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Experimental Study of Faults Arising on a DC Brushed Shunt Motor

***Mohamoud O. Alamyal*[1]*, El-Sharif A. Omer*[2]*, Ibrahim Daho*[3] *and Asmaeil Heeblu*[4]**

[1,2,3]*Electrical and Electronics Department, Sirt University, Sirt, Libya.*

[4]*Electrical and Electronics Department, Golf of Sidra University, Bengawade, Libya.*

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ABSTRACT

Faults do sometimes occur in direct current (DC) electrical machines result in a very costly downtime and safety concerns. Brushed type DC motors are cheap and easy to install, thus maintain a significant presence in the automotive, aerospace, and home appliance industries. Despite the popularity, faults occur which make analysis and detection of faults very important. Since there are many types of machines and each type has its own behavior when a fault developed, so that only with considerable experience can the cause of failure be correctly identified from the symptoms alone. In this paper a various faults mechanisms of brushed DC shunt motor are presented experimentally. Experimental results demonstrated how DC shunt motor are affected by various faults during the operation. The experiment results can be used to prove the validity of any method for modelling based fault diagnosis, detection and fault confirmation in DC motor, especially in the laboratories that have shortage in equipment.

1 Introduction

Electric motors have become essential elements to power many devices used in everyday life. Characterized by simple construction and easy to control their speed in a wide range, DC motors are largely used in many applications. DC motors have always been used in applications where good controllability is required [1-3]. Various application with low power (under 250W) and large power use DC motor. Examples of low power motor applications include automobiles, robots, food blenders, and in some medical devices [4-5]. Similarly, some applications of large motors are elevators, electric trains and heavy metal rolling mills.

Despite the popularity, faults occur which make diagnosis and detection of faults very important. Therefor, it is important to monitor the lifetime of healthy operation of the DC motor. If on a property organised schedule maintenance is carried out, the existence of fault will be the exception rather than the rulle. However, faults do simetimes occur and it is important to be able to deduce quickest way to repair it, since downtime can cost millions of dollars, especially in high-volume manufacturing industry. In some factories, a very expensive scheduled maintenance is performed in order to detect machine problems before they can result in catastrophic failure [6].

The common fault of DC machine can divide by two categories. First category is mechanical fault (not considered in this paper) such as bearing fault and eccentricity fault [7]. The other category is electrical fault, including field winding fault, armature winding fault, continuity fault, and commutation faults.

Although research in this area still not extensive, investigation of DC machine failure modes has been reported in the literature [8]. The majority of research in electric machines failure modes are done either on the ac induction machines or on synchronous machines [9]. Few works are reported on fault analysis for dc machines [10]. [8] focuses on a modeling approach that is used to investigate the effects of various fault mechanisms of the brushed DC generator at an early stage in their progression. In [11] and [12], a mathematical model is used to investigate the effects of short- and open-circuit armature coils. In [13] the Kalman filter and its iterations are mathematically modeled and is used for fault diagnosis of DC motor.

In this paper, the effects of various faults on DC brushed shunt motor have been investigated experimentally. The information from these experiments can be used to prove the validity of any method for modelling based fault diagnosis, detection and fault confirmation in DC motor, especially in the laboratories that have shortage in equipment and computer program are used more.

2 Modelling and simulation of DC shunt Motor

The motor model can be made by using all mathematical equations that describe the motor. Mathematical equations that describe DC shunt motor derives from equivalent scheme as shown in Fig. 1.

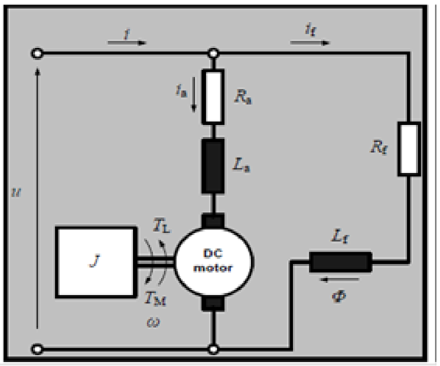

Fig. 1. Equivalent circuit of a DC Shunt motor [14].

