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Method for Determining the Mechanical Parameters of an Electric Drive

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Abstract

For tuning the electrical drive systems, the mechanical parameters of the drive must be known. The literature (including the standards) presents the method for determining the mechanical parameters, based on the free stop of the drive, but considering some approximations. The paper deals with a different method, more exact, that valorises the same experimental data (the free stop curve).

Key words: *mechanical parameters, driving system, free stop*

The "classical" approach

For determining he mechanical parameters of rotor, more methods are available, ones of them could being applied only if the rotor is dismounted (the torsion oscillations method, the oscillator pendulum method).

A simple method, which do not impose the detaching of the rotor and which allows to determine also the viscous friction coefficient k_v and the dry frictions torque T_f, is the free stop method. In addition, by using this method, it could be determined not only the mechanical parameters of the motor, but, very important, of the assembly motor-driven machine.

Based on the dependence of the speed versus the time during the free stop of the drive, Fig. 1, all the three mechanical parameters can be determined as follows:

- the moment of inertia J:

taking into account the general equation of the movement in the instant of the motor's disconnection

$$0 = T_{s0} + J\frac{d\Omega}{dt}, \tag{1}$$

and the fact that the torque in the first moment of the disconnection T_{s0} is due only to the mechanical looses, it finally results

$$J = T_{s0}\frac{dt}{d\Omega} = \frac{P_{mec}}{\Omega_0}\cdot\frac{\Delta t}{\Delta\Omega}, \tag{2}$$

where P_{mec} are the mechanical looses, determined by the known method [], it finally results

$$J = P_{mec} \frac{t_1 - t_0}{\Omega_0^2} ; \tag{3}$$

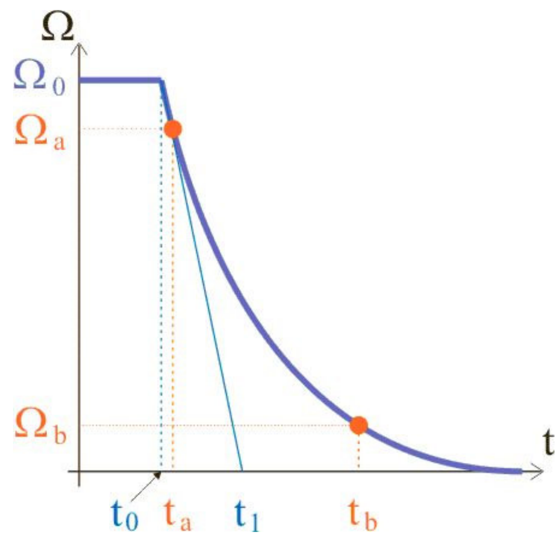

Fig. 1. The speed during the free stop in classical approach.

- the coefficient of the viscous frictions k_v:

starting from the general equation of the speed during the free stop

$$J \frac{d\Omega}{dt} + k_v \Omega + T_f = 0 , \tag{4}$$

where T_f is the dry frictions torque, it results that the mechanical time constant is

$$\tau = \frac{J}{k_v} \tag{5}$$

and consequently, the coefficient of the viscous frictions is

$$k_v = \frac{J}{t_1 - t_0} . \tag{6}$$

This is not totally correct, if dry frictions are to be considered, as will be shown later;

- the dry frictions torque T_f:

the solution of the general equation (4) is written for the two particular values, Ω_a and Ω_b (90% and 10% respectively of Ω_0), resulting:

$$\Omega_a = \left(1 + \Omega_0 \frac{k_v}{T_f} \right) e^{-\frac{t_a - t_0}{\tau}} - 1 \text{ and}$$

$$\Omega_b = \left(1 + \Omega_0 \frac{k_v}{T_f}\right) e^{-\frac{t_b - t_0}{\tau}} - 1 \text{ respectively.}$$

By considering the ration of the above expressions,

$$\frac{\Omega_a}{\Omega_b} = \frac{\left(1 + \Omega_0 \frac{k_v}{T_f}\right) e^{-\frac{t_a - t_0}{\tau}} - 1}{\left(1 + \Omega_0 \frac{k_v}{T_f}\right) e^{-\frac{t_b - t_0}{\tau}} - 1}, \tag{7}$$

the dry frictions torque T_f is expressed and finally is obtained

$$T_f = k_v \frac{\Omega_0 \Omega_a e^{-\frac{t_b - t_0}{\tau}} - \Omega_0 \Omega_b e^{-\frac{t_a - t_0}{\tau}}}{\Omega_b e^{-\frac{t_a - t_0}{\tau}} - \Omega_a e^{-\frac{t_b - t_0}{\tau}} + \Omega_a - \Omega_b}. \tag{8}$$

