The Journal of CIEES
Volume 4, Issue 1, 2024, ISSN: 2738-7283 (Print), 2738-7291 (Online)
DOI: 10.48149/jciees.2024.4.1.1

Determination of the Parameters of a DC Motor with Parallel Excitation by a Genetic Algorithm

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Abstract: This paper presents a method of determining the parameters of a DC motor with parallel excitation by the use of a genetic algorithm. An approach is described for determining the mutual induction coefficient, the equivalent moment of inertia of the motor armature, the coefficient of friction and the friction torque based on the transient response graphs of the armature current and the rotational frequency of the motor. The measured resistance and inductive reactance of the armature and field windings of the motor are used as input data in the optimization procedure. The determined correlation coefficient, mean deviation error and mean square error between the experimentally taken and model-derived transient response graphs of the armature current and rotational frequency of the motor confirm the applicability of the presented approach.

Received 8 May 2024
Accepted 28 June 2024
Published 26 September 2024

Keywords: DC motor, Matlab, Genetic Algorithm.

1. Introduction

DC motor drives are used in industry because they are easy to model and control. The problem is that some of the parameters of the DC motor, such as the armature winding resistance, armature winding inductance, field winding resistance and inductance can be measured while others, such as the coefficient of mutual induction, the equivalent moment of inertia of the armature, the friction coefficient and friction torque, are unknown. Therefore, an accurate mathematical model of the motor cannot be built and appropriate control cannot be implemented.

The determination of motor parameters is a subject of research. Various optimization techniques [1] are used, as well as model searching algorithms [2], the method of moments [3], the regression method [4]. There is an increasing use of evolutionary methods, among which is the GA [5,6,7,8]. It is a stochastic method for solving optimization problems with or without constraints, based on natural selection - the process determining biological evolution. The GA changes the population of individuals at each step, selecting those from the current generation that will continue their evolution, i.e., they will be used for the next generation. The best individuals are selected on the basis of a functional or functionals (objective functions) that provide an estimate of the fitness of the individual for the desired solution. The advantage of the GA over classical optimization methods is that it generates a population of individuals (points) at each iteration, and the optimal solution is reached by the fittest point in the population, as opposed to classical methods where one point is generated at each iteration, and the optimal solution is reached by a sequence of points.

The genetic algorithm can be applied to solve a number of optimization problems for which standard optimization methods are not suitable, including those where the objective function is discontinuous, non-differentiable, stochastic, or strongly nonlinear.

The aim of this paper was to use a genetic algorithm to determine the parameters of a DC motor, i.e., the coefficient of mutual induction, the equivalent moment of inertia of the armature, the coefficient of friction and the friction torque, using as input data the transient response graphs of the speed and armature current as well as the measured values of the resistance and inductive reactance of the armature and field windings.

2. Explanation

The object of study was a model of a DC motor with parallel excitation with rated power $P_r = 3$ kW, rated voltage $U_r = 220$V and rotational frequency $n = 1500\ \text{min}^{-1}$ [9].

The stages required to achieve the objective of this paper were as follows:

- Building a virtual model of a DC motor in Simulink;
- Measuring the resistance and inductive reactance of the armature and field windings;
- Experimentally obtaining data of the transient response graphs of the angular speed and armature current during idling of the DC motor;
- Determining the parameters of the motor under study by a genetic algorithm;
- Comparing the experimentally obtained transient response graphs of the angular speed and armature current of the motor with those obtained by the virtual model whose motor parameters were determined by a GA.

The motor model shown in Figure 1 was synthesized in Simulink [10, 11]. The model was built using the blocks from the SimPowerSystems library, namely DC Voltage Source – a DC voltage source supplying the armature and field windings of the motor respectively; DC_Machine – a model of a DC machine; Constant – used to set the motor shaft load (resistive torque); Demux – measurement block; Scope 1, Scope 2, Scope 3, Scope 4 – used to take the respective readings of the motor shaft angular speed (ω), the armature current value (i_a), the field current value (i_f), and the electromagnetic torque of the motor (M_e).

