ONLINE FAULT ANALYSIS OF DC MOTORS

David L. McKinnon, PdMA Corporation, *Member, IEEE*

***Abstract*—Over the last 20 years, Current Signature Analysis (CSA) has become an established tool for online fault analysis of AC Induction motors. Presently, very little research has been performed using current signature analysis on DC motors. This paper is a brief introduction to online fault diagnosis of DC motors using current signature analysis.**

***Index Terms*—Current Signature Analysis, DC Motors, Armature, Field, Motor Testing, and Measurement.**

I. INTRODUCTION

This research initiative was undertaken to further develop online fault detection of DC motors using current signature analysis in both the time and frequency domains. These faults include differential current, shorted armature windings, shorted field windings, and off magnetic neutral plane brush positions.

To detect the various faults in DC motors, we must develop a methodology to properly differentiate normal operating conditions from those of fault operating conditions. The first step is to establish a baseline of normal operating conditions. Once a baseline of normal operating conditions is established, a method of differentiating fault operating characteristics from baseline characteristics must be developed.

The primary differentiating methodology used in our study was a visual comparison of fault operating conditions to the baseline condition. For our study, a deterministic fault condition is considered one in which there is an obvious visual or numerical change in either or both the time or frequency domain. Visual changes may include variations in the waveforms in the time domain or the number of peaks, their amplitude, or their location in the frequency domain. For our purposes, numerically deterministic changes are those that exceed the measurement error sensitivity of the equipment in use by more than a specified amount beyond the maximum measurement error. For example, if the error sensitivity of the equipment is 1% of reading, and the specified change is 1%, the minimum fault differential required would be 2%.

II. DISCUSSION

A. *Turn-to-turn Short*

Many turn-to-turn or commutator bar-to-bar faults occur from carbon dust build up. Carbon dust from the brushes builds up on the commutator creating a short between commutator bars. To simulate the worst case of this fault condition, two wires that terminated on adjacent commutator bars were shorted together on the armature of the DC motor. The motor was then run and a current signature analysis in both the time and frequency domains was performed.

Figures 1 and 2 show a comparison of the current signatures in the time domain of a no fault condition to a turn-to-turn short (faulted condition). In the no fault condition, there is no modulation of the 120 Hz carrier frequency. In the fault condition shown in Figure 2, the waveforms have a modulation of the 120 Hz carrier of approximately 17 Hz.

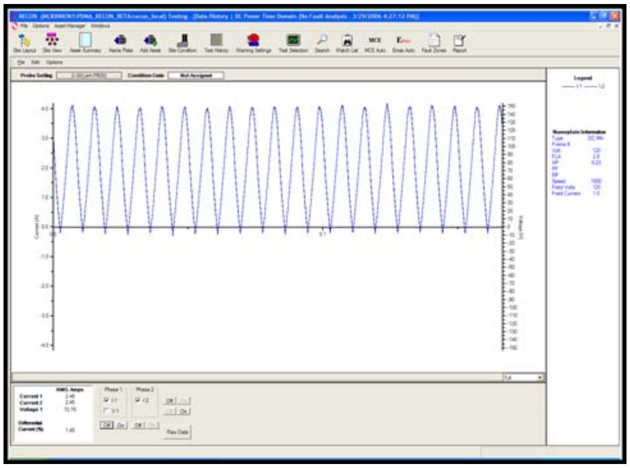

Figure 1 – No fault - full load, full speed, and brushes at zero magnetic neutral axis.

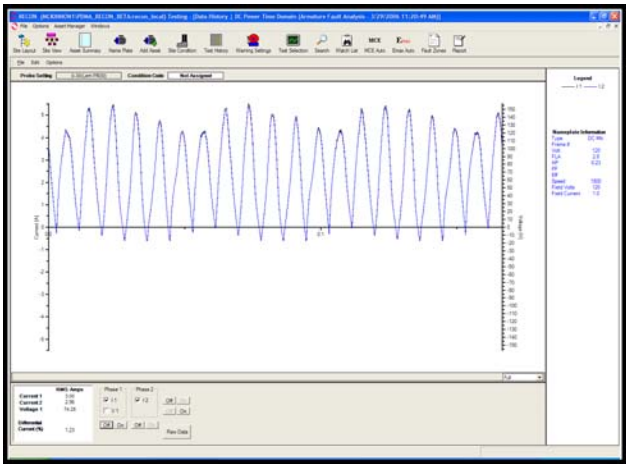

Figure 2 – Turn-to-turn short - full load, full speed, and brushes at zero.

