Fast Flashover Identification Methodology on Brushed DC Machines

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Abstract: **-** Direct current machines are applied in several industry sectors, such as steel, paper industry, mining, among others. However, the maintenance of this type of machine is quite complicated. For instance, brush sparking and flashing over can occur after a maintenance period, if interpole windings are connected in the reverse way. Since the commutator and brush assembly are high-wear parts of DC machines, a fast and simple maintenance methodology is necessary to ensure the proper commutation process and augmented equipment performance. This paper presents a research review about DC machines sparking and flashover causes and an experimental analysis with simple, fast and low cost test that can ensure that the interpole connections have been made correctly. This methodology can also be inserted into training protocols and service standards of the maintainers of DC machines.

Key-Words: **-** maintenance, availability, field maintenance, test machines, electric machines

1 Introduction

Even though power electronics has rapidly increased over the past decades, brushed Direct Current (DC) machines are still used in several industry sectors, such as steel, paper industry, mining, among others. The maintenance of this type of machine requires special attention due to failures caused by commuting problems. Since the commutator and brush assembly are high-wear parts of DC machines, a fast and simple maintenance methodology is necessary to ensure the proper commutation process and augmented equipment performance.

Commutation in DC machines is a rather difficult process, which can be accompanied, under certain conditions, by sparks and flashovers. Those problems may arise from mechanical issues, such as vibration, or electrical factors, such as overload, insulation issues, reverse polarity of the poles and rapid change of load. The brush sparking can also occur after a maintenance period, if interpole windings are connected in the reverse way. This situation is possible, for instance, when it is necessary to rewind the interpole coil or the interpole coil is burned and thus needs to be replaced. Therefore, the polarization aspects must be thoroughly analyzed.

Moreover, large machines are rarely tested in the repair office due to limitation of the test bed and the difficulty to test the machine at rated load. In these cases, the maintenance is undertaken at low load or no load, hindering the proper identification of sparking at brushes and flashing over at the commutator. These problems will only occur when the machine is connected back to the local process at rated load, possibly resulting in rework and time delay.

To support the DC machines repair process, this paper presents a research review about DC machines sparking and flashover causes and an experimental analysis with simple, fast and low cost test. Such test ensures that the interpole connections have been correctly made and the equipment will neither spark nor flashover when fed into their process workplace. Finally, this article also presents real case tests with five different DC machines.

2 Background

Technical articles related to commutation problems and machine behavior impacts have been presented in literature since last century. Some milestone researches of DC machines are: [1], [2], [3], [4]. The study of the sparking effect in several different applications is discussed in various technical papers. [5], [6] and, most recently, [7], for instance, have reported the case of automotive fuel pumps, where experimental equipment was developed to analyze the commutation phenomenon and its impact on the commutators life cycle. Other similar researches include [8], which analyzed the brushes current at a mining application by measuring the air gap machine field, and [9], that evaluated the characteristics of commutators wear. Also, there are few studies considering the commutation aspects, such as the specific research about contact reliability presented in [10] and the review of electric brushes application and maintenance activities related to DC motors presented in [11].

Furthermore, there are several articles about maintenance activities for electrical machines faults diagnosis. Among the engineering techniques used to diagnose faults in the armature circuit, it is possible to highlight the Frequency Response Analysis Method (FRA), as shown by [12], and the finite element method for modeling the arc and commutators, as presented by [13], [14]. Another application of finite element research is the modeling of the machine considering commutation aspects, including resistances and inductances, as presented by [15], and, recently, the model with coupled circuit discussed by [16]. Concerning maintenance techniques and tests, [17] presented some test aspects for identifying security levels in installations with arcs, and [18] studied the electromagnetic interference due to commutation arcs.

Finally, regarding the commutation process, [19] examined the brush sparking caused by an inadequate winding design, and an interesting approach with new commutators construction techniques is presented in [20]. [21] summarized the impacts on commutation of the insertion of power electronics in DC motor drives, and [22] highlighted the correct application of collector rings on DC machines. Quantitative and qualitative analyses of generated noises brush sparking are discussed and presented by [23]. Experimental tests for noise reduction in DC machines are discussed in [24] and a commutation comparison between machines with and without brushes for traction drive application is discussed in [25].

