Special Electrical Machines

Torque Production-cont.

The torque production in SRM can be explained using the elementary principle of electro-mechanical energy conversion. The general expression for the torque produced by one phase at any rotor position is

$$T = \left[\frac{\partial W^{'}}{\partial \theta} \right]_{i=const.}$$

Where T is the torque

W' is the co-energy

$\Delta\theta$ is the displacement of the rotor

The constant-current constraint in the formula ensures that during such a displacement, the mechanical work done is exactly equal to the change in the co-energy.

Torque Production-cont.

In a motor with no magnetic saturation, the magnetization curves would be straight lines. At any position, the co-energy and the stored magnetic energy are equal, which are given by

$$W_f = W' = \frac{1}{2} L i^2$$

Where *L* is the inductance of a exciting stator phase at a particular position. In this case the instantaneous torque can be derived as

$$T = \frac{1}{2} i^2 \frac{dL}{d\theta}$$

Energy Conversion process

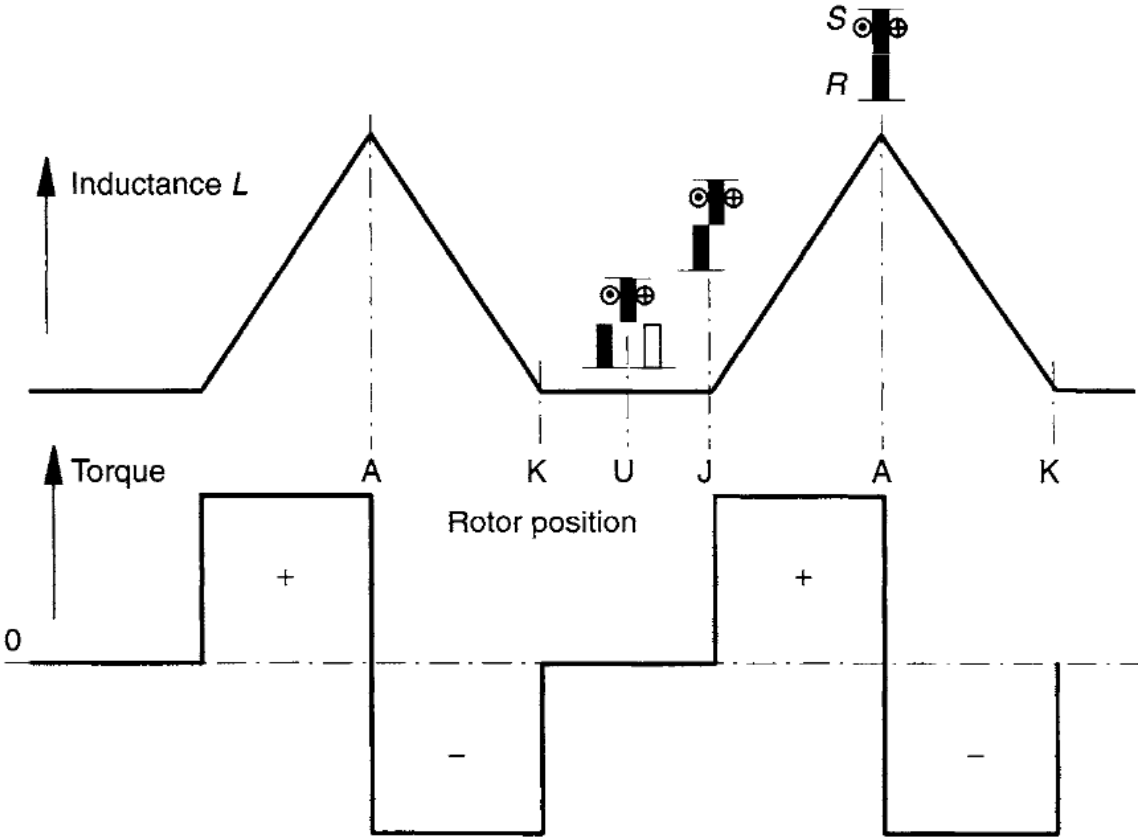
In the real switched reluctance motor, the energy conversion process in an SRM can be evaluated using the power balance relationship.