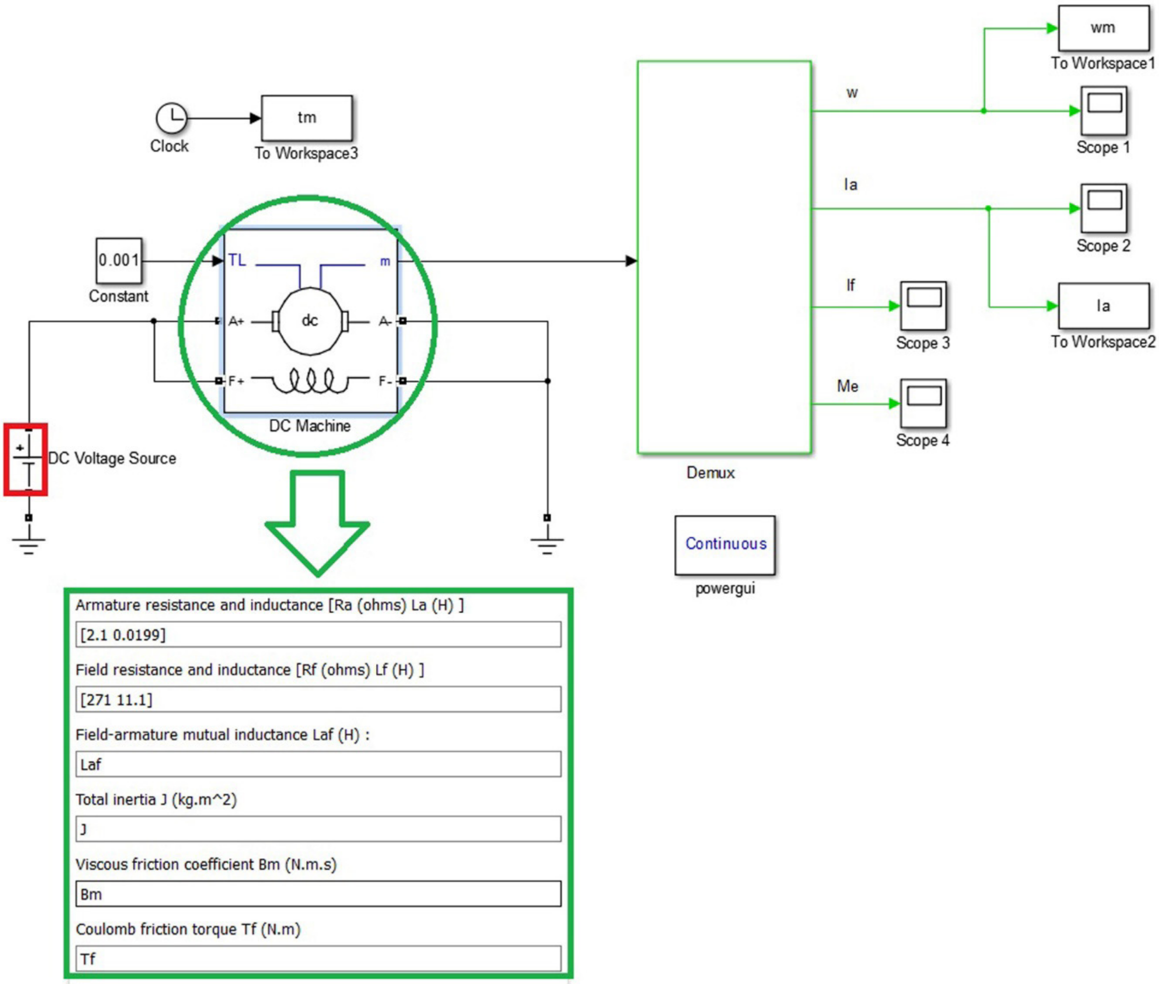

Fig. 1. Virtual model of study of a DC motor with parallel excitation.

The mathematical model that described the dynamics of an electric DC motor drive consisted of the following differential equations describing the electrical and mechanical processes in the drive:

$$U = E + Ri + L\frac{di}{dt}; \quad (1)$$

$$M - M_c = J\frac{d\omega}{dt}, \quad (2)$$

where U is the voltage of the armature winding of the motor, V; E – the armature electromotive force (EMF), V; i – the armature current, A; Φ – the magnetic flux in the air gap, Wb; M – the motor electromagnetic torque, N. m; M_c – the resistive torque, N. m; ω – the rotational speed of the motor shaft, $rad.s^{-1}$; R – the resistance of the armature circuit, Ω; L – the inductance of the armature circuit, H; J – the total moment of inertia of the armature and load, $kg.m^2$.

