Modeling and simulation for micro DC motor based on simulink

Hanxin Shen[1, a], Qiao Lei[1,b], Wenxiang Chen[1,2,c]

[1]. School of Optoelectronic and Communication Engineering, Xiamen University of Technology, Fujian Xiamen, 361005, China

[2]. Xiamen University School of Aerospace Engineering, Fujian Xiamen, 361005, China

E-mail: [a)] hxshen@xmut.edu.cn, [b)] lei929193@163.com, [c)] Corresponding author: wxchen@163.com

Abstract. The micro DC motor has a large market demand but there is a lack of theoretical research for it. Through detailed analysis of the commutation process of micro DC motor commutator, based on micro DC motor electromagnetic torque equation and mechanical torque equation, with the help of Simulink toolkit, a triangle connection micro DC motor simulation model is established. By using the model, a sample micro DC motor are simulated，and an experimental measurements has been carried on the sample micro DC motor. It is found that the simulation results are consistent with theoretical analysis and experimental results.

1. Introduction

Micro DC motor has the advantages of small volume, high efficiency, high torque, convenient control and low cost. It has been widely used in the fields of consumption, office, computer, home appliance, medical treatment and industrial control [1]. Although China's micro-motor production started late, the basic micro-motor manufacturing technology has been mastered, and there are more than a thousand micro-motor production enterprises in Zhejiang, Fujian, Guangdong and other coastal areas [2]. In order to regulate the quality of micro-motor products, the National Micro-Motor Standardization Technical Committee has revised a series of relevant national standards for the quality of micro-motor [3]. Likewise, in order to ensure the quality of manufactured products, enterprises have to conduct 100% testing of the products in the production line. However, due to the lack of effective automated detection methods for testing, the current micro-motor product testing is through artificial methods. The manual detection method cannot be guaranteed because of the experience, emotion and state of the testing operator. So the effectiveness of the testing cannot be guaranteed. Therefore, it is necessary to find an on-line automatic detection method of micro DC motor for the assurance of product quality. There are lots of research in Motor health diagnosis and fault detection at home and abroad, but the research mainly focuses on large motors, AC induction motor and brushless DC motor. The literature of the fault detection and diagnosis of Micro-DC motor is less common [4]. In order to detect the quality of micro-DC motor, paper [5] uses two motors with the same type, to do the same motor, a generator composed of electric power drag system, given a different drive voltage conditions, measuring speed, power voltage, armature current parameters, to determine the five indicators reflect the motor consistency model for motor performance testing. The paper [4] according to the time-frequency characteristics of the armature current, a fault diagnosis model of micro-DC motor based on fault multi-feature quantity is proposed, which is used to diagnose the fault of micro DC motor. The above method can realize the diagnosis of typical faults under certain conditions, but because the model used for the diagnosis cannot fully reflect the electromechanical characteristics of the micro DC motor, the diagnosis cannot be of universal significance. With the modern signal processing technology widely used in fault diagnosis, it should also be fully applied to micro-DC motor fault diagnosis, but because the micro-DC motor mathematical model cannot be resolved, most scholars can only numerical methods and computer simulation methods, such as the establishment of micro-DC motor model and its parameters are estimated, the use of model parameters and micro-DC motor electromechanical characteristics of the corresponding relationship between the micro-DC motor characteristics (armature inductance, coil resistance, induced electromotive force, mechanical rotation Inertia and friction coefficient, etc.)[6,7,8,9], according to the characteristics of the characteristics of the trend can be identified on the fault and then its fault diagnosis and diagnosis, but the motor modeling of the literature mostly for large motors or brushless motors, micro-DC motor modeling research rarely reported. The paper [8-12], modeling of DC motor is studied based on Simulink, but the simulation only simulates the no-load situation and lacks versatility. In this paper, the state equation of micro DC motor is established according to the electrical and mechanical energy transfer relation. By introducing the electromagnetic torque and mechanical torque equation, the simulation problem of DC micro-motor under load condition is solved, and the simulation model based on MATLAB/ Simulink is established. Through this model can be a good motor and a variety of fault motor simulation analysis.

2. Dynamic model of micro DC motor

Fig.1 for the micro-DC motor electrical, mechanical model, In Fig.1, u 、 r 、 i 、 L_m 、 e respectively represent drive voltage, armature coil resistance, armature current, coil inductance and back electromotive force, Φ represent the magnetic flux generated by the armature current, T 、 T_0 、 T_1 respectively represent electromagnetic torque, no-load torque and load torque; J 、 ω respectively represent the moment of inertia and angular velocity.