In this context, this paper presents a methodology to be applied by engineering and maintenance service companies in DC machine maintenance after the intervention in repair offices or field work to prevent interpoles connection errors. This article also presents five case studies of DC machinery maintenance as a way to demonstrate the methodology feasibility.

3 Methodology

After DC machines are disassembled for maintenance, a brush sparking can appear if interpole coils are connected reversely. This paper presents a method for easy identification of this connection error and presents some steps to support polarization, particularly when the machine has not a terminal identification. The load testing could be used to check if coil connections are correct. However, this test has a relatively high cost due to the difficulties of undertaking it at rated current, especially in high power machines.
The inversion of the interpole connection can cause brush spark and flashover problems, which are deepened with the current increase due to load increase, and the speed increase due to a voltage increase. The interpoles create a field that has the same intensity, but opposite direction of the armature reaction flow. The aim is to nullify or to reduce the armature reaction flow to a minimum acceptable value for operation. The expression for the voltage developed in the armature undergoing commutation is presented in Equation 1.

$$v(t) = E_a(t) + R_a i_a(t) + L_a \frac{di_a(t)}{dt} + v_i(t) \qquad (1)$$

Where v(t) is the applied voltage; Ea(t) is the voltage due to armature reaction; Raia(t) is the voltage due to ohmic resistance; La is the self-inductance of the coil undergoing commutation; ia(t) is the current in the armature coil undergoing; and vi(t) is the voltage due to interpole action, which depends on the mechanical speed of the machine, the rotational mutual inductances and the interpole current.

For better an understanding of the interpole reversal in relation to the armature, Fig. 1 illustrates the correct connection and Fig. 2 presents the wrong connection. As displayed in Fig. 1, the interpoles with the correct connections generate a counterforce for easing the armature reaction effect. As in Fig. 2, there is a reverse reaction, because the new flow intensifies the armature reaction shifting their neutral line and creating a considerable sparking, making easily identifiable by visual inspection.

The identification of this connection failure can be easily accomplished by checking the direction of magnetic flow of the armature. To carry out this test, few instruments (with low acquisition cost) are required, such as: AC adjustable voltage Source, True RMS AC Voltmeter and AC Ammeter. The following steps summarize the test methodology:

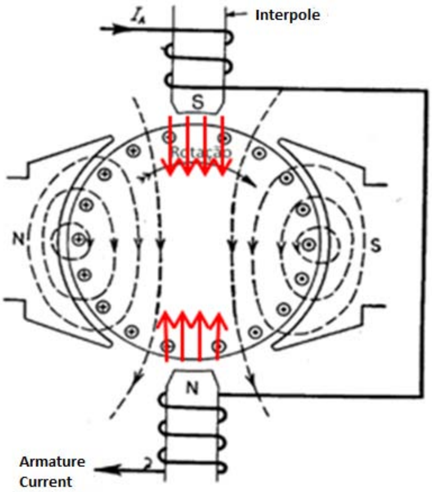

Fig. 1 – Correct connection

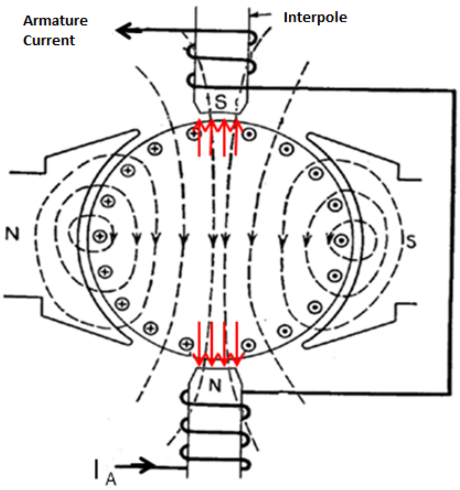

Fig. 2 – Wrong connection

Step 1- Application of a low AC voltage (due to safety reasons) at interpole terminals (Va-applied voltage);

Step 2- Measurement of the generated voltage at the armature terminals (Vg-Generated Voltage);

Step 3- Measurement of the total voltage (Vt-Total voltage) at armature circuit A1 and A2 (interpole + armature). This procedure is shown in Fig. 3;

Step 4- Confirm if the interpole connection is correct, Vt should be the subtraction of Va and Vg. If the interpole connection is reversed, there will be a sum of Va and Vg.

