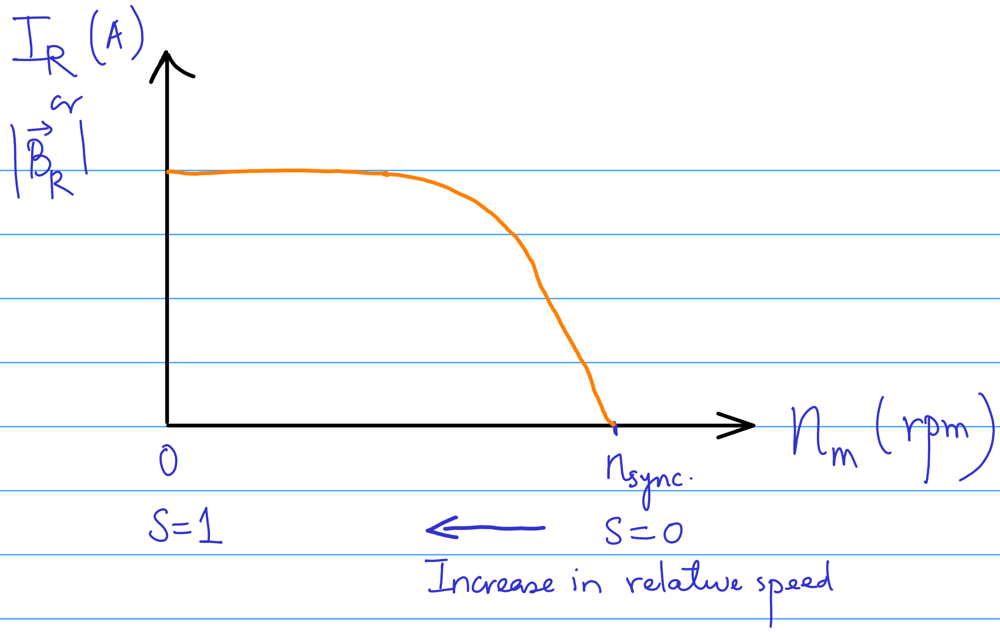
Therefore, to develop τ-speed characteristics, we should have to develop dependency of $\vec{B}_R$, $\vec{B}_{net}$, δ to the speed.

(i) Let look at the dependency of $|\vec{B}_R|$ on the slip(s).

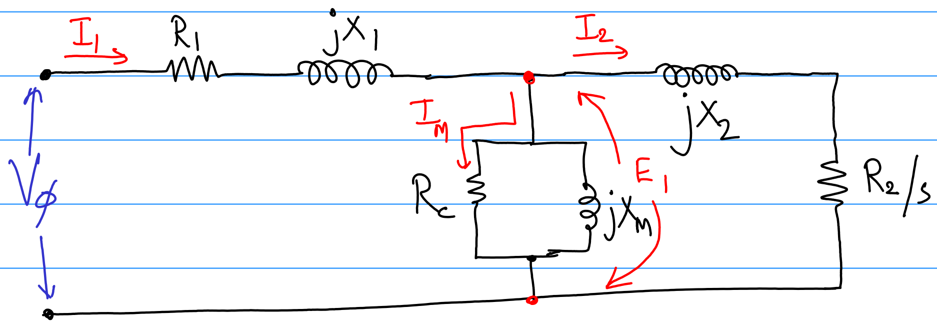
- the magnitude of $\vec{B}_R$ is directly dependent on the current I_R.

- Now, I_R increases with increasing slip (ie decreasing speed n_m)

$$I_R \uparrow = \frac{E_{RO}}{R_R/s \uparrow\downarrow + jX_{RO}}$$



• How $|\vec{B}_{net}|$ depends upon the speed ?



