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Characterization of the Direct Current Micromotor by Simscape

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Abstract: Direct current (DC) micromotors play a key role in micro robotic systems. The DC micromotor has a large market demand but there is a lack of theoretical research for it. The DC micromotor is still usable in many applications, despite the main problem that arises at the level of the connection between the brushes, or "carbons" and the rotary commutator. Mainly because their power circuit is simple to build. The main objective of this work is the evaluation by simulation under Simscape of the performance of Faulhaber permanent magnet DC micromotor and the study of its characteristics. Simulation results on MATLAB/Simscape software showed that a Simscape test bench is ultra-efficient for the study of electric drives. Students of engineering schools are thus prepared for the latest developments and real industrial requirements.

Keywords: DC Micromotor; $SIMSCAPE^{TM}$ simulation; Torque-speed characteristic

1. Introduction

In many electrical engineering applications, mechanical switching machines still constitute a relevant solution to the implementation of an electromechanical actuator. Their high reliability and relatively low manufacturing cost remain undeniable advantages despite recent advances in electronics. This justifies the current research on these machines. Brushed motors are the simplest and most frequently used motors especially for basic industrial equipment and low budget applications [1].

Four types of brush motors exist depending on the intended application. Series excitation motors are suitable for electric traction, Shunt excitation motors are mostly used for driving constant speed line shafting lathers, centrifugal pumps, machine tools. Compound excitation motors have the greatest application with intermittent high torque loads, for shears and punches, elevators. PMDC permanent magnet motors are mostly used in applications where good speed regulation and adjustable speed are required, typical applications are machine tools.

For permanent magnet motors. The field winding is replaced by a magnet made of ferromagnetic material. These motors are generally used in robotics (micromotor). The miniaturization sought by the designers finds in the direct current motor an ideal solution, because it presents a reduced size thanks to a good efficiency [2].

All low power dc motors and micromotors are permanent magnet motors, now they represent the majority of dc motors, they are very easy to use, we find hundreds of brands of dc motors offered by Axes Industries®, Mechatronics reference media, such as Faulhaber micromotors.

The commutator of conventional DC motors remains a fragile part, produces sparks, and this engine should be avoided in a dusty, flammable or explosive environment. Therefore, the current DC motor manufacturers mass-produce them. As Faulhaber DC motors are built with two different types of commutation systems: precious metal commutation and graphite commutation. Precious metal commutated motors provide the best performance, and "graphite commutated" is very robust and best suited for high current dynamic applications with fast starts and stops or overload conditions [3].

However, the integration of the motor with the function in a large number of applications, in complex systems, they must be designed with a view to integration with the general function. For example, the use of PMDC motors in a function in the health field (in various medical equipment).

As a result, it is natural that the study of unconventional electric micro machines in technical universities must become a priority didactic objective within the framework of disciplines such as electric machines or special electric machines [4].

Simscape models can be used to develop control systems and test system-level performance. The contribution of this work is significantly expedient in the field of electromechanical system, and control systems and the described approach represents a valuable tool in the teaching of electromechanical system for graduate engineering students [5]. We have chosen to simulate our system in real time, because in real time simulation the inputs and outputs of the simulation virtual world are read or updated synchronously with the real world.

The main objective of this work is the evaluation by simulation under Simscape of the performance of Faulhaber permanent magnet DC micromotor and the study of its characteristics. Simulation results on MATLAB/Simscape [6] software showed that a Simscape test bench is ultra-efficient for the study of electric drives. Students of engineering schools are thus prepared for the latest developments and real industrial requirements.

2. Methods and Results

2.1 Mathematical Model of PMDC Motor

PMDC commutator motors (Figure 1) are constructed similarly to DC motors replace the electromagnetic excitation system with PM. This means that the speed of a standard d.c. PM commutator motor can normally be controlled only by changing the armature input voltage or armature current.