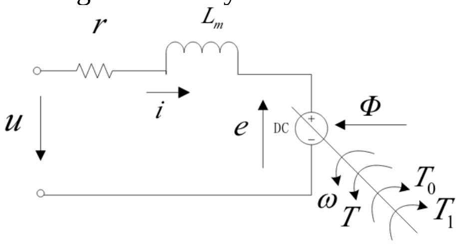


Figure 1. Electricity, machine characteristics model of micro DC motor

According to the principle of motor mechanics, the electromagnetic torque generated by the magnetic flux should be equal to the mechanical torque of the motor drive shaft. Therefore, the electrical and mechanical characteristics of Fig. 1 can be expressed by the dynamic equation [9],

$$\begin{cases} u = ri + \dfrac{di}{dt} + e \\ T = T_0 + T_1 + J\,\dfrac{d\omega}{dt} \end{cases} \qquad (1)$$

Where $e = C_e \Phi n$ is the back electromotive force, $T = C_T \Phi i$ is the output torque, n is the motor speed, C_T is the back electromotive force coefficient, According to (1), in the motor characteristics, the electromagnetic equation and the mechanical equation are coupled with each other and have strong

IOP Conf. Series: Materials Science and Engineering **242** (2017) 012079 doi:10.1088/1757-899X/242/1/012079

nonlinear. It is difficult to obtain the analytical solution. In most cases, the iterative method is used to obtain the numerical solution or the computer simulation.

3. Simualation model

3.1. Equivalent circuit model of micro DC moter

The motor commutation of the state can be described as:

(1) The three connecting ends of the triangular connecting coil windings correspond to three brush commutators K_1, $K2$, K_3;

(2) The three commutators are connected to the positive or negative terminals of the drive power at a certain timing during operation. Can be used to switch the six switches to simulate the three commutators need to achieve positive and negative two working conditions, each commutator corresponds to two switches, a switch will be connected to the drive power supply positive pole, a switch will change Device connected to the power supply negative, according to this idea can be micro-DC motor equivalent circuit model shown in Fig.2:

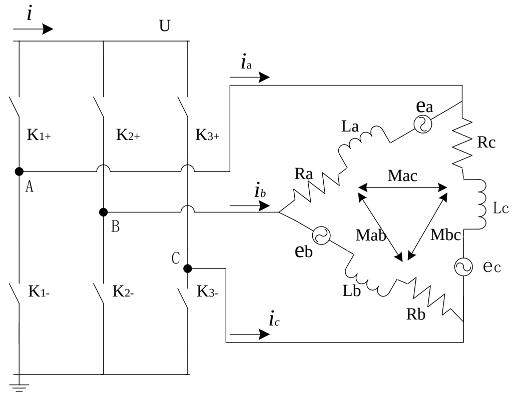


Figure 2. Micro DC motor equivalent circuit diagram

K_{1+} conduction means that the brush K_1 in Fig.2 is connected to the positive pole of the driving power source, K1- conduction means that the brush K_1 in Fig. 2 is connected to the negative pole of the driving power source, and the other switches in the figure are so pushed. 4; R_a is the equivalent resistance of the a-phase winding, L_a is the self-inductance of the a-phase winding, M_{ba} is the mutual inductance of the b-phase winding to the a-phase winding, M_{ca} is the mutual inductance of the c-phase winding to the a-phase winding, and so on.

In Fig. 2, A phase winding voltage $U_a=U_A-U_B$, that is, the voltage between point a and point b; B phase winding voltage $U_b=U_B-U_C$, that is, between b and c point voltage; C phase winding end voltage $U_c=U_C-U_A$, that is, point c and a point of the Between the voltage. The KVL equation is established for the three windings of the armature.

$$\begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} = \begin{bmatrix} R_a & 0 & 0 \\ 0 & R_b & 0 \\ 0 & 0 & R_c \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} L_a & M_{ba} & M_{ca} \\ M_{ab} & L_b & M_{cb} \\ M_{ac} & M_{bc} & L_c \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (2)$$

The timing sequence of u_a, u_b and u_c is corresponds to K_1, K_2 and K_3; i for the armature current, that is, through the brush current, ia, ib and ic is the corresponding phase winding current, armature current and three-phase current between (2);ea, eb and ec for the winding back electromotive force.