2.1 Motor static characteristics

As shown on Figure 1, DC motor can be explained by using two electrical circuits. Armature circuit and field circuit. The equation that describes the armature circuit is:

$$U = E + I_a R_a \tag{1}$$

where U is armature voltage, E is induced voltage, I_a is armature current and R_a is armature resistance. Induced voltage can be expressed with following equation:

$$E = k_e N \tag{2}$$

where k_e is electrical constant of specified DC motor, and N is motor speed in rpm.

The equation that describes field circuit can be expressed as:

$$U = I_f R_f \tag{3}$$

where I_f is field circuit current, R_f resistance of field circuit. Torque on motor shaft (T_M) can be expressed as:

$$T_M = k_m I_a \tag{4}$$

where k_m is mechanical constant of specified DC motor. In dc shunt motor k_m=k_e. It can be seen on Fig. 1 that sum of currents for shunt DC motor is:

$$I = I_a + I_f \tag{5}$$

2.2 Motor dynamic characteristics

Motor dynamic characteristic can be obtained by using differential equations model.

$$u = R_a I_a + L_a \frac{di_a}{dt} + e \tag{6}$$

$$e = k_e \omega \tag{7}$$

$$u = R_f I_f + L_f \frac{di_f}{dt} \tag{8}$$

$$T_M = k_e i_a \tag{10}$$

One more equation that describes the mechanical model is:

$$T_M - T_L = J \frac{d\omega}{dt} \tag{11}$$

where T_L is load torque, J is moment of inertia and ω is speed rads. Sum of current is represented with instant values of currents in armature and field circuit:

$$i = i_a + i_f \tag{12}$$

After the configuration of mathematical model, Simscape library components (part of Matlab Simulink), which can simulate electrical and mechanical parts of DC machines, is used to construct the model (Figure 2).

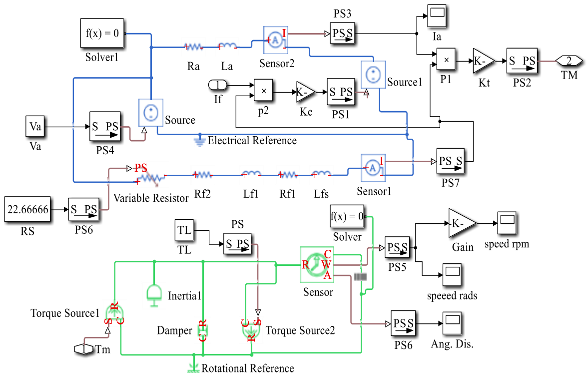

Fig. 2. A model of a shunt DC motor using Simscape blocks

As the parameters are not provided for our motor the main classical identification methods were used to calculate the DC shunt motor parameters and the results are shown in Table 1.

Table 1. The motor parameters

$L_a = 0.083$ H	Field Inductance
$R_a = 4.6$ Ohms	Armature Resistance
$R_f = 6.6$ Ohms	Field Resistance
$L_f = 0.264$ H	Field Inductance
$B_m = 0.00095$	Friction Coefficient
$J_m = 0.00083$	Inertia Constan
$K_e = 0.3$	Voltage constant

Parameters presented in Table 1 were fed to the DC shunt motors' model shown in Fig. 2, load torque and rotor speed plot is shown in Fig. 3. This result mush very closed to the experimented result for normal operation of the motor, confirming the calculation of the parameters.

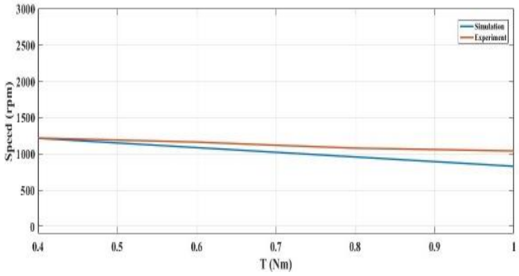

Fig 3. Speed and load torque

3 Faults Occurring Laboratory Experiments

A series of laboratory experiments were performed on a DC shunt motor for healthy operation (No fault operation) as well as a variety of winding failure modes. Scenarios evaluated include:

1- Field winding short circuit test
2- Armature winding fault test.

For these tests, a 2-pole DC motor with 4 commutator segments was operated using Dissectible Machines System shown Fig. 5.