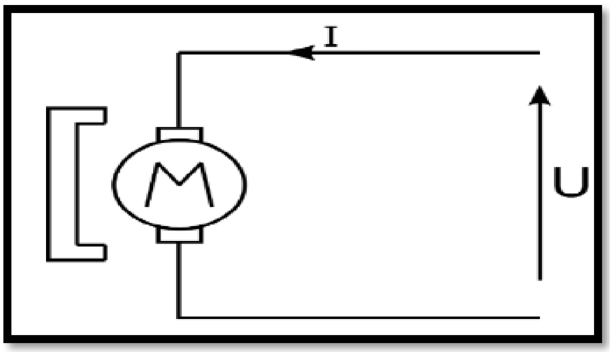

Figure 1. Symbol of a permanent magnet DC motor

The dynamic model for a PMDC motor converts electrical power into mechanical rotating motion. It is a typical Multi-Domain system as it uses both electrical and mechanical power. Current, voltage, back emf, armature resistance, and armature coil inductance are I and U, E, R, and L through and across electrical ports. The torque, load torque and angular speed through and across the mechanical ports are T, Tr and w. Then K and B are respectively the torque constant (and back emf constant) and damping speed. The equations describing the characteristics of a PMDC motor is follow as [4]:

$$U - E = R\,I(t) + L\frac{dI(t)}{d(t)} \tag{1}$$

$$E(t) = K\,w(t) \tag{2}$$

$$\mathrm{T(t)=Tr+J}\frac{dW(t)}{d(t)} + Bw(t) \tag{3}$$

$$T = K\,I(t) \tag{4}$$

2.2 Sim Scape DC Electric Motor

Sim scape is an extension to Simulink to model physical systems in the electrical, mechanical, and thermal domains, etc. Sim scape is built around libraries of components specific to power electronics applications, which are described by the mathematical relations, which link its physical quantities. The physical system that uses physical connections (such as torque or speed for a motor) can be directly connected to a Simulink model for the control of these physical signals. Sim scape also makes it possible to create multi-domain systems (such as the DC motor with its electrical armature and mechanical part on which one can insert inertial couples, friction and make measurements of speed, torque, etc.).

We simulate the motor drive which is a system covering the electrical and mechanical domain. We model the physical components of the drive system with blocks Simscape™, to connect them in a realistic model, and to use also blocks Simulink®, then to simulate and modify a permanent magnet motor model (Figure 2) and Table 1.

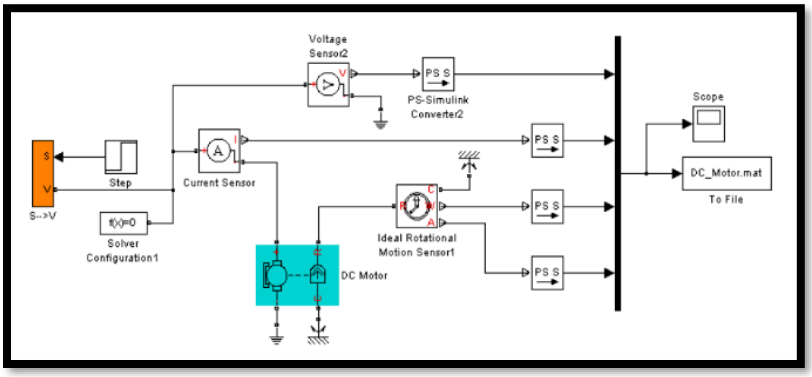

Figure 2. PMDC motor with Sim scape blocks

Table 1. Machine parameters type

Parameters	Values
Armature resistance	3.9 Ohm
Self	$1.2\ 10^{-5}$ H
Back EMF Constant	$7.2\ 10^{-5}$ V/(rpm)
Inertia	0.01 g.cm^2
Damping speed	10^{-8} N.m/(rad/s)
initial rotation	0 tr/mn
No-load current	0.03 A

We use this model to evaluate motor performance in a given application by adding a required mechanical load model [4].

We apply a voltage step of 12V to the armature, for a no-load test the angular speed measure on motor shaft or deduced from the speed profile is: $1.611* \ 10^4$rad/s. We calculate the back-electromotive force by Eq. (2):

$$E=7.2* 10^{-5}*1.611* 10^4 \ *60/ (2*pi) = 11.0764 \text{ V}$$

We deduce that the difference between the voltage applied to the armature (12V) and the back emf (11.0764 V) is due to the voltage drop, which is caused by the ohmic resistance of the armature and we can introduce the resistance of brush-collector contact.

We add on the motor shaft (rotor) a moment of inertia Motor Inertia J, of value 10 g.cm^2 and a couple of frictions, Friction Mr of 0.02 10−3N*m. As shown on the circuit in the following Figure 3.