If the interpole connection is reverse, it is possible to correct it by changing the brush-holder cables, as shown in Fig. 4

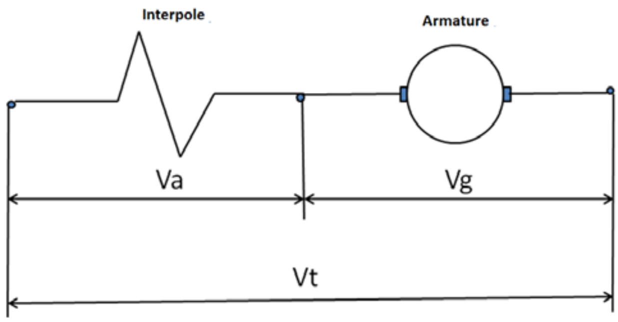

Fig. 3 – Magnetic Flux Circuit

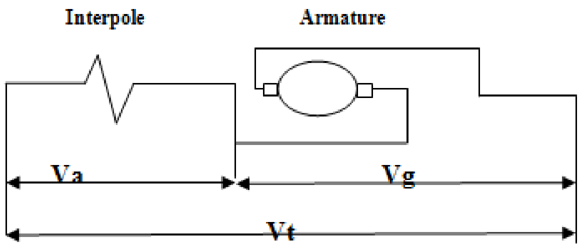

Fig. 4 – Magnetic Flux Circuit

4 Real Life Examples

In this study, five different case studies are presented to technically demonstrate the methodology proposed.

Case 1: The first case study involves didactic machines analyzed in the university's laboratory and simulated to carry out different machine connections to check the methodology and to support the team training. This case was used to confirm in laboratory the test sequence and the correct use of the measurement instruments. Table 1 presents the test equipment specification utilized during this analysis.

The step 1 test results are shown in Table 2. In this example, the motor connections are the original one done by manufacturer and the value of Vt is the same, confirming the correct interpoles connection.

Table 3 presents the test sequence result for the same motor connections considering the circuit supply connected to the windings with a lower voltage, confirming that the applied voltage does not influence on Vt response.

Table 1: 0.5 HP DC Machine Technical Specification

Application:	Laboratory Motor Test
Manufacturer:	Equacional
Rated Voltage:	220 Vdc
Rated Current:	2 A
Work Duty:	S4
Connection:	SHUNT
Power/Speed:	0.5HP/1600 rpm

Table 2: Tests results with original manufacturer connections

Data from the test carried out under normal conditions		
Va =10.15V	Vg = 7.10 V	Vt = 3.05V
Vt = Va – Vg	Vt = 10.15 – 7.10	Vt = 3.05V

Table 3: Tests results with original manufacturer connections supplying the windings with a lower voltage

Data from the test carried out under normal conditions		
Va = 5.28V	Vg = 3.7V	Vt = 1.55V
Vt = Va – Vg	Vt = 5.28 – 3.7	Vt = 1.55V

To confirm the test about correct connection method, it is necessary to reverse the interpole circuit polarity and do new measurements. The data of these new measurements are shown in table 4. It is observed that Vt is now the sum of voltages Va + Vg and no longer Va-Vg.

Table 4: Tests results with interpole inverted polarity

Data from the test carried out with interpole inverted polarity		
Va = 10.15V	Vg = 7.10V	Vt = 17.25V
Vt = Va + Vg	Vt = 10.15 + 7.10	Vt = 17.25V

If the test is repeated with low voltages considering interpole inverted connections, the results are proportional, confirming that the applied voltage has not influence over the field identification, as shown in table 5.

Table 5: Tests results with interpole inverted polarity and low voltage applied

Data from the test carried out with interpole inverted polarity and low voltage		
Va = 5.4V	Vg = 3.76V	Vt = 9.23V
Vt = Va + Vg	Vt = 5.4 + 3.76	Vt = 9.23

To prove the sparking effect, the machine was retested with the interpole connection inverted and applying 32 Vdc at the field and 40 Vdc at armature and the result was a great sparking. It also took another test in which applied 30 Vdc at field and 75 Vdc at armature, featuring a dynamic test machine. In this test was noted an increase sparking and an audible noise.