The exact approach

Considering the origin of the time at the instant of the disconnection, the solution of the general equation (4) is

$$\Omega = \left(\Omega_0 + \frac{T_f}{k_v}\right) e^{-\frac{t}{\tau}} - \frac{T_f}{k_v}. \tag{9}$$

It results, that theoretically, the stationary speed is not zero, as is depicted in Fig. 1, but rather has a negative value, as is plotted in Fig. 2.

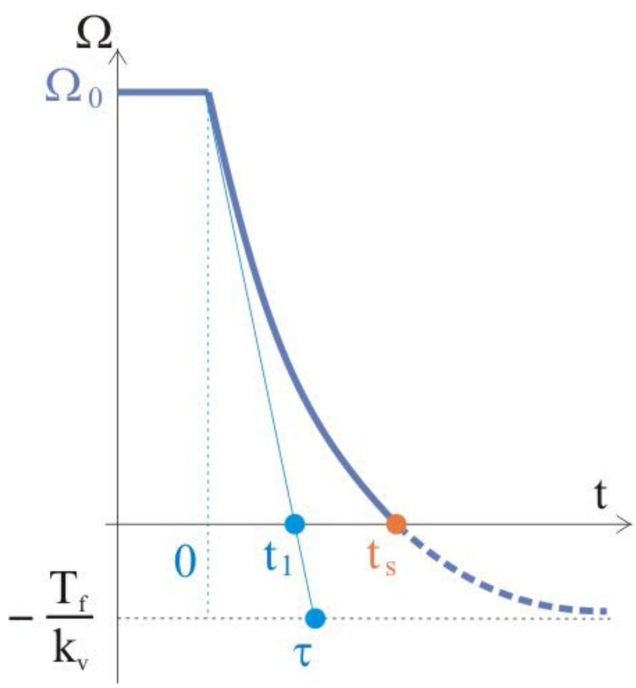

Fig. 2. The plot of the speed during the free stop.

The calculus of the mechanical parameters of the drive could be computed as follows:

- by taking into account the same considerations as in the classical approach, the last result of the expression (2) will be considered and the particular values replaced in that equation:

$$J = \frac{P_{mec}}{\Omega_0} \cdot \frac{\Delta t}{\Delta \Omega} = \frac{P_{mec}}{\Omega_0} \cdot \frac{\tau}{\left(\Omega_0 + \frac{T_f}{k_v} \right)} . \tag{10}$$

It could be easily notice that

$$\frac{t_1}{\tau} = \frac{\Omega_0}{\Omega_0 + \frac{T_f}{k_v}} \quad \text{or} \quad \frac{\tau}{\Omega_0 + \frac{T_f}{k_v}} = \frac{t_1}{\Omega_0} \tag{11}$$

and consequently, the moment of inertia J can be computed using the same expression as in the “classical” approach (3),

$$J = P_{mec} \frac{t_1}{\Omega_0^2} ; \tag{12}$$

- the coefficient of the viscous frictions k_v:

at any instant during the free stop of the drive, the value of the speed could be obtained based on the solution of the general equation (4)

$$\Omega = -\frac{T_f}{k_v} + \left(\Omega_0 + \frac{T_f}{k_v} \right) e^{-\frac{t}{\tau}} . \tag{13}$$

By considering in (13) the particular instant of the stop t_s ($\Omega = 0$), it results:

$$\left(\Omega_0 + \frac{T_f}{k_v} \right) e^{-\frac{t_s}{\tau}} = \frac{T_f}{k_v} \quad \text{or} \quad \left(k_v \Omega_0 + T_f \right) e^{-\frac{t_s}{\tau}} = T_f . \tag{14}$$

From the equations (1) and (4) it results the expressions of the torque in the first instant of the disconnection T_{s0}

$$T_{s0} = k_v \Omega_0 + T_f . \tag{15}$$

Considering (15), from (1) it results

$$J = -T_{s0} \frac{\Delta t}{\Delta \Omega} = \left(k_v \Omega_0 + T_f \right) \frac{t_1}{\Omega_0} , \quad \text{or} \quad J = \left(k_v + \frac{T_f}{\Omega_0} \right) t_1 . \tag{16}$$