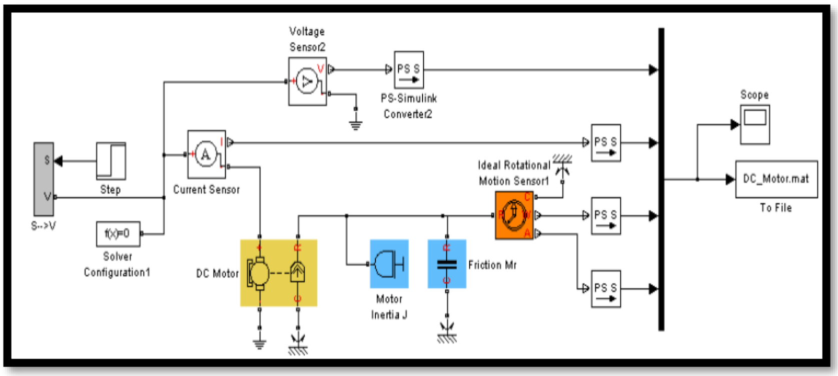

Figure 3. Simscape drive system

In Table 2, we will present the values of the armature current at no-load in steady state, calculate by Eq. (1) and measure by the model in Figure 1. As well as the value of the armature current under load.

Table 2. Armature current measure and calculate

No-load armature current calculate (I)	0.2368 A
No-load armature current measure (I^*)	0.2388 A
$I^* - I$ **(No-load)**	0.2%
Load armature current	0.2639 A

The variation on the value of the analytical and measuring armature current is only 0.2%. The load current value is higher. This is because of increased friction and inertia. The Simscape model gives good results.

2.3 Evaluation of DC Micromotor

Electric micromotors associated with assembly of automation equipment, have nominal mechanical power between fractional hundredths of a watt and about 750 w Magnet-excited micro DC motors are used as a servomotor [2]. Using Simscape (Figure 4), we will evaluate the performance of a Faulhaber 0615 series DC micromotor (Table 3), which drives a constant load.

Table 3. Data seet of dc micromotor Faulhaber (Product 0615N1. 5S)

Parameters	Values
UN (V)	1.5
n0 (rpm)	19.100
T_max (mNm)	0.24
T_min (mNm)	0.17

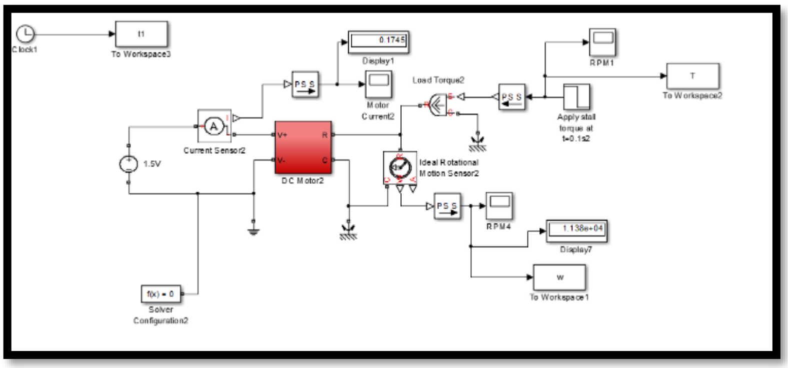

Figure 4. Drive system by DC micromotor under Simscape

For a no-load test, the curves of the speed and of the armature current as a function of time are represented by Figure 5 and Figure 6. we note that the value of the measured speed is very close to the value given by the manufacturer. The armature current in static mode is: I≅0.03A. The results show a good level of agreement with the manufacturer's data.