$$P_{in} = i_{ph}^2 R_s + \frac{d}{dt}\left(\frac{1}{2} L_{ph} i_{ph}^2\right) + \frac{1}{2} i_{ph}^2 \frac{dL_{ph}}{d\theta}\,\omega$$

The first term represents the stator winding loss; and
The second term denotes the rate of change of magnetic stored energy; The third term is the mechanical output power.

The second term always exceeds the third term. The most effective use of the energy supplied is to maintain phase current constant during the positive $dL_{ph}/d\theta$ slope, in which way, the second term is equal to zero

Four-quadrant Operation



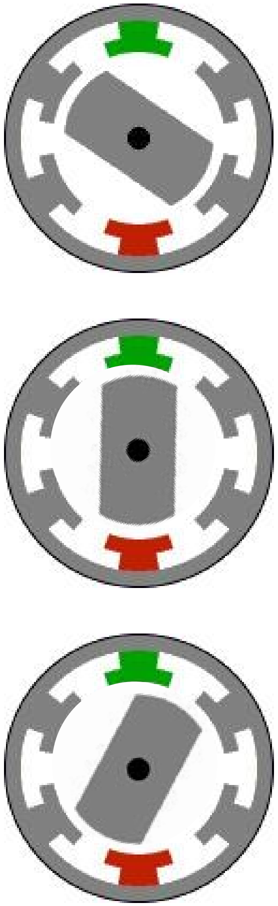


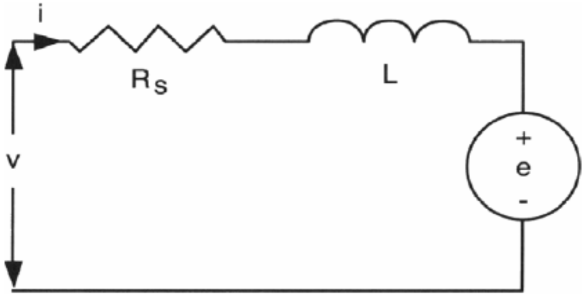
Fig. 3.4 Variation of inductance and torque with rotor position; coil current is constant. The small icons show the relative positions of the rotor and stator poles, with the rotor moving to the right. A = aligned position; U = unaligned position; J = start of overlap; K = end of overlap.

Torque Production-summary

- The torque is proportional to the square of the current and hence, the current can be unipolar to produce unidirectional torque.
- Since the torque is proportional to the square of the current, it has a good starting torque.
- Because the stator inductance is nonlinear, a simple equivalent circuit development for SRM is not possible.
- The torque characteristics of SRM are dependent on the relationship between flux linkages and rotor position as a function of current.

Equivalent Circuit

An elementary equivalent circuit for the SRM can be derived neglecting the mutual inductance between the phases as following:

