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METHOD ON THE ESTABLISHMENT OF PERFORMANCES OF THE VECTOR CONTROL SYSTEM OF NON-SYNCHRONOUS TRACTION ENGINES FOR LOCOMOTIVES

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ABSTRACT

The method treats the determination of performance of the vector control system of the non-synchronous traction engine of locomotives taking into consideration the deviation between the rotor flow and the electro-magnetic torque.

KEY WORDS

- LOCOMOTIVES
- NON-SYNCHRONOUS TRACTION ENGINE
- VECTOR CONTROL OF NON-SYNCHRONOUS ENGINE
- PWM VOLTAGE RECTIFIERS FOR LOCOMOTIVES
- VECTOR CONTROL SYSTEMS FOR RAILWAY TRACTION

1. Principles and phenomena

Aiming to establish the influence of the modification of rotor time of the non-synchronous traction engine with rotor in short - circuit the following relation is analyzed:

$$f_r = \frac{m_e r_r}{\Psi_r^2} \quad (1)$$

where:

f_r is rotor frequency ;
m_e - electro-magnetic torque;
r_r – rotor resistance;
Ψ_r - rotor flow.

This analysis is made in order establish the deviation level of the vector control which leads to the loss of connection between the rotor flow (Ψ_r) and the electro-magnetic torque (me).

The reason for deviation of the vector control resides in the modification of the rotor resistance (rr) due to temperature and pelicular effect. In case relation (1) is also presented taking into consideration

$$f_r = \frac{r_r}{l_r}\frac{l_m i_{sq}}{\Psi_r} \qquad (2)$$

where:

l_r is rotor inductance ;

l_m – gap inductance;

i_{sq} – statoric (fixed coil) current on axis q.

The deviation from the controlled revolutions may be established for the non-synchronous traction engine.

In such a case rotor inductance (l_r) may be considered constant as the engine operates at constant rotor flow and thus the saturation level remains the same. Due to this reason it may be considered that the variation of the rotor time is owed only to the rotor resistance.

2. System distortion

Through the simulation of the effects of the rotor time variation three situations are existing, namely:

Case 1 - the response of the indirect vector control system, to the variation of fixed coil torque m_s (figure 1a) and the variation of the electro-magnetic torque (m_c) subject to time (fig. 1b) for en equal ratio,

$(l_r/r_r)^*=(l_r/r_r)$;

Case 2 - the response of the indirect vector control system, to the variation of the variation of the fixed coil torque m_s subject to time (figure 2a) and the variation of the electro-magnetic torque (m_c) subject to time (fig. 2b) for $(l_r/r_r)^*=0,4(l_r/r_r)$;

Case 3 - the response of the indirect vector control system, to the variation of m_c torque (figure 3a) and the torque variation (m_c) subject to time (fig. 3b) for $(l_r/r_r)^*=2(l_r/r_r)$;

The simulation has been made on an indirect vector system with a DWM voltage rectifier current controlled (fig.4). It is stated that the method on indirect vector control based on the rotor flow is one of the simplest methods to process signal.

3. Indirect vector control

The regulator for indirect vector control (RI- Ψ_r) presented in figure 4 generates the octogonal components of the phaser of the fixed coil current imposed in the oriented system i^*_{sd} and i^*_{sq} and the relative rotor frequency (f_r) by means of the imposed torque (m^*_e) and the imposed rotor flow ($\Psi_r{}^*$) .

From the analysis of the three cases being presented above it comes out the system response in case 1, $(l_r/r_r)^*=(l_r/r_r)$, that has a rapid torque response, without oscillations and that indicate the correct introduction of the rotor time.

For cases 2 and 3, where the imposed rotor resistance (r_r) differs from the normal one, according to the isolation class, the system has an oscillating response (fig. 2.b and fig. 3.b) different from the optimum one (fig. 1b).

Because the rotor resistance is the one that determines the dynamic performance of the indirect vector system, it is compulsory to establish the calculation of the orientation errors that determine errors in the rotor flow and the electro-magnetic torque.

With low-power traction engines, at a variation of ? 25% of the rotor resistance it is determined, on high drifts, the case of motor vehicle start, a variation of approximately ? 25% of the rotor flow (see figure 5).

Due to the flow error, an error will also appear in the electro-magnic torque (m_e) as against the imposed value (m^*_e) and the imposed traction force(F^*_0) at the hoop of the motor wheel of the imposed fixed coil current (i^*_s) .