The following motor parameters had to be entered in the respective setting fields (DC_Machine block in Fig.1): R_a- resistance of the armature winding; L_a- inductance of the armature winding; R_f and L_f –resistance and inductance of the field winding. They were measured and their values are shown in Table 1.

Table 1. Parameters of the motor under study

R_a, Ω	L_a, H	R_f, Ω	L_f, H
2.1	0.0199	271	11.1

The experimentally obtained transient response graphs of the angular speed of the motor shaft ω_s and the armature current i_s are shown in Figure 2 and Figure 3.

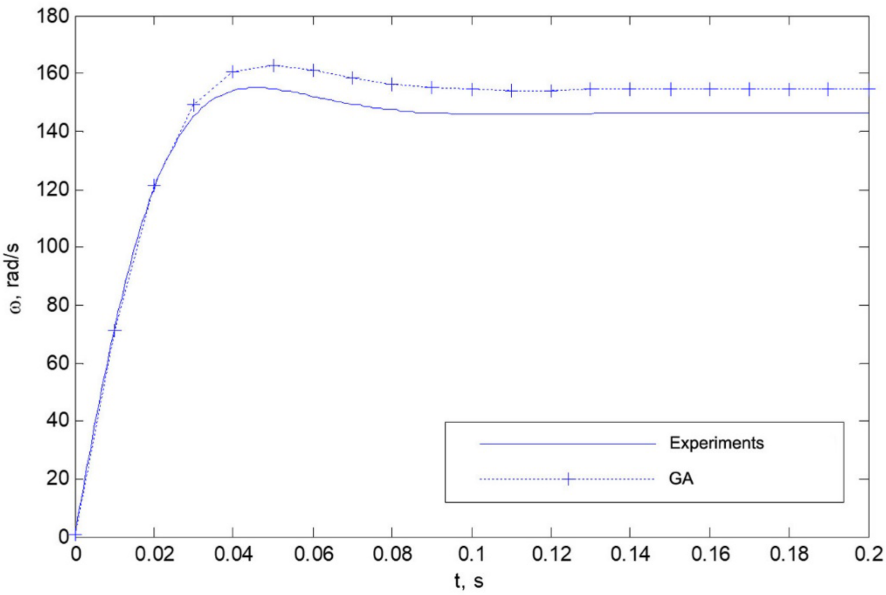

Fig. 2. Transient response graph of the angular speed of the DC motor with parallel excitation under study.

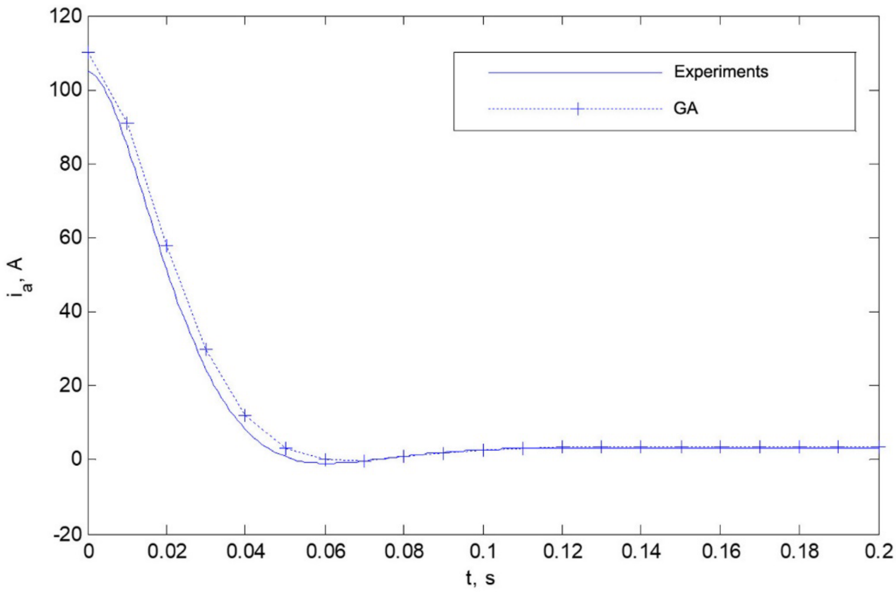

Fig. 3. Transient response graph of the armature current of the DC motor with parallel excitation under study.