Another test was held, applying 30 Vdc at Field and 75 Vdc at armature (despised the interpole connection leaving it disconnected from the circuit under test). The machine presented sparking, but not noise. In the sequence, the interpole was reconnected to their original connection (correct) and 30 Vdc was applied at field and 40 Vdc at armature. As expected, there was no abnormal noise or sparking in the machine. Afterwards, the machine was retested with 30 Vdc applied at field circuit and 75 Vdc at armature. In this situation, neither sparking nor noise was noticed.

Case 2: The tests were performed in the steel industry repair office. Table 6 presents test equipment data. It was chosen to test a 50 HP locomotive generator.

Fig. 5 illustrates one of the test steps in normal interpole polarization and measurements. Fig. 6 illustrates the brushes machine voltage measurement.

Table 6: 50 HP D.C. Generator Technical Data

Application:	Locomotive Generator	
Manufacturer:	GE	
Rated Voltage:	240 Vdc	
Rated Current:	45 A	
Work Duty:	S1	
Connection:	Series	
Power/Speed:	50 HP/2000 rpm	
Data from the test carried out under normal conditions		
Va = 6.67V	Vg= 3.24V	Vt = 3.20V
Data from the test carried out with interpole inverted polarity		
Va = 3.59V	Vg= 1.12V	Vt = 4.64V

Fig. 5: Voltage interpole measurement (normal operational)

Fig. 6: Brushes machine voltage

Case 3: The methodology was confirmed with 2500 HP DC motor test and study was assembled in a rolling mills section. The tests were performed on the local process during March 2013. Table 7 presents equipment data and the tests results.

Table 7: 2500 HP DC Motor Technical Data

Application:	Cold Mill #2 5th Driver Motor	
Manufacturer:	GE	
Rated Voltage:	700 Vdc	
Rated Current:	2840 A	
Work Duty:	S1	
Connection:	SHUNT	
Power/Speed:	2500 HP/350 rpm	
Data from the test carried out under normal conditions		
Va = 2.7V	Vg= 1.6V	Vt = 1.1V
Data from the test carried out with interpole inverted polarity		
Va = 2.7V	Vg = 1.6V	Vt = 4.4V

Case 4 Test with a 5000 HP motor assembled in a rolling mills section. The tests were performed on local process during May, 2013. Table 8 presents the equipment data and tests results.

Case 5: Another test carried out to demonstrate the methodology took place in a 1250 HP motor assembled in a section of rolling mills. The tests were performed on local installation during June, 2013. Table 9 presents the equipment data and tests results.

Table 8: 5000 HP DC Motor Technical Data

Application:	F5 Section Mill Driver	
Manufacturer:	GE	
Rated Voltage:	700 Vdc	
Rated Current:	5800 A	
Work Duty:	S1	
Connection:	SHUNT	
Power/Speed:	5000 HP/ 160 rpm	
Data from the test carried out under normal conditions		
Va = 1.5V	Vg= 1.27V	Vt = 0.36V
Data from the test carried out with interpole inverted polarity		
Va = 1.5V	Vg= 1.27V	Vt = 2.77V

Table 9: 1250 HP D.C. Motor Technical Data

Application:	F1 Main motor Section #3 Mill	
Manufacturer:	GE	
Rated Voltage:	700 Vdc	
Rated Current:	1425 A	
Work Duty:	S1	
Connection:	SHUNT	
Power/Speed:	1250 HP/ 350 rpm	
Data from the test carried out under normal conditions		
Va = 6.2V	Vg = 5.0V	Vt = 1.2V
Data from the test carried out with interpole inverted polarity		
Va = 6.1V	Vg = 5.0V	Vt = 11.1V

5 Discussion

This paper presented a practical methodology to eliminate possible interpole coils connections errors of any power DC motor. It has been demonstrated that it is an easy-to-apply methodology, which does not require great test equipment investments for its implementation. These tests can be performed in the maintenance office or at the testbed and, with voltage measurements, it is possible to identify if the connections are correct. The methodology can also be introduced to improve the sparking concepts understanding. The training practical part can be done with small power machines in the training centers or universities laboratories.

In a second analysis, the maintenance worker can do a check analysis of the voltage measured during the tests (Vg). It is possible to check the neutral line motor condition and thus to do the correct actions to adjust the position if necessary. It should be noted that one of the reasons of large sparking in motor DC commutators is the neutral line position. This paper demonstrated through five real cases with different power machines the methodology applicability and the four basic steps to implement these easy maintenance activities.

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