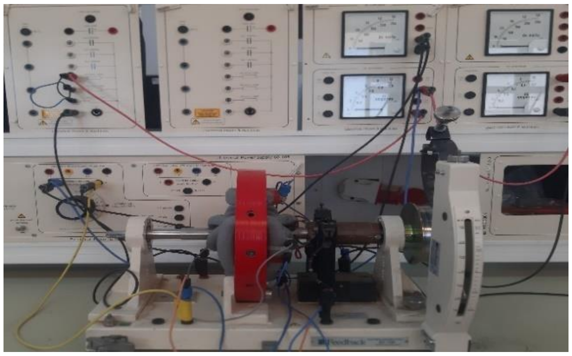

Fig 5. Connection of DC brushed shunt motor

3.1 Healthy operation

The motor fed to 50 volts and the rotational speed was measured using a tachometer. The armature current, the field current and the speed are measured under deferent load conditions. The sound the motor makes and the brush sparking are recorded. The measured readings were taken and recorded at different load as shown in Table 1.

Table 1: Experimental measurement at steady state with different load

T_L **(Nm)**	**I_a** **(A)**	**I_f** **(A)**	**N** **(rpm)**	**Brush Sparking**	**Motor Noise**
0	0.65	1.75	1513	Very Little	Low
0.2	1	1.75	1464	Little	Low
0.4	1.91	1.75	1300	increased	low
0.6	2.5	1.75	1209	increased	low
0.8	6.8	1.75	1117	increased	Little Noisy

3.2 Field winding short circuit fault.

Following the no fault test, a short circuit of the one of the field winding coils was established. The measured readings were taken and recorded at different load as shown in Table 2.

Table 2: Experimental measurement for field winding short circuit test.

T_L	**I_a**	**I_f**	**N**	**Brush Sparking**	**Motor Noise**

(Nm)	**(A)**	**(A)**	**(rpm)**		
0	0.7	2	2138	Small increase	noise with vibration
0.2	1.45	2	1882	Small increase	noise with vibration
0.4	2.4	2	1544	severe	Noisy
0.6	3.4	2	1369	severe	Noisy
0.8	4.4	2	1126	increased	More noise with vibration

3.3 Armature winding fault

1- Short circuit one of the armature coils

With the power off, a shorting link was provided across two commutator segments, so that it short circuits an armature coil. The results for this test was taking for no-load only and very quickly to avoid damaging the commutator or winging. The measured readings were taken and recorded at no-load only as shown in Table 3.

Table 3: Experimental measurement for armature winding short circuit.

T_L **(Nm)**	**I_a** **(A)**	**I_f** **(A)**	**N** **(rpm)**	**Brush Sparking**	**Motor Noise**
0	11.2	1.7	740	Very much increased	More noise very high vibration

2- Open circuit one of the armature coils

Open-circuit one of the armature coil. This is done by removing one of the armature coil leads from one of the commutator segments. The measured readings were taken and recorded at different load as shown in Table 4.

Table 4: Experimental measurement for armature winding open circuit.

T_L **(Nm)**	**I_a** **(A)**	**I_f** **(A)**	**N** **(rpm)**	**Brush Sparking**	**Motor Noise**
0	0.4	1.7	1530	Very little	low
0.2	1.1	1.7	1330	Small increase	More noise
0.4	1.8	1.7	1158	increased	More noise with vibration
0.6	2.65	1.7	1000	Very much increased	More noise with vibration

4 Discussion

From table 2 short circuiting one of the field winging will increase the armature current and the field current in a different ratio. This makes the speed increased to enable the motor to generate a back emf closer to supply voltage.

Table 3 shows that short circuiting one of the armature winding coils will result in a highly increase in the armature current with drumming noise due to the asymmetry of the forces acting on the armature. Insulation failure could be expected if this fault is allowed to occurred when the motor loaded.

For open circuiting one of the armature coils as shown in table 4. Similar to the previous case in term of motor noise and brush sparking except less increased in armature current.

5 Conclusions

The effect of various faults in DC shunt motors investigated experimentally in this paper. All the faults applied in this experiment were winding faults. Open circuit faults and short circuit faults. These faults in practice will affect only one of parallel paths, causes the undamaged windings to carry excess current and overheat. This makes it particularly valuable to have a set of reference measurement, against which following performance can be compared. All the results summed up in tables and can be used to prove the validity of any method for modelling based fault diagnosis, detection and fault confirmation in DC motor. This study is part of an ongoing research on the modelling fault diagnosis in electrical machines.

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