In order to determine the parameters of the DC motor under study by a GA, the values of the resistance and inductive reactance of the armature and field windings were entered in the DC_Machine block in Fig. 1. The wanted parameters were the mutual induction coefficient, the equivalent moment of inertia of the motor armature, the coefficient of friction and the friction torque. When simulating the operation of the motor under study using the model in Fig. 1, the obtained data (in Scope 1) for the armature current i_{GA} and the rotational speed of the motor shaft ω_{GA} were sent to the MATLAB workspace. The experimentally obtained data for the armature current i_s and the rotational speed of the motor shaft ω_s were also present in the workspace. The F function that computed the optimization criterion was recorded in the M-file. It contained the declared global variables L_{af}, J, B_m, T_f, i_s and ω_s. The **sim** command was used to call the SIMULINK model and compute the corresponding objective function.

$$F = \frac{1}{N}\sum_{i=1}^{N}\left(\left(\frac{i_{GA}-i_s}{i_{s,max}}\right)^2 + \left(\frac{\omega_{GA}-\omega_s}{\omega_{s,max}}\right)^2\right), \quad (3)$$

The genetic algorithm was run using the **gamultiobj** command. The vectors defining the lower and upper bounds of the optimization parameters $L_{af}, J, B_m\ and\ T_f$, were set within bounds that included their expected values.

The optimization procedure was terminated when the set accuracy level was reached. The transient response graphs of the angular speed and armature current of the DC motor with parallel excitation under study (Figure 2 and Figure 3), as well as the parameters of mutual induction coefficient $L_{af} = 1{,}8$, the equivalent moment of inertia of the motor armature $J = 0{,}02$, the coefficient of friction $B_m = 0{,}0295$ and the friction torque $T_f = 0{,}0058$, were obtained by a GA.

In this work, the correlation coefficient R was calculated by the formula

$$R = \frac{N\sum_{i=1}^{N} Y_{M,i}Y_{e,i} - \sum_{i=1}^{N} Y_{M,i}\sum_{i=1}^{N} Y_{e,i}}{\sqrt{\left(N\sum_{i=1}^{N} Y_{M,i}^2 - \left(\sum_{i=1}^{N} Y_{M,i}\right)^2\right)\left(N\sum_{i=1}^{N} Y_{e,i}^2 - \left(\sum_{i=1}^{N} Y_{e,i}\right)^2\right)}} \quad (4)$$

where $Y_{e,i}$ represented the i-th measurement, $Y_{M,i}$ represented the armature current (angular speed) for the corresponding measurement, N was the number of observations.

The obtained values for the coefficient of correlation for the angular velocity and the armature current were as follows: $R_\omega = 0.9990$, $R_i = 0.9991$.

The mean bias error MBE and the mean squared error $RMSE$ were calculated by the following formulas:

$$MBE = \frac{1}{N}\sum_{i=1}^{N}\left|Y_{e,i} - Y_{M,i}\right|; \quad (5)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(Y_{e,i} - Y_{M,i}\right)^2\right]^{\frac{1}{2}} \quad (6)$$

The obtained error values for the angular speed were: $MBE_\omega = 6.9833$, $RMSE_\omega = 6.5488$, and for the armature current: $MBE_i = 1.6757$, $RMSE_i = 2.7024$.

The correlation coefficient was close to one, while the mean bias error and mean squared error between the experimentally taken and the model-derived transient response graphs of the armature current and rotational frequency of the motor were less than 7%.

3. Conclusion

This paper presents an approach for determining the parameters of DC motors when such parameters are unknown. A genetic algorithm was used with the following input data: the resistance and inductive reactance of the armature and field windings of the motor, the transient response graphs of the armature current and the angular speed. The output (wanted) data were the mutual induction coefficient, the equivalent moment of inertia of the motor armature, the coefficient of friction and the friction torque.

The study was conducted on a DC motor with parallel excitation. The motor parameters and the transient response graphs of the angular speed and armature current were determined using a genetic algorithm.

The determined correlation coefficient, mean bias error and mean squared error between the experimentally taken and model-derived transient response graphs of the armature current and rotational frequency of the motor confirm the applicability of the presented approach.

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