GRAPHICAL ASSESSMENT OF 8/6 SWITCHED RELUCTANCE MOTOR PERFORMANCES

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Abstract: *An electromagnetic approach of a 4-phase 8/6 switched reluctance motor is presented, starting with an experimental test. The current drop at phase disconnecting is registered for various starting currents and rotor positions, using a PC with an I/O interface module. The National Instruments HiQ environment is used in order to process the experimental data, which provides magnetisation curves, magnetic coenergy, inductivities and torque variation. The resulted torque is compared to measured torque and a good superposition is obtained.*
Keywords: *Experimental test, Magnetisation curves, Coenêrgy, Inductivities, Torque.*

1. INTRODUCTION

At present Switched Reluctance Motors (SRM) are ones of the most preferable driving motors due to their advantages versus other electrical motors [5]. For all that the SRM modelling is difficult due to its non-linear magnetic circuit [6]. This make the simulation of the motor to be possible only with major simplicity assumptions. These ones refer to the linearity of magnetic circuit, to sinusoidal variation of the electromagnetic torque with rotor angle, neglecting the leakage flux, hysteresis phenomena and iron loses etc. With these restrictions the SRM behaviour may be simulated taking into account the linearized model [1], but simulation results are in general unsatisfactory.

The paper proposes a graphic non-linear approach of the SRM, taking into account the magnetisation curves that are determined by experimental test. With a complete set of flux-linkage values versus phase current and rotor positions, the modelling is possible by the use of a powerful environment of investigation as HiQ of National Instruments [4]. In this propose an experimental test is made on the basis of current drop registration for a given position of the rotor. From the magnetisation curves as a function $\Psi(i,\theta)$, with usual notations, static and dynamic phase inductivities, magnetic coenergy and electromagnetic torque developed by a motor phase can be calculated. The deduced variations are the most adequate for a complete and rigorous modelling and simulation of SRM drives.

2. EXPERIMENTAL INVESTIGATION

In order to obtain magnetisation curves the method of phase current drop is used and its digitally storing at a phase disconnecting (OFF state of the phase). In this purpose a set-up arrangement is considered, where the motor phase is connected to the DC source. The current drop control is given by labVIEW environment loaded on a PC[2]. Figure 1 depicts the block diagram of the electrical part of the set-up arrangement used for measuring and storing the phase current drop [3]. The ON state of the motor phase (*R,L*) is switched by a transistor (*Q*), while the OFF state flows through a suppression circuit that contains a diode (*D*) and an additional resistor (R_e). The ON-OFF state control and current storing are handled by the PC with a labVIEW L1200 interface.

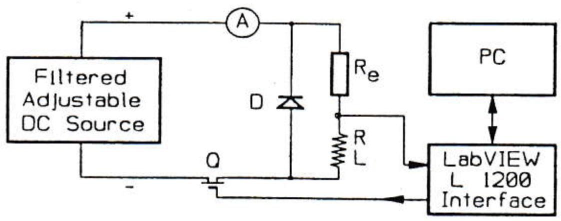


Fig. 1. *Set-up arrangement for phase current drop control.*

The SRM is locked on a rotary table, which enables the measurement of rotor positions between θ=0° and θ=30° (half of a polar-step) with a step of 3°. The registration of the current drop is made for various initial phase current between *I*=2A and *I*=12A with a step of 2A. The symmetry of motor characteristics with respect to rotor angle is taken into consideration. For instance, in figure 2 is shown the waveform of the current with respect to *N*, as number of sampling periods equal to 0.1 ms (10 kHz). The LabWIEV environment creates an ASCII file for each current drop waveform (totally 6 currents x 11 positions = 66 waveforms).

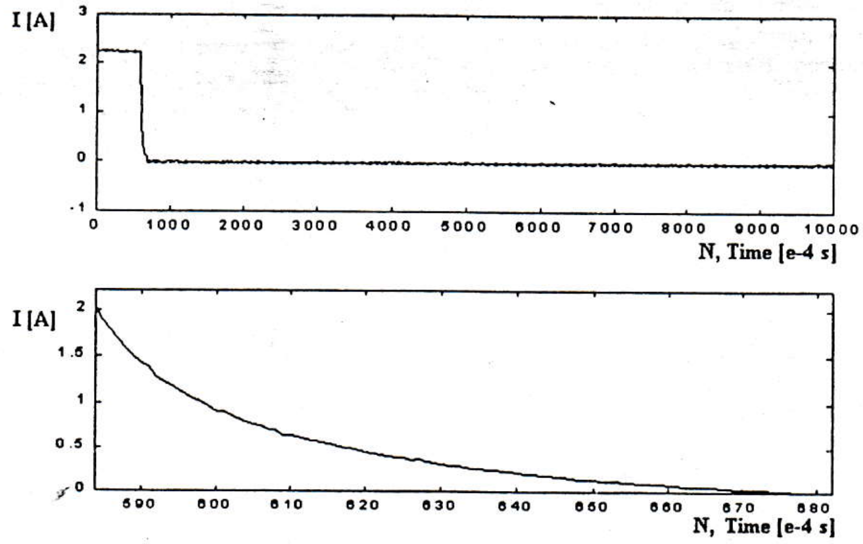


Fig. 2. *Stored current drop waveform at 2A, 0 degree.*

Each file is taken by HiQ environment for data processing. The flux-linkage variation is obtained from the voltage equation of the phase k:

