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Increasing Energy Efficiency of Electric Motors by Post-integration Parameter Calibration

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Abstract:
In this study, in order to optimize the energy efficiency of a brushless DC motor (BLDC), a post-integration parameter calibration scheme is proposed and tested. The controller gains are calculated in the model using the motor parameters directly. A self-calibration algorithm is implemented, the change in parameters is logged and the resulting efficiency change is calculated and presented. At the end of the studies, a more effective system is obtained by checking the resistance and the inductance values.
Keywords: Energy Efficiency - Electric Motors - Electric Motor Controller - Controller Parameter Calibration - Electric Motor Parameter Calculation.
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1. Introduction

Electric motors have been around since the 1800s. Since then, their usage only increased and currently they are being used intensively in the industry and inside consumer electronics such as fridges, computers, cars, etc. According to a research done in 2011, electric motors are responsible for around 45% of the global electricity consumption, which is more than twice the closest second, lighting [1]. Considering electric motors' giant share of electricity consumption, any kind of increase in efficiency might have profound effects.

Drive electronics for electric motors have been improving, with powerful processors becoming available in smaller sizes and lower prices. This allows designers to implement more efficient motor control algorithms using the more computing intensive variable-frequency drive methods such as direct torque control and field oriented control. The design of these controllers requires knowledge of the motor parameters, which are usually taken from the catalogue supplied by the manufacturer.

The parameters vary slightly with each individual motor; but they can also change considerably after integration with the target system. Any deviation in motor parameters causes a decrease in efficiency, if the controllers are not updated accordingly. To overcome this problem, several approaches are possible.

In Wei Wu's study, step command is applied to DC motor and answer is reviewed. The electrical time constant, the mechanical time constant and the friction values of dc motor are calculated with the analysis on the answer [2]. A. A. Bature and his friends calculated motor parameters by using least square parametric estimation method and made real time control [3]. Phuc Huynh and colleagues have calculated the parameters of a single-phase induction motor (SPIM) with a locked-rotor test, and a no-load test method [4]. Differently from the literature, in this study we propose that the R and L values are measured before the system starts working and the controller parameters are adjusted to the new values. As this is done at the post integration stage, all the added effects of the production are automatically taken into account. At first, the theoretical design of the system is done and then the system is modeled using CAD tools. Finally, the DC motor behavior is studied under different conditions. In this way the DC motor is driven more effectively, and energy savings are achieved.

2. DC Motor Equations

For simplicity's sake, the operation of an electrical motor can be explained using DC motor equations. As an electrical machine, the equations need to be shown utilizing both electrical and mechanical terms. The electrical equation is given in (1), the mechanical equation is given in (2) and the relationship between the torque and the winding

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current is given in (3).

$$E_a(t) = i(t)R + L\frac{di}{dt} + K_e\omega_m(t) \tag{1}$$

$$T_m(t) = T_L(t) + J\frac{d\omega_m(t)}{dt} + B\omega_m(t) \tag{2}$$

$$T_m(t) = i(t)K_T \tag{3}$$

In order of appearance, E_a is the applied motor voltage (V), i is the winding current (A), R is the terminal winding resistance (Ω), L is the terminal winding inductance (H), K_e is the back-emf constant (V / rad/s), ω_m is the rotor speed (rad/s), T_m is the generated torque (N.m), T_L is the load torque (N.m), J is the inertia (kg.m^2), B is the viscous friction (N.m.s) and K_T is the motor torque constant (N.m/A).

A simulation model built using the motor equations described above is given below in Figure 1.

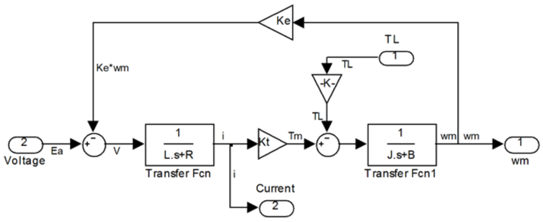

Figure. 1. DC motor model in MATLAB Simulink.

3. Obtaining Stator Resistance and Inductance

There are various methods for estimating the stator resistance and the stator inductance [5-7].

In the scope of this study, the rotor is locked in place using an integrated brake, and a motor voltage is applied for enough time for the winding current to settle. The applied voltage versus current graph is given in Figure 2.

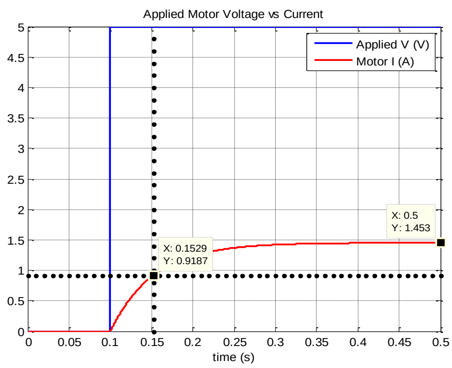

Figure 2. Applied motor voltage vs. current, with current value at 1 time constant (τ) marked.

$$R = \frac{V_{applied}}{i_{settled}} - R_{shunt} \tag{4}$$

Here R_{shunt} is the resistor used to measure the current, if applicable. It is usually of small enough value to ignore completely.