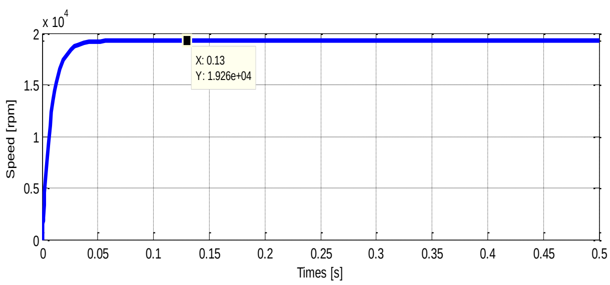

Figure 5. Curve of speed vs times

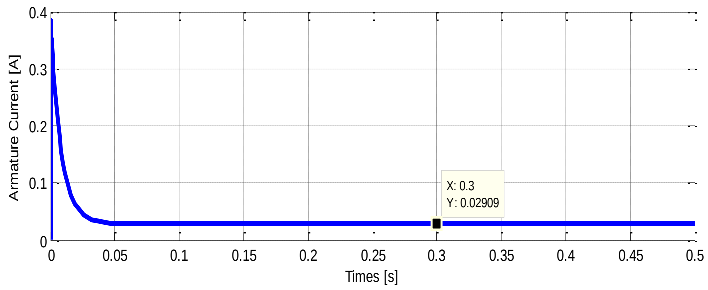

Figure 6. Curve of armature current vs times

Stall torque T_max [mNm] this is the torque developed by the motor at zero speed (locked rotor) and at nominal voltage, this value may vary depending on the type of magnet [4]. We note according to Figure 7 and Figure 8. taken respectively for 0.24mNm and 0.25mNm that the stall torque is indeed 0.24 mNm. Because for 0.25mNm the motor gives zero speed. On the other hand, for 0.24mNm the motor gives a minimum speed of 350 rpm.

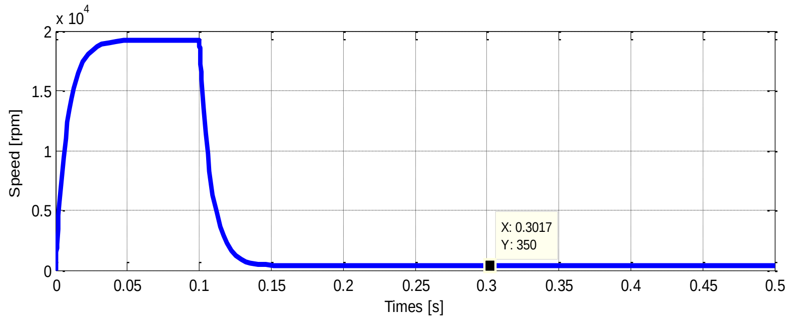

Figure 7. Curve of speed vs times for 0.24mNm

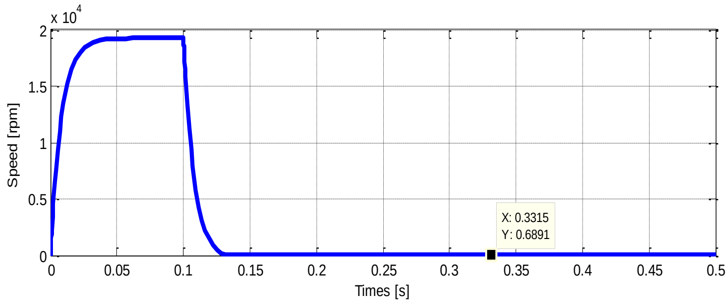

Figure 8. Curve of speed vs times for 0.25 mNm

We reduce the supply voltage to 1.25 volts (to simulate battery discharge). Vary the load torque to find the stall torque corresponds to this reduced voltage. We set the load torque by the subsystem: Step Input and double-click on the Step source block. Enter different final values for the input signal and run the simulation again.

According to Figure 9, the stall torque corresponding to 1.25 V supply voltage is 0.20 mNm.

We validate the result simulation, by calculating the motor torque, which corresponds to the reduced supply voltage. Knowing that the amplitude of the torque-speed curve is proportional to the voltage for a DC motor. To calculate the torque we use the following Eq. (4):

$$T_{max} = K\frac{U_n}{R} - T_R \tag{5}$$

$$T_R = KI_0 \tag{6}$$

T_R is the frictional torque, it is the torque losses caused by the friction of the brushes, commutator and bearings. The temperature affect the friction torque.

We calculate the motor torque by Eq. (5):

$$T_{max} = 7.2 * 10^{-5} * \frac{1.25}{3.9} - 7.210^{-5} * 0.03 = 0.202 \text{ mNm}$$

We find that the measured value and the calculated value are very close. The results show a good level of agreement.