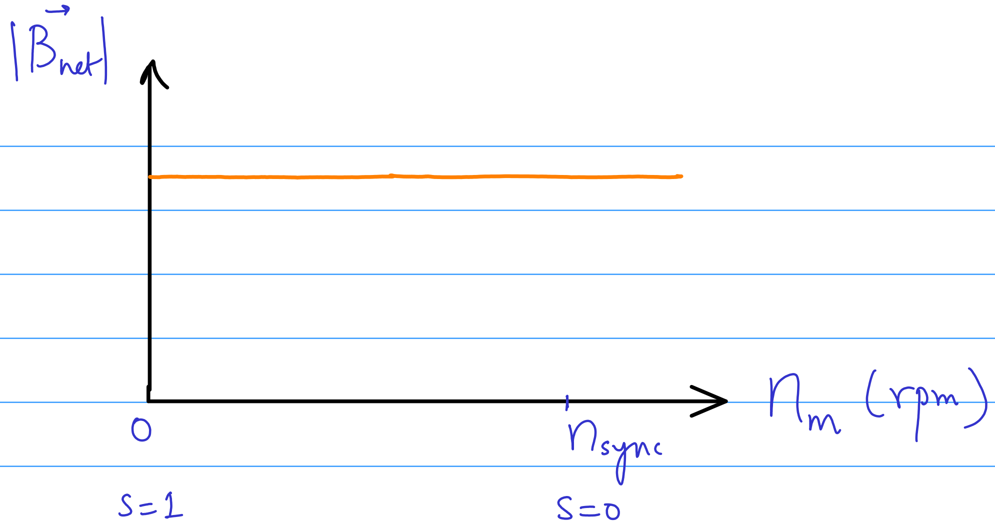
I_1 = stator current $\longrightarrow$ $\vec{B}_s$

I_2 = Rotor current $\longrightarrow$ $\vec{B}_R$

$I_1 - I_2 = I_M$ $\longrightarrow$ $\vec{B}_{net}$ $(\vec{B}_s - \vec{B}_R)$

here, the value of I_m depends upon E_1; however, the value of E_1 remains (approximately the same at all the value of I_2)

Therefore, I_m remains approx. constant, hence for practical purpose, $\vec{B}_{net}$ remains constant with speed



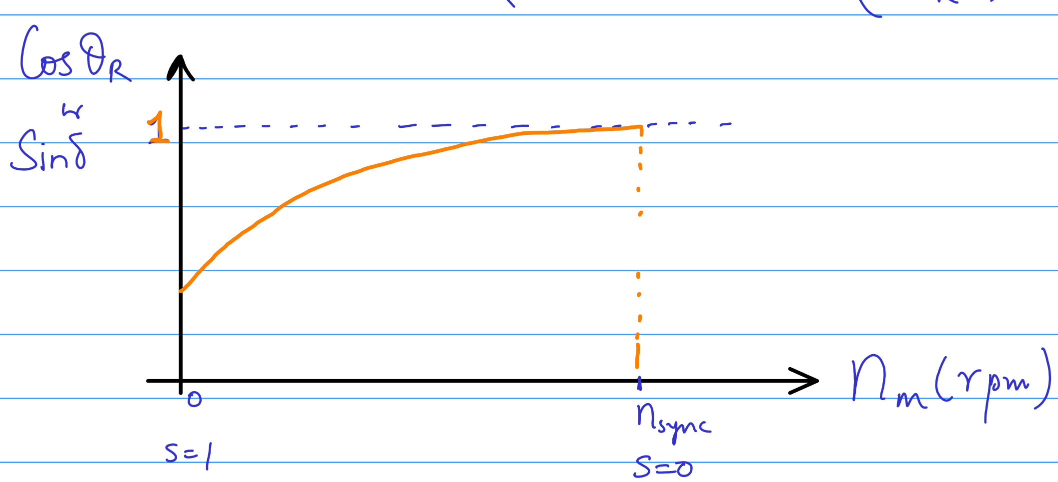
- How '$\sin\delta$' varies with the speed?

