DETERMINATION OF A DC MOTOR'S AND DRIVE'S PARAMETERS USING SPEED AND CURRENT RESPONSES AT THE MOTOR'S START AND STOP

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Abstract **– A method is presented for the parameters` determination of a direct current (DC) motor and drive. The basis for the parameters` determination are the speed and current responses at the start and stop of the motor. Differential Evolution (DE) was chosen for the parameters` determination. The simulation of the motor operation, which was used for the Objective Function calculation, is described with two coupled Differential Equations. The Runge-Kutta fourth order method was used for the solving of the system of two coupled Differential Equations, which is a part of the objective function calculation.**

I. INTRODUCTION

Drives with Direct Current motors (DC motors) are still used widely in industrial applications. They are easy to control, which is why they are often used for industry control systems. Often the drive's and DC motor's parameters are not known, or the motor's parameters provided by the motor manufacturer could have relatively large tolerances [1], especially for the smaller and cheaper DC motors. In order to determine the times of transient phenomena and energies, it is necessary to know the inertia and friction, which are often unknown.

II. DC MOTOR'S MODEL

The DC motor is shown schematically in Figure 1. The parameters can be determined only for the motor, or for the motor connected to the working machine.

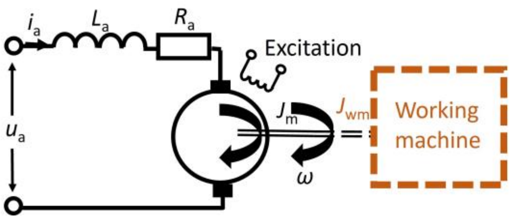

Fig.1. DC motor and working machine

L_a is the inductance of the DC motor (we assume it is constant, which is a simplification of the model), R_a is the ohmic resistance of the DC motor, i_a is the current of the DC motor, u_a is the voltage at the DC motor, ω is the angular speed at the axis of the motor, J_m is the inertia of the motor, and J_{wm} is the inertia of the working machine.

Two coupled Differential Equations, written as (1) and (2), were used for the simulation of the drive operation.

The excitation must be switched on before switching on the motor's armature.

$$u_a = i_a \cdot R_a + L_a \cdot \frac{di_a}{dt} + e \tag{1}$$

$$T_m - T_{load} = J\,\frac{d\omega}{dt} \tag{2}$$

e is the induced voltage and J is the inertia of all parts in the drive. Equations (1) and (2) are coupled, because T_m depends on the current i_a, and e depends on the angular speed ω, as written in (3) and (4).

$$e = c_m \cdot \omega \tag{3}$$

$$T_m = c_m \cdot i_a \tag{4}$$

c_m is assumed to be a constant, and it is called the motor's constant. T_{load} written in (2) is due to the different forms of the load divided into more parts, written in (5).

$$T_{load} = T_{la} + T_{lb} \cdot \omega + T_{lc} \cdot \omega^2 \tag{5}$$

Rewriting (1) and (2), considering (3), (4) and (5), we obtain (6) and (7), which presents the mathematical model used.

$$u_a = i_a \cdot R_a + L_a \cdot \frac{di_a}{dt} + c_m \cdot \omega \tag{6}$$

$$c_m \cdot i_a - \left(T_{la} + T_{lb} \cdot \omega + T_{lc} \cdot \omega^2\right) = J\,\frac{d\omega}{dt} \tag{7}$$

Simulation of the motor's transient behaviour at start and stop was made with numerical solving of the Differential Equations written in (6) and (7). A Runge-Kutta fourth-order method was used. Derivatives must be expressed for numerical solving of (6) and (7). The current derivative is expressed from (6) and written in (8), and the speed derivative is expressed from (7) and written in (9).

$$\frac{di_a}{dt} = \frac{1}{L_a} \cdot \left(u_a - i_a \cdot R_a - c_m \cdot \omega\right) = f\left(t, i_a, \omega\right) \tag{8}$$

$$\frac{d\omega}{dt} = \frac{1}{J} \cdot \left[c_m \cdot i_a - \left(T_{la} + T_{lb} \cdot \omega + T_{lc} \cdot \omega^2\right)\right] = g\left(t, i_a, \omega\right) \tag{9}$$

III. METHOD FOR PARAMETERS` DETERMINATION

Parameters` determination (R_a, L_a, c_m, J, T_{la}, T_{lb} and T_{lc}) was based on the comparison of the measured current and speed response at start and stop, with calculated responses based on the described mathematical model. An inverse problem is solved, for which a direct approach is used using optimisation. The chosen optimisation method was Differential Evolution (DE), which was used for parameters` determination [2,3]. The used strategies were DE/rand/1/exp and DE/best/1/bin, the used crossover probability was 0.8 and the used amplification of the differential variation was 0.6.

