EVALUATION OF THE INFLUENCE OF THE MAGNETIC SYSTEM IN RELAYS

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ABSTRACT

The paper evaluates the influence of different cores on the performance of relays. In particular two types of c-cores, all made from low quality magnetic steel, are considered. The two cores, one butt-constructed and the other interleaved, are mathematically modelled and the results are analyzed and obtained experimentally. Then the two sets of results are compared with those of a c-shaped core of excellent magnetic material with the aim of qualifying the influence of the core material. It is observed that the method of constructing the core also influences the performance.

INTRODUCTION

The main element in a relay is the core. It consists of magnetic steel which usually operates at the point of saturation. The investigation aims at qualifying the influence of the magnetic system on the performance of relays. If, say, the operating point of the steel is changed by O.1T within the linear region, by how much will its operating current (or time) change? Likewise, if the quality of steel is changed, how will the operating current (or time) of the relay be affected. The investigation involved two types of steel, one with excellent magnetic quality (operating point above 1.25T) and the other of very low quality.

The low quality steel was also used in two types of cores - which differed in their construction method - to further investigate the magnetic system's influence, through variation of its reluctance, on both the operating current and time of the relay.

MODELLING OF THE MAGNETIC SYSTEM

In order to evaluate its influence, modelling of the magnetic system was necessary.

Magnetic Resistance of Relay Core

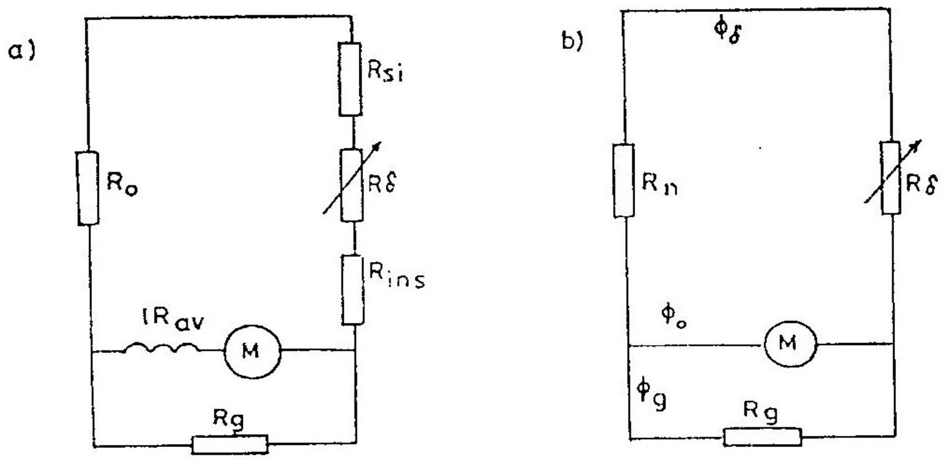

Fig. 1: An equivalent circuit used for modelling the magnetic system of relays

Figure 1 shows an equivalent circuit of the magnetic system used for modelling the two cores. The total resistance of the circuit is:

$$R_m^{'} - lR_{av} + \frac{R_g(R_b + R_o)}{R_o + R_g + R_b}$$

Where $R_g = \dfrac{1}{G_y}$ and $R_b = R_\delta + R_{ins} + R_{si}$

In the expressions above R_g - relative magnetic resistance obtained by taking into account flux leakages; R_b - magnetic resistance of the relay airgap taking into account the fastenings attaching the core to the relay base; R_δ - magnetic resistance of the airgap dependent on the movement and hence position of the armature; R_{ins}-magnetic resistance of the gap in between the armature and the core when the armature is fully attracted; the space in question usually has some non-magnetic material; R_{si} - magnetic resistance of the gap in between base and the armature along the motion axis of the latter, this value is considered not dependent on position of the armature; R_o - magnetic resistance of the joint between the core and the casing at the base of the former; l = length of the core; R_{av} - average magnetic resistance per unit length of the relay core and base.