3.2 Simulation model based on simulink

Combined with Fig. 2 and the formula (2), the application of the torque sub-module and the induced electromotive force and mutual sub-module can be established micro-DC motor simulation model shown in Fig. 3. In Fig.2, six switches K_{1+}~K_{3-} is corresponding to the corresponding MOSFET in Figure 3 Tube K_{1+}~K_{3-} replacement; *(R-L)a*, *(R-L)b*, *(R-L)c* represent the self-inductance and equivalent resistance of the armature a、b、c respectively. The Te-model and the (M + e) -model modules are the torque sub-module and the induced electromotive force and the reciprocal sub-module respectively.

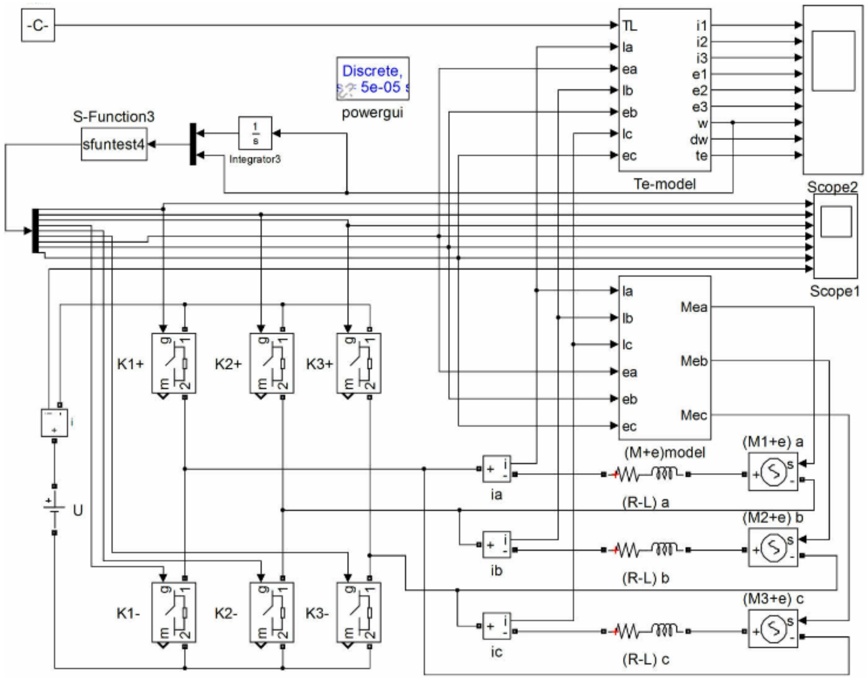


Figure 3. Micro DC motor simulation model

4. Simulation and experiment results

The motor is widely used in the fields of optical drive, printer, home appliance and so on. The social demand is very large, and it is of great theoretical and engineering significance to study the general micro DC motor produced by a motor factory. Its electrical parameters as shown in Tab. 1:

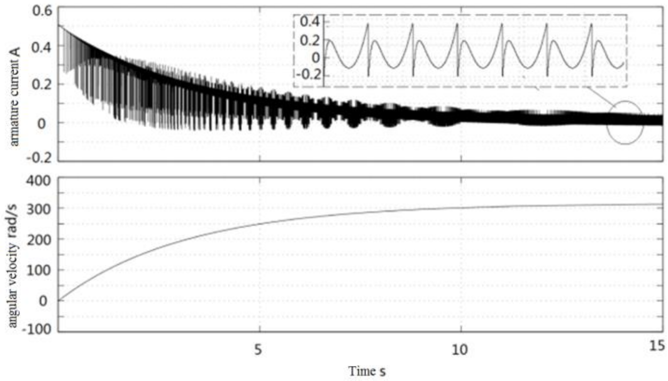
Table 1. Parameters of experiment micro DC motor

Parameter name	Value
Rated voltage	5.0 V DC
Working voltage range	1.5 V ~ 9.0 V DC
Rated torque	0.0015Nm
No-load speed (rated voltage)	6050±650 r/min
Fixed load speed	2800±300 r/min
No-load current	50mA max
Starting current	500mA max

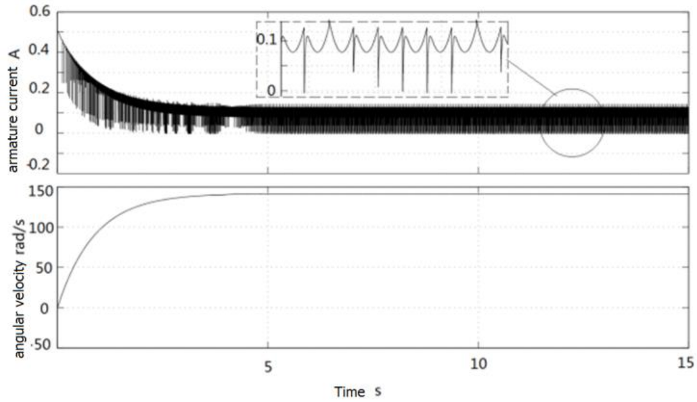
According to the data provided by the manufacturer, the parameters in the simulation model are as follows: self-inductance 4.56mH, mutual inductance 120uH, winding resistance 16Ω.