From the fig 7.15, it is evident

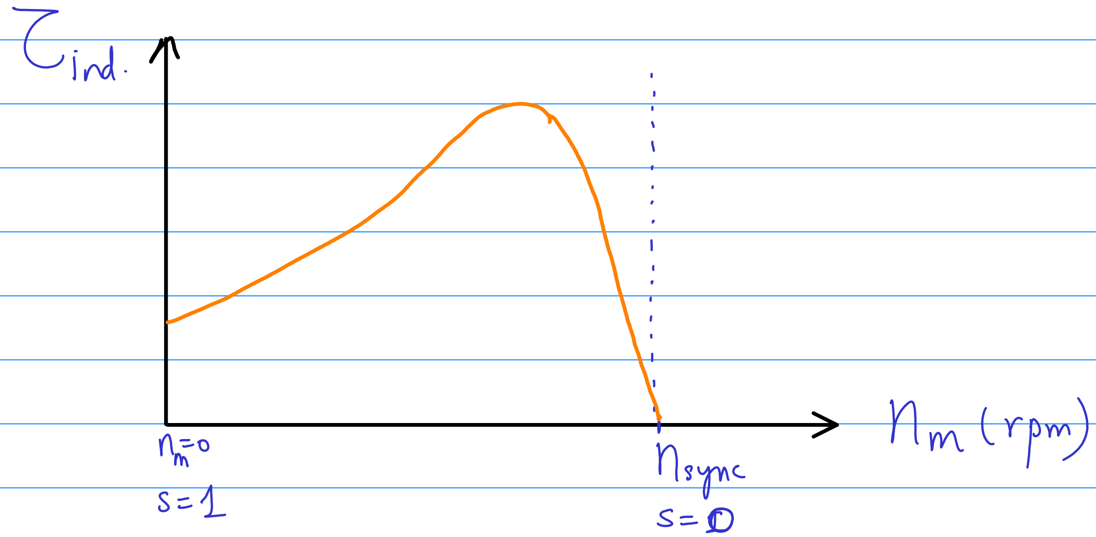
$$\delta = \theta_R + 90^\circ$$ where 'θ_R' is the angle b/w E_R & I_R r

$$\sin\delta = \sin(\theta_R + 90^\circ) = \cos\theta_R$$

Also, $$\theta_R = \tan^{-1}\left(\frac{X_R}{R_R}\right) = \tan^{-1}\left(\frac{sX_{R0}}{R_R}\right)$$



$$\tau_{ind} = k\,\underbrace{|\vec{B}_R|}\,\underbrace{|\vec{B}_{net}|}\,\underbrace{\sin\delta}$$



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Torque-Speed Characterstics of the I.M.

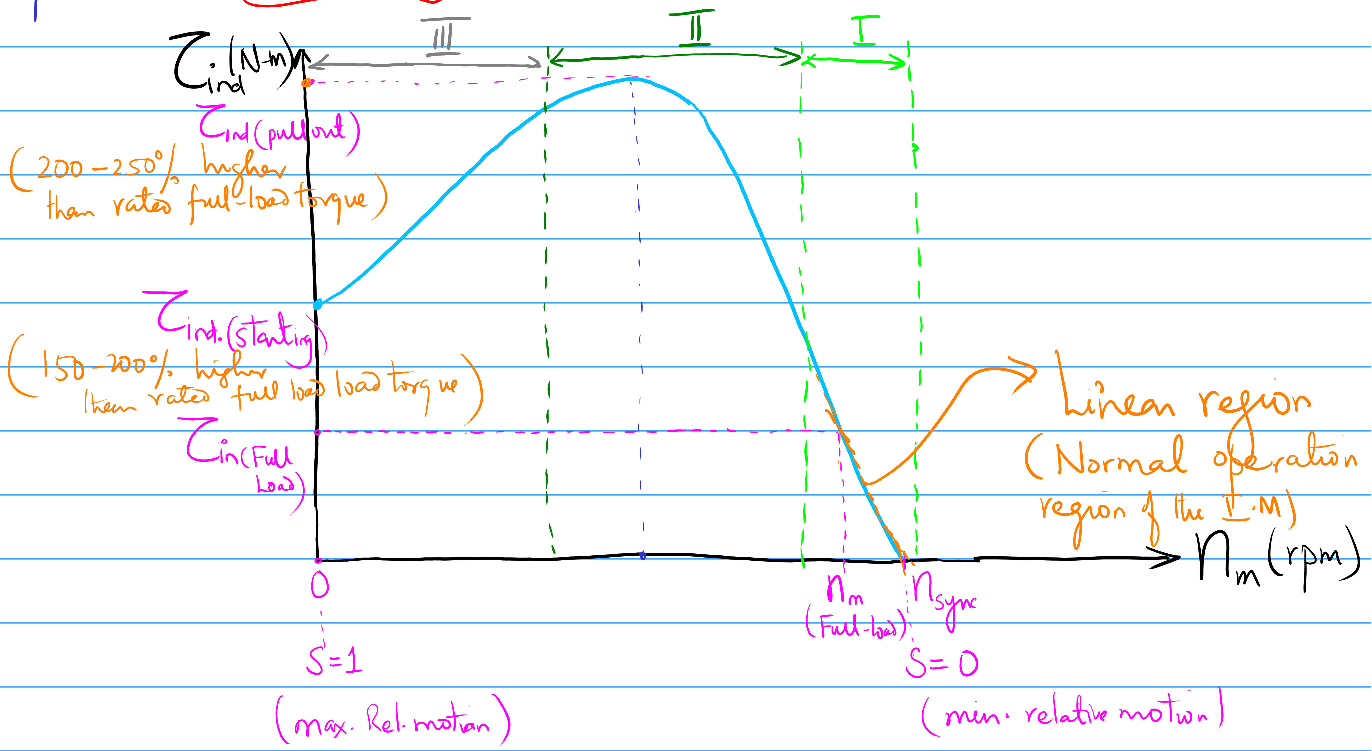
$$\boxed{\tau_{ind} = k\,|\vec{B}_R|\,|\vec{B}_{net}|\cdot \sin\delta}$$