To obtain the value of flux at the end of the core at the poles it is necessary to divide winding mmf by the equivalent magnetic resistance R_m; the latter's value can simply be found by considering the equivalent circuit of the magnetic system with the help of Ohm's and Kirchoff's laws:

$$R_m = R_b + R_o + lR_{av} = \frac{R_{av}}{R_g}(R_b + R_o) \tag{1}$$

If leakages are neglected ($R_g = \infty$) the expression can be simplified as follows:

$$R_m = R_b + R_o + lR_{av} = R_\delta + R_n \tag{2}$$

Magnetic resistance of the airgap is given by:

$$R_\delta = \frac{1}{G_\delta} = \frac{1}{G'_\delta} - R_{ins} = R'_\delta - R_{ins} \tag{3}$$

where R'_δ - total magnetic resistance of the airgaps taking into account the non-magnetic material within the flux path.

If neglect the magnetic resistance of soft iron of the core and the casing ($R_{av} \approx O$) then full magnetic resistance of the relay circuit[1]:

$$R_m = \frac{R_g(R_b + R_o)}{R_b + R_o + g} = \frac{R_g(R_n + R_\delta}{R_g + R_n + R_b} = \frac{R_g(\mu_o S R_n + \delta)}{\mu_o S(R_g + R_n) + \delta} \tag{4}$$

where δ is the airgap length and R_n - the total magnetic resistance of the elements in the magnetic circuit the value of which is independent on the position of the armature.

Relay Inductance

It is known that the expression for static inductance of the relay (at an equilibrium position) is:

$$L_o = \frac{N^2}{lR_{av} + qR_b}(1 + \frac{R_b g l}{3}) = \frac{3 + R_b g l}{3(lR_{av} + qR_b)} N^2 = K_o N^2 \tag{5}$$

where g - magnetic admittance of the leakage flux within a unit length (1 metre) of the magnetic circuit and q is given by:

$$q = \frac{l\sqrt{gR_{av}}}{\tanh l\sqrt{gR_{av}}}$$

The value K_o is a relative magnetic conductance of the relay given by[2]:

$$K_o = \frac{1}{lR_{av} + qR_b}[1 + \frac{R_b}{lR_{av}}(q-1)] = \frac{3 + R_b g l}{3(lR_{av} + qR_b)} = \frac{1}{R_m} \tag{6}$$

The value K_o depends upon the configuration of the relay, the size of the space in between the soft-irons and ampere turns.

Magnetic Energy and Pulling Force

In the case when the winding of the electromagnetic is switched to a constant supply the following equation may be written:

$$U = iR + \frac{d\psi}{dt} \tag{7}$$

Energy supplied through time t minus energy lost as heat is changed into magnetic energy.

$$W = \int_0^{\psi} i d\psi \tag{8}$$

Graphically this energy is the area between flux curve and the y-axis.

Magnetic energy consumed during motion of the armature is obtained as a difference between input energy to the system and that remaining after the motion.

$$W_m = W_1 + W_2 - W_3 \tag{9}$$

Pulling force of the armature electromagnet and the torque it creates may be expressed as follows:

$$F = \frac{dW_m}{d\delta} \qquad \text{and} \qquad T_a = -\frac{dW_m}{d\alpha} \tag{10}$$

Due to the non-linearity of the magnetization curve the easiest way to calculate pulling force is by using a graphical method. However, if assume that the magnetization curve of the relay is a straight line (μ = const) and the value of current within the motion time of the armature does not change, pulling force can be obtained by analytical means.

Pulling Force - Total magnetic conductance of the relay airgap can be expressed by the following equation:

$$G_\delta' = G + G_1 + G_2 \qquad \text{and} \qquad \frac{dG_\delta'}{d\alpha} = \frac{dG}{d\alpha} + \frac{dG_1}{d\alpha} + \frac{dG_2}{d\alpha} \tag{11}$$

where G_1 and G_2 are components of a resultant magnetic flux entering through two routes, along the edge in between the side and front surfaces and along the side surfaces of the pole-tips respectively.