The terminal winding inductance can be calculated using (5).

$$L = R\tau \tag{5}$$

The current sampling frequency should be at least 10 times greater than 1/τ to accurately determine the value of τ, or the inductance calculation error will be too great. τ is derived by finding the time step where the winding current has reached ~63.2% of its final value, which is marked in Figure 2.

4. Setting Controller Parameters

The overall block diagram of the system is shown in Figure 3. We are calibrating the current controller in our study, which is subsumed by the controller block shown in the figure.

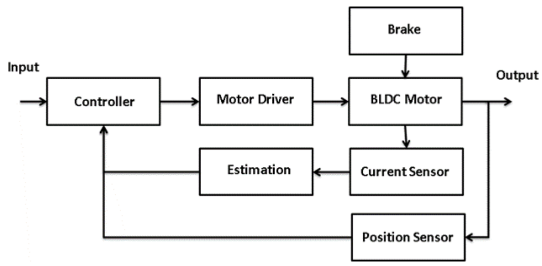

Figure 3. Block Diagram of System.

A simplified PID DC motor current control loop is shown in Figure 4.

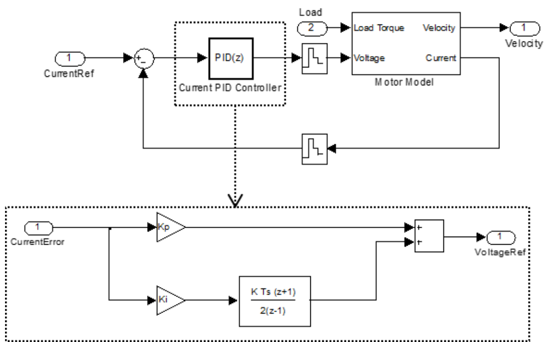

Figure 4. DC motor current control loop.

The gains (K_p & K_i) of the PI controller in the winding current control loop can be calculated using the winding resistance and inductance values and the desired current loop bandwidth (BW) in rad/s as shown in (6) and (7) [8].

$$K_p = L * BW \tag{6}$$

$$K_i = R * BW \tag{7}$$

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As the current loop bandwidth is pre-determined and is constant, with the measured R and L values the new controller gains can be easily calculated and saved in the non-volatile memory of the controller electronics.

The catalogue parameters for the motor used in this study are given in Table 1.

Table 1. Motor catalogue parameters.

Parameter	**Value**
Nominal voltage (V)	24
No load speed (rpm)	12900
No load current (mA)	121
Nominal torque (max. continuous torque) (mNm)	22.7
Terminal resistance (ohm)	3.44
Terminal inductance (mH)	0.182

5. Experimental Results

In experimental studies, motor voltage was applied in three different temperature conditions. Power values are obtained by adding DC motor current data. The speed response of the motor at different temperatures are given in Figure 5.

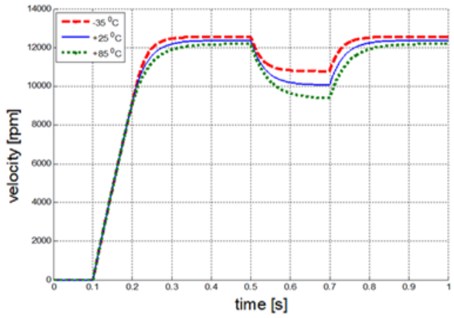

Figure 5. DC motor velocity.

The power consumption of the motor is given below in Figure 6.

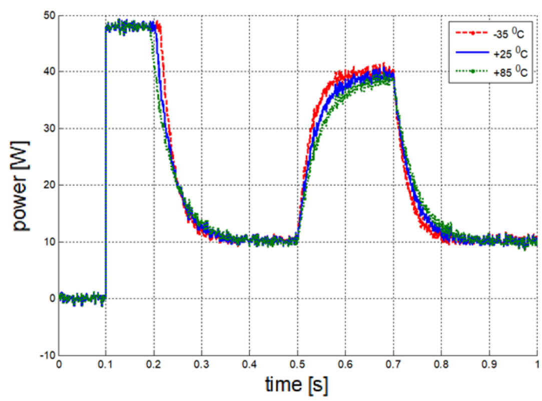

Figure 6. DC motor power.

Different currents of DC motors were obtained under different temperatures. This situation also changes the power values obtained from the motor. With the above method, the values can be calculated in advance and the relevant controller parameters can be changed.

6. Conclusions

Today, electrically operated systems have begun to take the place of other alternatives on almost every platform. Researchers, especially in the automotive and aerospace industries, are working towards longer distances with smaller power sources. In this study, efficiency studies were carried out on a DC motor which is one of the basic drive elements of electric vehicles. It has been worked on a controller that adapts itself to changing weather conditions. As a result of the workings, the variability of the L and R values is determined and the related controllers are set according to the new values. In this case, power is provided at the more suitable values than the power source in the system and the efficiency of the system is increased.

Acknowledgments

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