$|\vec{B}_R|$ varies with the n_m —(i)

$|\vec{B}_{net}|$ varies with the n_m —(ii)

$\sin\delta$ or $\cos\theta_R$ varies with n_m —(iii)

Combining these variations w.r.t speed n_m, we plotted τ_{ind} versus n_m



Region-I : Low-slip region (Low relative speed)

- Normal steady-state operating range of the I.M.
- Within this region, the value of slip (s) increases linearly (approximately) with increase in load.
- Since $n_m \downarrow = (1-s\uparrow)\, n_{sync.}$; therefore, n_m decrease linearly with increase in load.

Region-II : Moderate-Slip (s) region.

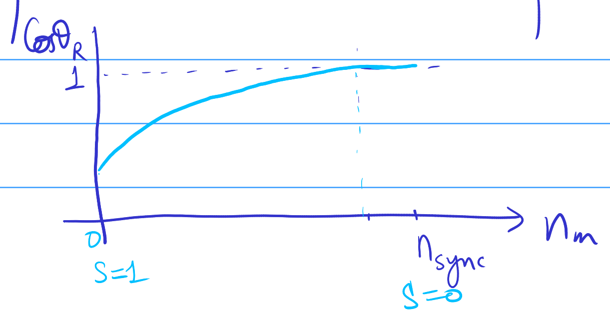
- Here, the rotor frequency (electrical) is higher.

  Since, $f_R = s f_e$

- Since the frequency of the rotor current is having moderate value, therefore, within this region,

$$X_{Rotor} (= \omega_R L) \sim R_{rotor}$$

- The rotor current (I_R) is no longer increases as rapidly as in the linear region.
- Power factor starts to drop



- There is peak in the τ_{ind} appearing called "Pullout Torque".

Region-III : High-slip(s) region

- Here, the $\tau_{ind} \downarrow$ with increase in load.
- Any increase in rotor current (ie, increase in $|\vec{B}_R|$) is completely overshadowed by the decrease in the rotor power factor (ie, $\cos\theta_R$ or $\sin\delta$)

Important point :

(i) when $n_m = n_{sync}$; $\tau_{ind} = 0$

(ii) In normal operation of the I.M. (ie, Operation b/w No-Load to Full-Load condition);

the τ_{ind} Vs n_m is nearly linear.

In this cond^n; $R_R >> X_R$ (since f_R is low)

So, I_R (or B_R or τ_{ind}) increases linearly with 's'.

(iii) There is a maximum possible induced torque that cannot be exceeded.

"Pull-out torque" or "Breakdown torque"

(iv) The starting Torque on the motor is higher than the τ_r(Full-load).

So the motor will start carrying any load that it can supply at full power.