IOP Conf. Series: Materials Science and Engineering **242** (2017) 012079 doi:10.1088/1757-899X/242/1/012079

In the no-load and full load (0.0015Nm) under the conditions of simulation, the results shown in Fig. 4,



a No load；

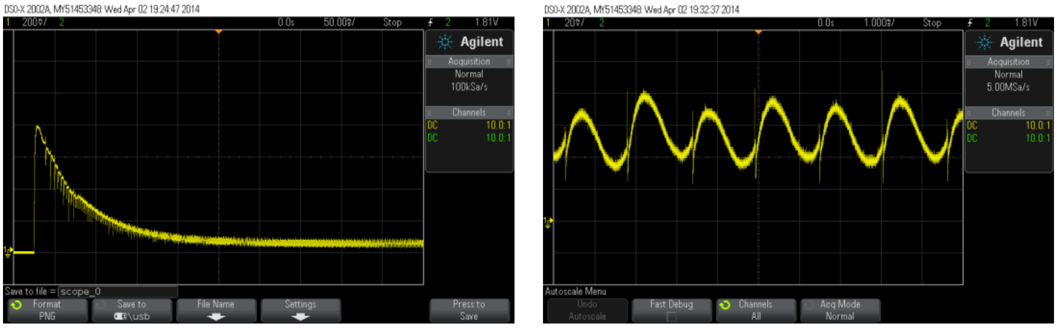


b rated load

Figure 4. The armature current, rotation velocity simulation results

In Fig.4, *a* is the case of no-load simulation results, to be able to see the current waveform, the figure of the circle within the current waveform expansion in the virtual box (later analyzed the same), you can see the armature starting current 500mA and decreases with time index, the instantaneous output torque is 0.008Nm and decreases exponentially. The speed rises from 0 to exponential. After stabilization, the armature current drops to 5mA, the torque drops to 0, the speed is stable at 6000 rpm (Angular velocity of 310 rad/s). B is the simulation results in the case of rated output torque, the armature starting current is 500mA and decreases with the time index, the instantaneous output torque is 0.015Nm and exponentially decreases, the speed starts from 0 and the armature current drops to 15mA, the output torque is 0.0015 rated torque, the speed down to 2030 r / min (angular velocity 280rad/s). The above data show that the simulation results of the simulation model are consistent with the motor data given in Tab. 1.

Take an actual motor, the actual test under rated torque conditions, Fig.5 for the test results. From the two oscilloscope screenshots can be seen, the actual test results and simulation results consistent.



a b

Figure 5. Actual sample motor armature current waveform

For further analysis, Fig. 6 shows the rated load case of *a* phase winding back electromotive force and armature current in the case of rated load. The winding back electromotive force is sinusoidal. The armature current has six changes in a 360°electrical angle. Each process corresponding to a commutation process, which is consistent with the theoretical analysis of commutation process; in each commutation process armature current for the oscillation changes, the waveform has a second-order system characteristics, and Fig. 2, Fig.3 and the theoretical analysis of formula 2 Consistent.