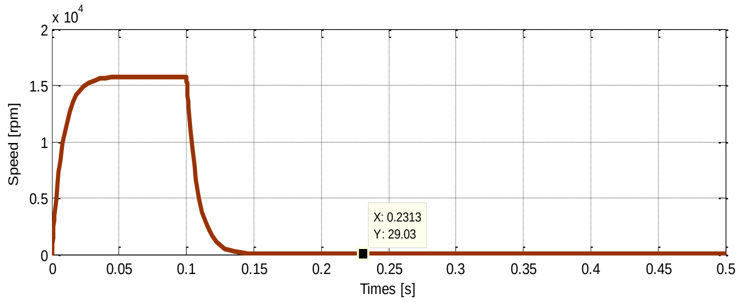

Figure 9. Curve of speed vs times

2.4 Characteristic Curves of the DC Micromotor

The permanent magnet DC motor drives a mechanical load. We maintain the voltage of the armature at 1.5 V, vary the load torque, and take the value of the rotational speed of the motor, as well as the current of the armature. Then, we carry out the same measurements for an armature voltage of 1.25 V. The following Tables 4 and 5 give the results found.

Table 4. Results of the study of the effect of load torque on speed and current (1.5V)

T [Nm]	-0.1e-3	-0.15e-3	-0.2e-3	-0.25e-3
Ω[rpm]	11380	7440	3501	0.69
I[A]	0.1745	0.2473	0.32	0.3846

Table 5. Results of the study of the effect of load torque on speed and current (1.25V)

T[Nm]	-0.1e-3	-0.15e-3	-0.2e-3	-0.25e-3
Ω[rpm]	7907	3968	29.02	-758.8
I [A]	0.1745	0.2473	0.32	0.32

From the results found the characteristic curves are drawn, and presented by the following Figures 10-12.

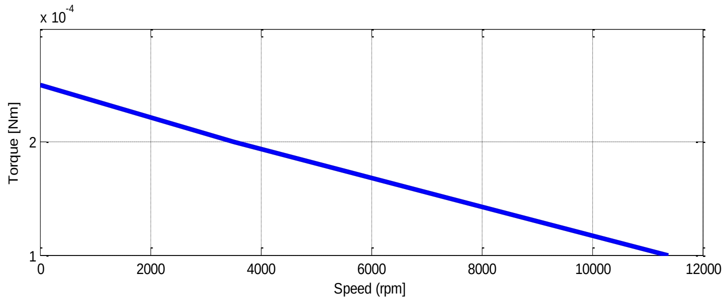

Figure 10. Torque curve vs speed

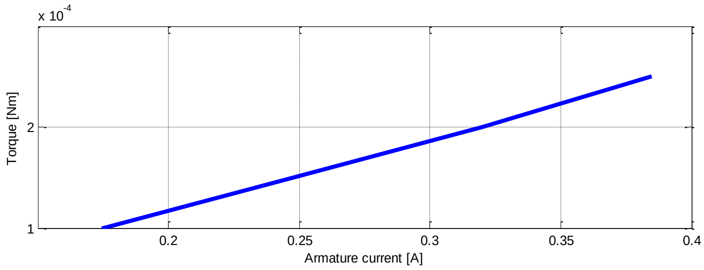

Figure 11. Torque curve vs armature current

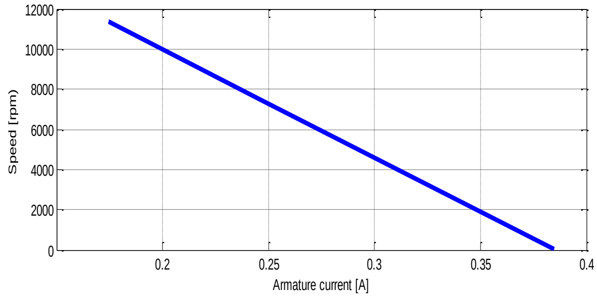

Figure 12. Speed curve vs armature current

The results of the PMDC curves are in agreement with the theoretical notions and PMDC curves [1, 2].

3. Conclusions

- Replacing physical devices, such as motors, resistors, and coils with virtual devices can give us near real life testing.
- PMDC motor with Sim scape blocks are used to verify the no load speed, no load current and stall torque of a Faulhaber 0615 series DC micromotor. The Simscape model gives good results.
- The simulation results showed that the curves of the mechanical, electromechanical and electrical characteristics are in agreement with the theoretical notions and curves of the PMDC motor.
- The contribution of this work is significantly useful in the field of electromechanical and control systems and the approach described, the test bench of Simscape and the PMDC motor equations represent a valuable tool for teaching electromechanical systems to electrical engineering students.
- As a perspective we recommend further research into the PMDC motor, where modifications to the conventional motor are required to reduce or eliminate the drawbacks of the commutator. Also, the study of new PMDC motor brands, and the integration of the motor into a domain function.

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