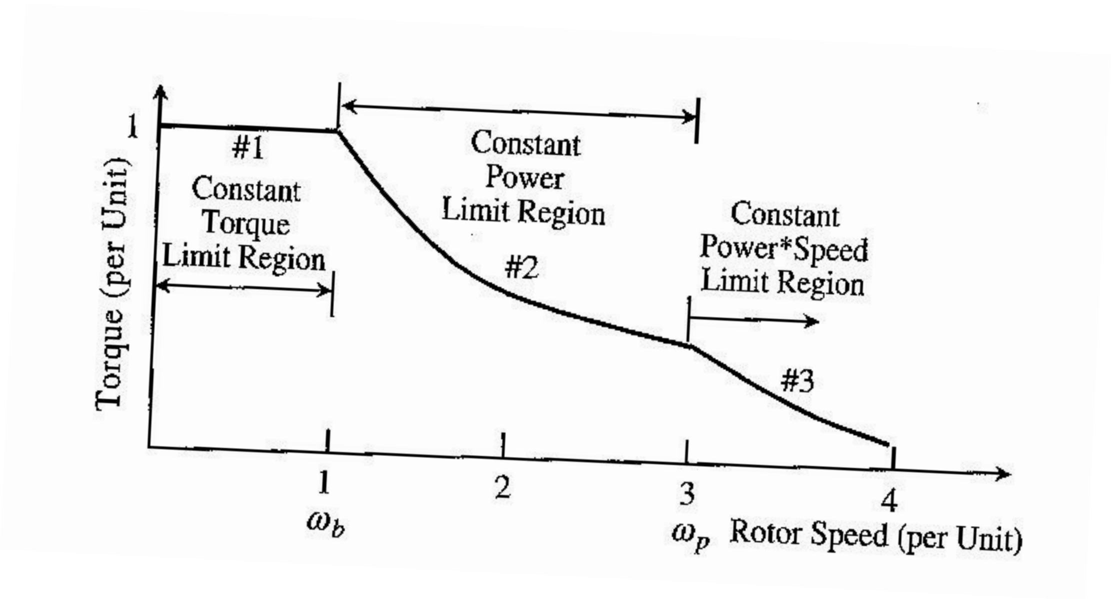


$$V = i_{ph}R_s + \frac{d}{dt}\left(L(\theta, i_{ph})i_{ph}\right)$$

$$= i_{ph}R_s + \frac{di_{ph}}{dt}L(\theta, i_{ph}) + \frac{dL(\theta, i_{ph})}{dt}i_{ph}\omega_m$$

- The first term is the resistive voltage drop
- The second term is the inductive voltage drop, and
- The third one is the induced emf, which can be very high at high speeds

Torque-speed Characteristics



The torque-speed plane of an SRM drive can be divided into three regions: constant torque region, constant power region and constant power*speed region

Torque-speed Characteristics-cont.

- Region1: The constant torque limit region is the region below the base speed ω_b, which is the lowest possible speed for the motor to operate at its rated power. For the small back-emf in this region, the current can be set at any desired level by means of regulators such as hysteresis controller or voltage PWM controller.

- Region2: The constant power limit region is the region where the controller maintains the torque inversely proportional to the speed. In this region, the phase excitation time falls off inversely with speed and so does the current. Because torque is roughly proportional to the square of the current, the rapid fall in torque with speed can be countered by adjusting the conduction angle q_{dwell}. By advancing the turn-on angle to increase the conduction angle until it reaches its upper limit at speed ω_p, the phase current can be increased effectively to maintain the torque production at a high level.

Torque-speed Characteristics-cont.

- Region 3: In this region, the q_{dwell} upper limit is reached when it occupies half the electrical cycle. The torque in this region is governed by natural characteristics, falling off as $1/\omega^2$.

Power Losses

Stator copper losses

When consider the case where phase currents are overlapping with both the previous and succeeding phases, note that the stator copper losses at any time are the sum of the copper losses contributed by the instantaneous phase currents. The resistive losses are the result of the cumulative effect of all three currents, evaluated as follows:

$$p_{cu\_loss} = I_{ph}^2 R_s \left[1 + \frac{(T_r + T_f)\omega_m N_s N_r}{12\pi} \right]$$

where I_{ph} is the peak value of phase current, R_s is the per-phase resistance of the stator winding, T_r and T_f are the current rise and fall time, N_s and N_r are the number of stator poles and rotor poles, and ω_m is the rotor speed in rad/s.

Power Losses-cont.

Core losses

The core losses are difficult to predict in the SRM due to the presence of flux densities with various frequencies in stator segments for these flux densities are neither pure sinusoids nor constants. The core losses consist of hysteresis and eddy current losses. The magnitude of the hysteresis losses is determined by the frequency of flux reversal and its path. To reduce the eddy current losses, the stator and rotor cores are laminated.

THANKS….

Queries Please…