IV. RESULTS

SIEMENS SIMOREG DC-Master drive was used for the parameters` determination. The measurement was made with the use of the "Trace" function, which is a part of the SIEMENS software. The start and stop of the drive was made using an n-control closed loop with the following data: t_{speed_up}=0 s, t_{speed_down}=0, ω_{final}=182 s^{-1}, i_{a_limit}=12,48 A (120% of I_{a_rated}), no load, 400 measured points. To consider closed loop operation, voltage u_a was measured and used as the input value for the mathematical model.

Different controller adjustments influence the motor's voltage, which represents input data to the motor model. With that in mind, the motor (drive) dynamic is considered fully by the presented model.

The Objective Function (OF) is defined as the square of differences between the measured and simulated data written in (10). in this way, it is achieved that the measured and calculated responses are as similar as possible.

$$OF = \frac{1}{N}\sum_{i=1}^{N}\left(\left(\frac{i_{a\_simulated\_i} - i_{a\_measured\_i}}{i_{a\_measured\_\max}}\right)^2 + \left(\frac{\omega_{simulated\_i} - \omega_{measured\_i}}{\omega_{measured\_\max}}\right)^2\right) \tag{10}$$

N is the number of points of the measured values.

The parameters` limits were set between 0 and 100 for R_a and L_a, between 0 and 5 for c_e, between 0 and 1 for J, between 0 and 20 for T_{la}, between 0 and 9.55·10^{-2} for T_{lb} and between 0 and 4.56·10^{-6} for T_{lc}. The population number was set to 70 and the stopping criteria were 2,000 iterations.

TABLE I
BEST (B), WORST (W), MEAN VALUE (M) OF THE OBJECTIVE FUNCTION AND STANDARD DEVIATION (SD) FOR THE 50 INDEPENDENT RUNS

OF	DE/rand/1/exp	DE/best/1/bin
B	4.9432·10^{-4}	4.9432·10^{-4}
W	4.9432·10^{-4}	6.0877·10^{-4}
M	4.9432·10^{-4}	5.0119·10^{-4}
SD	1.0842·10^{-19}	2.7178·10^{-5}

Based on Table I, it can be seen that the calculation procedure was robust in the case of DE/rand/1/exp. The same results were obtained for each run of 50 independent runs. The DE/best/1/bin strategy was slightly worse for the given case.

The calculated parameters are presented in Table II.

TABLE II
KNOWN AND CALCULATED PARAMETERS FOR DE/RAND/1/EXP CALCULATION

Parameter	Known value	Calculated value
R_a	5.66	4.535
L_a	0.0472	0.0541
c_m	1.356	1.359
J	≈ 0.03725	0.0249
T_{la}	≈ 0	2.911·10^{-15}
T_{lb}	≈ 0	5.187·10^{-3}
T_{lc}	≈ 4.8·10^{-3}	5.645·10^{-20}

The measured and calculated responses are presented in Figure 2.

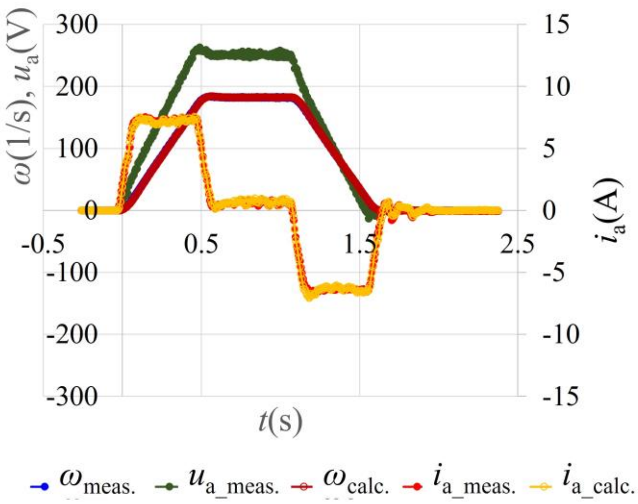

Fig.2. Measured and calculated values for the DE/rand/1/exp calculation

V. CONCLUSIONS

From Table I it can be seen that chosen DE/rand/1/exp is a very robust and stable optimisation method. The DE/best/1/bin strategy was slightly worse for the given case. The calculated results presented in Table II show good agreement between the known and calculated parameters. A good match between the measured and calculated time responses is evident in Figure 2, which confirms the quality of the presented method.

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