$$V_k = R_k i_k + \frac{d\psi_k}{dt} \quad (1)$$

where R_k includes total resistance of the phase suppression circuit. Along the current drop period, the flux-linkage of phase k is given by the expression:

$$\psi_k = \int (V_k - R_k i_k) dt \quad (2)$$

where $V_k = 0$ during suppression time. A family of areas calculated for each current drop (totally 66 areas) is obtained with this integral.

3. MAGNETIZATION CURVES

The family of curves $\Psi(i,\theta)$ is obtained from plotting the areas magnitudes calculated with expression (2). Figure 3 shows magnetisation curves of the SRM. The effect of saturation of magnetic circuit is observed starting with medium phase current magnitudes. The effect of saturation is more significant at aligned rotor position, in the vicinity of θ= 0 degree, while for unaligned position, around θ= 30 degrees, the saturation effect is negligible.

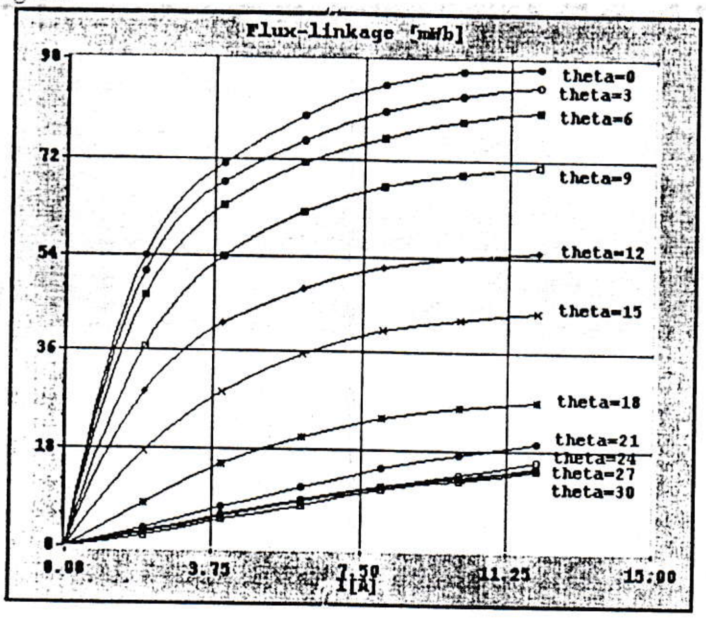


Fig. 3. *Magnetisation curves.*

4. PHASE INDUCTIVITY

The 8 stator windings are so connected to result 4 phases, each phase consisting of two diametrically opposite windings, so magnetically oriented to cancel the mutual inductivities [7]. In this way the phase inductivity is reduced to self-inductivity. Static inductivity is deduced from magnetisation curves using the expression:

$$L(i,\theta) = \frac{\Psi(i,\theta)}{i} \tag{3}$$

while dynamic inductivity is calculated with:

$$l(i,\theta) = \frac{d\Psi(i,\theta)}{di}\Big|_{\theta=const} \tag{4}$$

Both inductivities are strongly affected by the saturation effect. Figures 4 and 5 show respectively these inductivities variations.

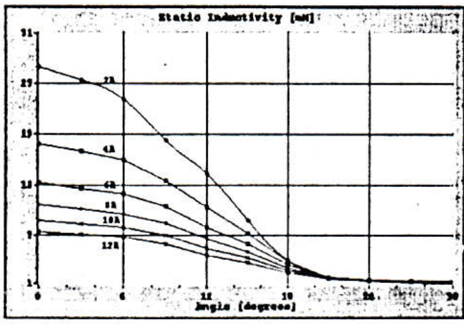


Fig. 4. *Static inductivity.*

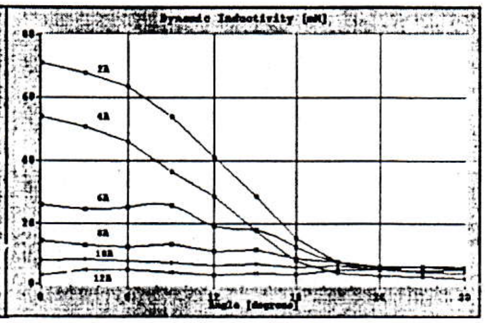


Fig. 5. *Dynamic inductivity.*

4. MAGNETIC COENERGY

In order to deduce the contribution of each phase to the developed electromagnetic torque, magnetic coenergy is calculated with the expression [6]:

$$W_k = \int_0^i \Psi_k(i_k, \theta_k)\, di_k \tag{5}$$

which represents the aria below $\Psi(i)$ curves until a given current for each rotor position.