4. Establishing of the current phasers

The imposed rotor current phaser ($\underline{i}^*_r$) is calculated from the relation :

$$\underline{i}^*_r = \frac{ff_r^* x_m}{k_r r_r^* + ff_r^* x_r} i_s^* \tag{3}$$

components of the rotor current phaser are determined based on the relations :

$$i_{rd} = -\frac{\left(f_r^*\right)^2 x_r r_r^* (1-k_r)}{r_r^*[(k_r r_r^*)^2 + (f_r^* x_r)^2\}} \Psi_{rd}^* \tag{4}$$

$$i_{rd} = -\frac{f_r^*[k_r (r_r^*)^2 + (f_r^* x_r)^2}{r_r^*[(k_r r_r^*)^2 + (f_r^* x_r)^2} \Psi_{rd}^* \tag{5}$$

The electro-magnetic torque at the shaft of the traction engine is calculated taking into account the flow projections and those of the rotor current:

$$m_e = \frac{(\Psi_{rd}^*)^2 f_r^*}{r_r^*}\left[\frac{k_r (k_r - 1)^2 (f_r^* r_r^* x_r)^2}{[(k_r r_r^*)^2 + (f_r^* x_r)^2]^2} + \frac{(k_r r_r^*)^2 + k_r (f_r^* x_r)^2}{(k_r r_r^*)^2 + (f_r^* x_r)^2}\right. \tag{6}$$

5. Estimation of parameters

The estimation of the required parameters for the indirect vector regulation based on the rotor flow is made in real time using numeric systems.

In order to estimate the parameters values of the indirect vector regulation based on the rotor flow reference will be made to the method of the vector product, known also as DOMI method which compare, on one side, the values of the induced flow (Ψ_r *), and on the other side, the measured values of voltages and fixed coil current (U_s ; i_s), more exactly the model values are compared.

$$\frac{1}{w_n}\left(\frac{l_m}{l_r}\right)^* \frac{d_i}{d_t} \tag{7}$$

to the model

$$\begin{aligned} \Psi_{ra}^* &= \Psi_r^* \cos\Theta_k^* \\ \Psi_{rb}^* &= \Psi_r^* \sin\Theta_k^* \end{aligned} \tag{8}$$

6. Determination of system error

The error between the two models (7) and (8) is produced by the rotor time.

Correction system $\Delta(\frac{r_r}{l_r})$, is calculated in accordance with the error criteria of the vector product, namely : $\Delta(\frac{r_r}{l_r}) = e_{ra} e_{rb}^* - e_{rb} e_{ra}^*$

Where the components of the electric motor voltage (e_{ra}, e_{rb}) induced by the rotor flow in the fixed coil system fix $\alpha - \beta$?are calculated based on the relations:

$$e_{ra}^* = -e_r^* \sin\Theta_k^*$$

$$e_{ra}^* = -e_r^* \cos\Theta_k^*$$

where: $e_r^* = f_s^* (\frac{l_m}{l_r})^* \Psi_r^*$

7. Criterion of method convergence

The criterion that gives an appropriate convergence to the mentioned method is presented under the form:

$$\Delta(\frac{r_r}{l_r}) = e_{ra} \cos\Theta_k^* - e_{rb} \sin\Theta_k^*$$

8. Block diagram

The block diagram of this method is presented in figure 4.

This method is based on the estimation of the induced electric motor voltage, taking into consideration the fixed coil resistance that varies with temperature. Taking into consideration the fact that traction engines have high powers, of the level of MVA and they are controlled in terms of temperature by forced ventilation systems existing on the locomotive, the issue of the rotor resistance variation due to temperature may be ignored, however not totally.

One remark should be made, namely that the method does not consider the idle running of the locomotive, when the rotor current is null and also when the locomotive is standing, respectively when the engine revolution equals 0. In fact such cases are not of concern for the railway traction and due to this reason this method does not tackle such cases.

9. Conclusions

Based on the presented method the driving and vector control diagrams are set for non-synchronous traction engines of the locomotive. In addition, the design performances are established the same as the operational ones in order to ensure an efficient locomotive operation, irrespective of the train traffic speed.