The relations (16) could be used for expressing, on one hand the dry frictions torque

$$T_f = \left(\frac{J}{t_1} - k_v \right) \Omega_0 \tag{17}$$

and on the other hand, the round parenthesis $\left(k_v \Omega_0 + T_f \right)$

$$\left(k_v \Omega_0 + T_f \right) = \frac{J}{t_1} \Omega_0 . \tag{18}$$

By substituting (17) and (18) in (14), it results

$$\frac{J}{t_1}\Omega_0 e^{-\frac{t_s}{\tau}} = \left(\frac{J}{t_1} - k_v\right)\Omega_0 . \tag{19}$$

Finally results

$$k_v = \frac{J}{t_1}\left(1 - e^{-\frac{t_s}{\tau}}\right), \text{ or } k_v = \frac{J}{t_1}\left(1 - e^{-\frac{t_s}{J/k_v}}\right). \tag{20}$$

The unknown in the above equation is the coefficient of the viscous frictions k_v. The equation can be solved only numerically, the form of the solution being

$$k_v = \left[W\left(-e^{-\frac{t_s}{t_1}} \cdot \frac{t_s}{t_1}\right) + \frac{t_s}{t_1}\right] \cdot \frac{J}{t_s}, \tag{21}$$

where $W(a)$ is the W Lambert function. This is the inverse of the function $x \cdot e^x$. Its value for $a = -e^{-\frac{t_s}{t_1}} \cdot \frac{t_s}{t_1}$ results numerically, as solution of the equation $x \cdot e^x = a$.

- the dry friction torque T_f is finally obtain on the basis of the obtained parameters and (17):

$$T_f = \left(\frac{J}{t_1} - k_v\right)\Omega_0 .$$

On-line resource

The demonstration presented above, as well as numerical application are available on-line, totally free, on the site of the e-LEE Association, as a part of the resource dedicated to the determination of the parameters of an electrical drive:

www.e-lee.net\EN\realisations\MachinesElectriques\Induction\MiseEquations \MesureParametres\MesureParametres.htm,

or its mirror on the site of the Faculty for Electromechanical Engineering Craiova,

www.em.ucv.ro\eLEE\EN\realisations\MachinesElectriques\Induction\MiseEquations \MesureParametres\MesureParametres.htm.

The site was developed within a Minerva action, by four European institutions: Université Catholique de Louvain, Belgium; École des Hautes Études d'Ingénieur, Lille, France; Instituto Superior Técnico - Universidade Tecnica de Lisboa, Portugal; Faculty for Electromechanical Engineering, University of Craiova, Romania.

All the developed lessons, virtual laboratories, MCQs, are available on-line, totally free on the mentioned site, both in English and Romanian, starting from http://www.e-lee.net, or the Romanian mirror http://em.ucv.ro/eLEE/EN, http://em.ucv.ro/eLEE/RO respectively.

Conclusions

The "classical" approach for determining the mechanical parameters of a driving system uses the plot of the speed during the free stop depicted in Fig. 1 and leads to the expressions(3), (6) and (8) for the calculus of the inertia J, the coefficient of viscous frictions k_v and dry frictions torque T_f respectively.

If the dry friction torque is considered, the theoretical "steady state" speed is negative and consequently, the intersection of the tangent to the speed plot in the disconnection instant with the time axes is not anymore the mechanical time constant, as is considered in the "classical" approach.

A more precise method was considered. On this basis, for the same mechanical parameters (the inertia J, the coefficient of viscous frictions k_v and dry frictions torque T_f) there were obtained the expressions (12), (21) and (17) respectively.

The approach and the differences for the "classical" approach are presented by the paper.

References

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Metodă de determinare a parametrilor mecanici ai unui sistem de acționare

Rezumat

Pentru acordarea sistemelor de reglare ale acţionărilor electrice, trebuie cunoscuţi parametrii mecanici ai acesteia. Literatura, inclusiv standardele, prezintă metoda de determinare a parametrilor mecanici bazată pe evoluţia vitezei la oprirea liberă, dar făcând anumite aproximări. Prezentul articol propune o altă metodă, mai exactă, de valorificare a aceloraşi date experimentale (curba lansării).