In a case when the effect of magnetic conductance especially at tips and sides of the poles can be neglected and so is the magnetic conductance of all the parts not dependent on rotational angle of the armature then torque delivered by the relay armature becomes[3]:

$$T_a = -\frac{(IN)^2}{2}\frac{dG}{d\alpha} = \frac{(IN)^2 \pi\mu_o}{\alpha^2}(c_1 - \sqrt{c_1^2 - r^2}) \tag{12}$$

where G is the conductance in between the poles of the circular cross-sectional area and the armature and C_1 is the distance between the axis of the core and the axis of rotation of the armature.

TRANSIENTS AT SWITCHING THE RELAY

Transients taking place within the relay circuit at switching the relay winding to a constant voltage may be analyzed with the help of the following equation:

$$U = iR + \frac{d\psi}{dt} \tag{13}$$

If the flux is small then $\psi = \phi$ N and hence equation (13) becomes

$$U = iR + N\frac{d\phi}{dt} \tag{14}$$

In order to solve this equation it is necessary to establish the relationship between flux and time i.e. ϕ = f(t)[4]. The curves showing the relationship between ψ and i or ϕ and iN for the electromagnet with its armature firstly unattracted and then attracted are shown in figure 2.

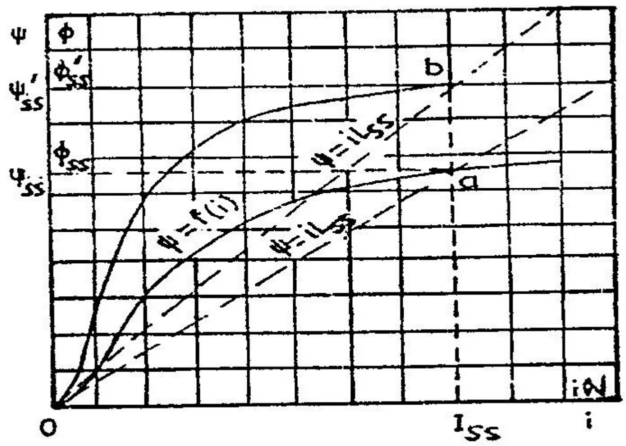

Fig. 2: Relationship between flux and current

The relationship between i and ψ t and ϕ and t may be obtained using different methods. However, in this investigation the method of conditional linearization is used.

RESULTS

Three cores were investigated. The first was from excellent magnetic material whereas the other two were from low quality magnetic steel. Two cores, one from either type of steels, were interleaved and the third was butt-constructed. In each case normal design procedures which determine operating time of the relay was used given a specific operating point within the magnetization curve of the material. The type of construction of the core considered was taken into account during the computation stage. The computed results were further verified through experimentation. Table 1 summarizes the results. Evaluation was done using the expression:

$$Evaluation = \frac{Previous.reading - Present.reading}{Previous.reading} x100\%$$

CONCLUSION

The paper has successfully shown and analyzed the influence of magnetic steel on the operating current and time of a relay. It has also, through the results obtained, qualified the magnetic systems role in relays.

Table 1: Results of the effect of the magnetic system on performance of relays

Type of core	Operating point [T]	Computed Operating Current [A]	Experimental Operating current [A]	Evaluation (Current) [%]	Computed Operating time [mSec]	Experimental operating time [mSec]	Evaluation (time) [%]
Excellent quality magnetic steel (Interleaved)	1.55	3.54	3.63	-	8.02	8.11	-
	1.45	3.31	3,45	4.96	10.54	10.68	-31.69
	1.35	3.08	3.27	5.15	13.72	13.99	-30.99
	1.25	2.85	3.10	5.06	18.17	18.39	-31.42
Low quality magnetic steel (Interleaved)	1.00	6.25	6.32	-	18.08	18.22	-
	0.90	5.63	5.70	9.81	22.15	22.36	-22.72
	0.80	5.00	5.15	9.65	27.32	27.40	-22.55
	0.70	4.38	4.65	9.75	33.46	33.66	-22.84
Low quality magnetic steel (B[illegible] co[illegible])	1.00	7.82	7.92	-	21.74	21.99	-
	0.90	7.04	6.94	12.34	27.69	27.82	-26.51
	0.80	6.26	6.10	12.02	34.84	35.18	-26.47
	0.70	5.47	5.35	12.23	44.48	44.60	-26.78

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