REFERENCES

[1] Mihailescu D., Tulbure V., (2001), "*Driving and control of locomotives with non-synchronous traction engines*" , Publishing House ALL, Bucharest

[2] Tulbure V., (2001), "*Vector control with current sources of the non-synchronous traction engine for locomotives*" Romanian Railways Review, Bucharest, no.3

[3] Tulbure V., (2001), "*Vector control with current sources of the non-synchronous traction engine for locomotives*" Romanian Railways Review, Bucharest, no.4

[4] Mihailescu D., (1997), "*Locomotives and electric trains with non-synchronous traction engines*", Publishing House "Editura Didactica si Pedagogica", Bucharest

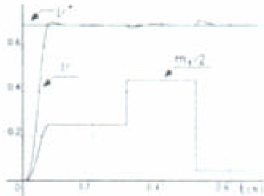

Fig. 1.a The answer of the regulation indirect vectorial system on the couple variation m_r for $(1/r_r)^*=(1/r_r)$

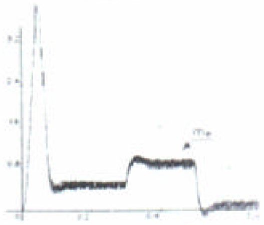

Fig. 1.b The electromagnetic couple m_e for $(1/r_r)^*=(1/r_r)$

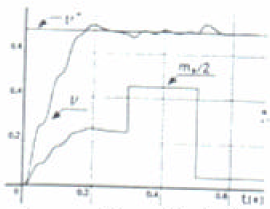

Fig. 2.a The answer of the regulation indirect vectorial system on the couple variation m_r for $(1/r_r)^*=0,4(1/r_r)$

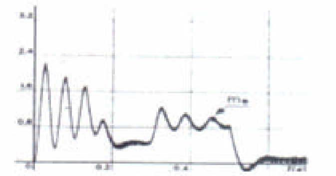

Fig. 2.b Electromagnetic couple m_e for $(1/r_r)^*=0,4(1/r_r)$

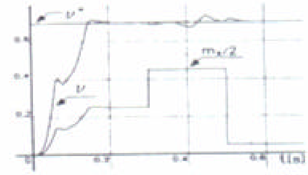

Fig. 3.a The answer of the regulation indirect vectorial system on the couple variation m_r for $(1/r_r)^*=2(1/r_r)$

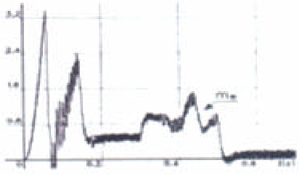

Fig. 3.b Electromagnetic couple m_e for $(1/r_r)^*=2(1/r_r)$

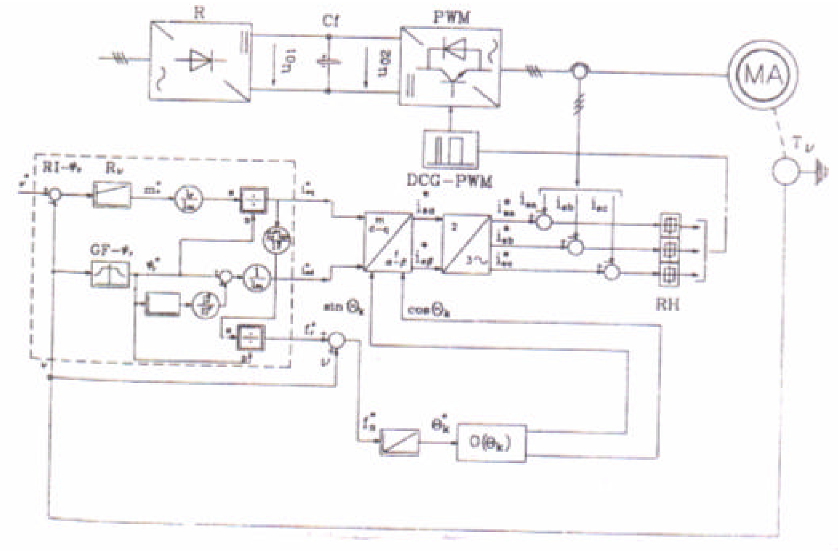

Fig. 4. Indirect vectorial system with PWM voltage invertor ordered in current

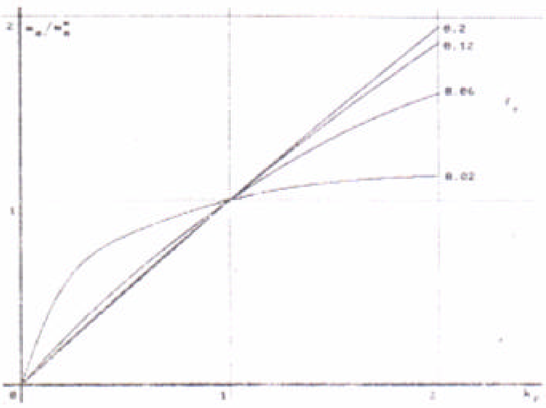

Fig. 5. The engine couple variation due to the rotor resistance variation for f_r=constant