Figure 6 shows the variation of coenergy with respect to rotor angle for different phase currents. The coenergy increases with phase current for a given angular position.

5. ELECTROMAGNETIC TORQUE

The expression of electromagnetic torque results by differentiating the expression:

$$M_k(i_k,\theta) = \frac{dW_k}{d\theta}\Big|_{i_k=const.} \tag{6}$$

that represents the theorem of generalised forces applied in case of SRM. Figure 7 depicts the electromagnetic torque variation as function of phase current and rotor angle.

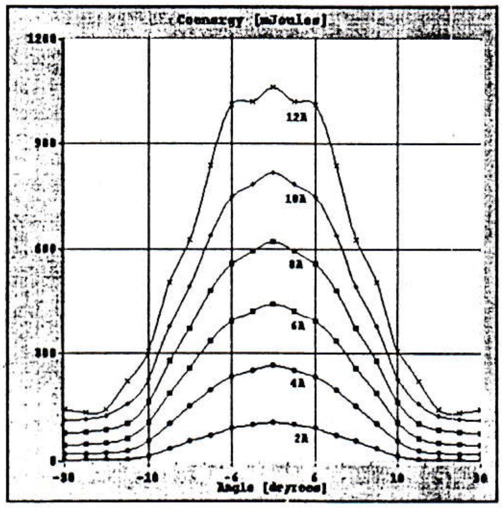
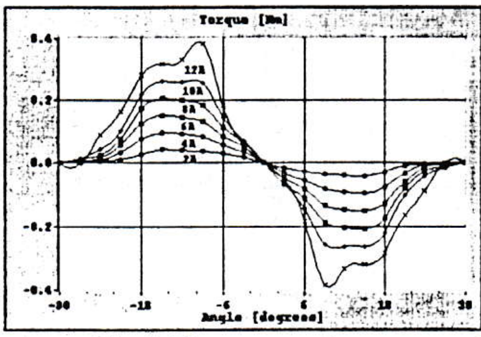


Fig. 6. *Magnetic coenergy.*

As expected, the variation of torque with rotor angle is not sinusoidal, but symmetrical with respect to aligned rotor positions. Spatial representation of electromagnetic torque is given in figure 8.



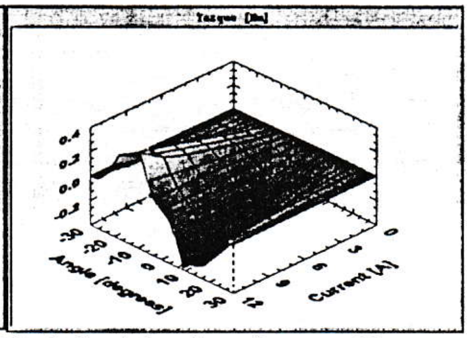


Fig. 7. *Electromagnetic torque.* Fig. 8. *Spatial surface of torque with respect to phase current and rotor position.*

The electromagnetic torque developed by each phase of SRM, as calculated from the magnetisation curves, is compared to measured torque for a phase current of 10A. Figure 9 presents a comparison between the calculated and measured torque developed by phase 1. A good superposition of the two curves is obtained.

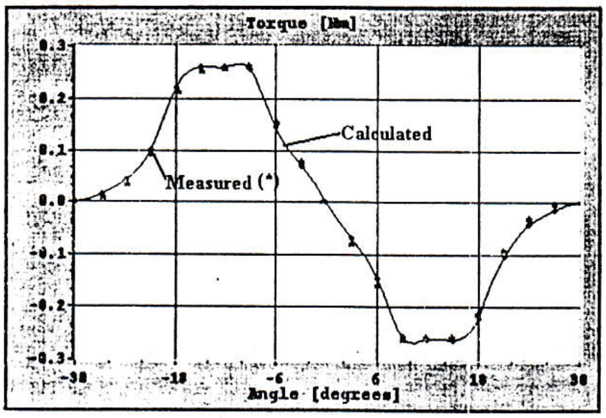


Fig. 9. *Calculated and measured torque for 10A.*

5. CONCLUSIONS

Graphical approach of SRM performances is made with the aim to encourage a more rigorous study. Mathematical modelling of SRM can be successfully accomplished using as start real magnetisation curves from experimental investigations. As a result numerical simulation based on non-linear parameters is more adequate than classical approach, due to its simplicity and also to its real basis. Dynamic equations of the SRM are of simpler structure, that avoid to explicit flux-linkage as function of inductivities. Also they include the major nonlinearity due to magnetic saturation.

6. REFERENCES

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