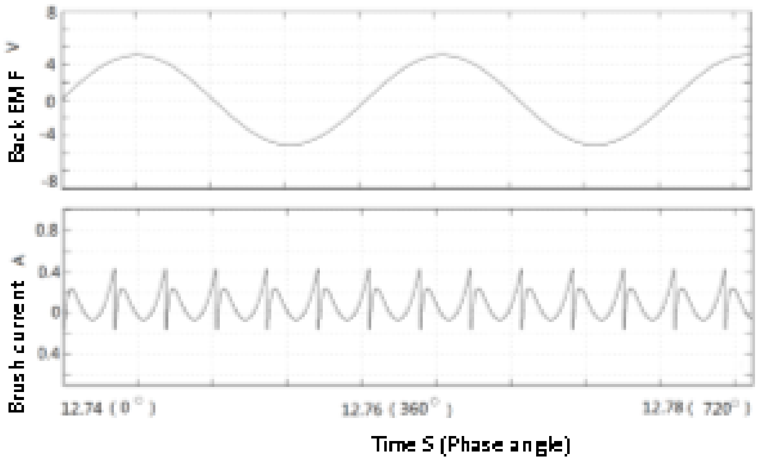


Figure 6. Simulation results of armature current and electromotive force

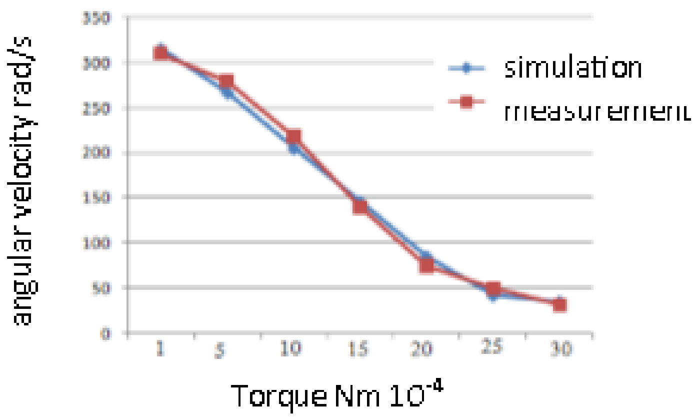


Figure 7. Simulation and measured results of mechanical properties

Fig.7 for the simulation and the actual measurement of the mechanical properties, mechanical properties of the actual measurement is the use of paper [1]. The simulation results are in good agreement with the measured results.

5. Conclusion

Based on the analysis of the commutation process, the micro-DC motor simulation model is established in the Simulink environment based on the electromagnetic torque and the mechanical torque equation. The model is modular and has the generality. The simulation results of the model are in accordance with the theoretical analysis and the actual test results. The work done in this paper can provide a better experimental simulation platform for micro DC motor.

Acknowledgments

This work was financially supported by the Xiamen Science and Technology Project of Fujian Province of China (3502Z20173034) and the Collaborative Innovation Center for R&D of Coach and Special Vehicle Project of Fujian Province of China (2016BJC004).

References

[1] Zhengwen Die. Micro-motor application in electronic equipment, household appliances and cars. Micro-motor. 2005, 38 (1): 76-79.
[2] Lindi Huang, Daxu Huang. Micro-motor market overview at home and abroad. Micro-motor.2007, 40 (7): 75-78.
[3] Qiaobin Guo. The development of micro motor industry in 2007.Micro-motor. 2008, 41 (8): 60-62.
[4] Zhiping Xie, Wei Wu, Jianfeng Hong. DC micro-motor armature current features and fault characteristics study. Electric Machines and Control. 2015, 19 (8): 107-114.
[5] Lianghe Ma. A New Method for Measuring and Performance of DC Micro - motor. Development & Innovation of Machinery & Electrical Products., 2014, 27 (1): 65-67.
[6] MOSELER O, JURICIC D, RAKAR A, et al. Model-based fault diagnosis of an actuator system driven by the brushless DC motor [C]. // proceedings of the Proceedings of the 1999 American Control Conference (99ACC). San Diego, USA: IEEE. 1999, 6: 3779-3783.
[7] MOSELER O, ISERMANN R. Application of model-based fault detection to a brushless D C motor [J]. IEEE Transactions on Industrial Electronics, 2000, 47(5): 1015-1020.
[8] Zhiping Xie. Research on DC micro - motor modeling and fault diagnosis. Xiamen: Xiamen University, 2015
[9] Manlan Liu, Haifang Yu, Shumei Cui. A fault diagnosis method of permanent magnet DC motor. Transactions of China Electrotechnical Society. 2007, 22 (10): 42-48.
[10]Yanfeng Xu, Hanxu Sun, Qingxuan Jia, Wei Xi. Simulation model of fault detection and diagnosis for brushless DC motor.Journal of Vibration, Measurement & Diagnosis. 2015, 25 (3): 190-192.
[11]Yunhua Yin, Bin Zheng, Haoxin Zheng. Modeling and simulation of brushless DC motor control system based on MATLAB. Journal of System Simulation. 20 (2): 293-298.
[12]Dongliang Liu, Yanfei Cui, Meibin Chen. Method of back EMF estimation for brushless DC motor.Transactions of China Electrotechnical Society. 2013, 28 (6): 52-58.