This fault condition is further noticed in the frequency spectrums shown in Figures 3 and 4. The frequency spectrum shown in Figure 3 is the no fault condition. Figure 4 shows the frequency spectrum of the turn-to-turn fault condition. Notice the dramatic increase in the harmonics throughout the spectrum.

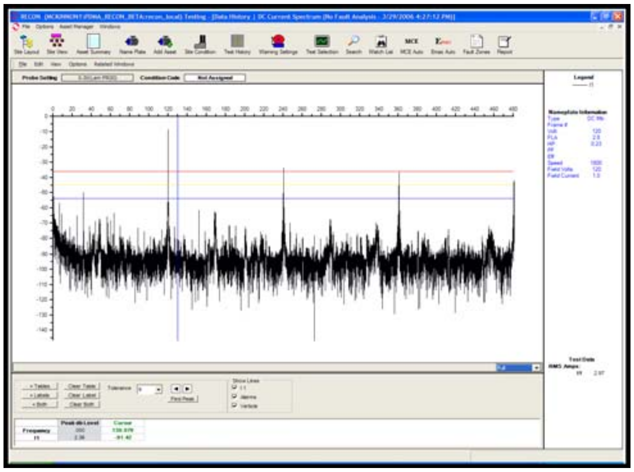

Figure 3 – No fault - full load, full speed, and brushes at zero.

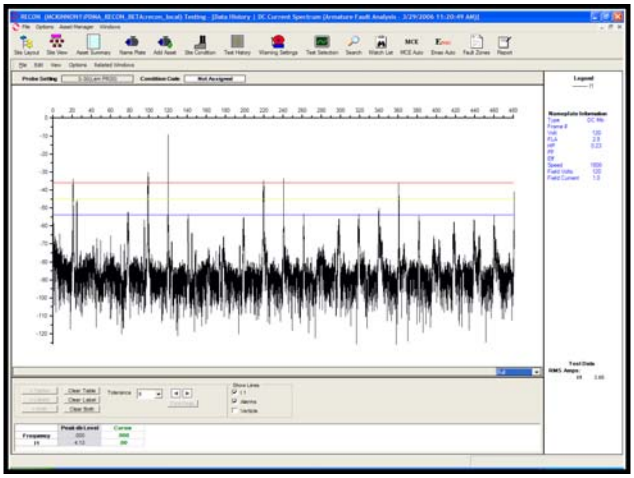

Figure 4 – Turn-to-turn short - full load, full speed, and brushes at zero.

B. *Coil Group Short*

Figure 5 shows a fault operating condition in which an entire coil group is shorted. Notice this increase in modulation as compared to the turn-to-turn short shown in Figure 2.

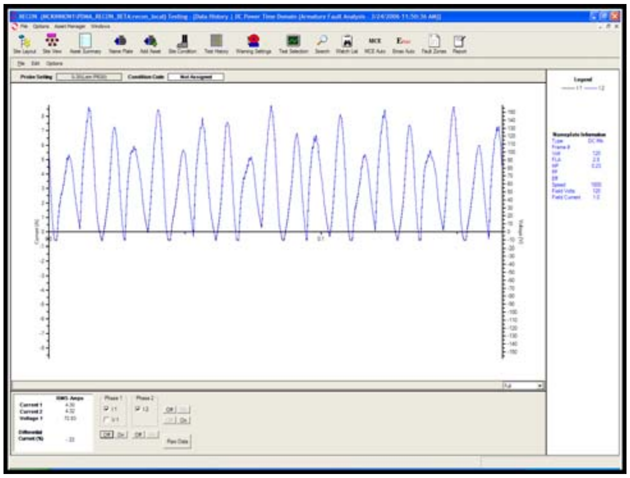

Figure 5 – Coil group short - full load, full speed, and brushes at zero.

Figure 6 shows the frequency domain of the coil group fault operating condition. There is a significant increase in the harmonics throughout the spectrum.

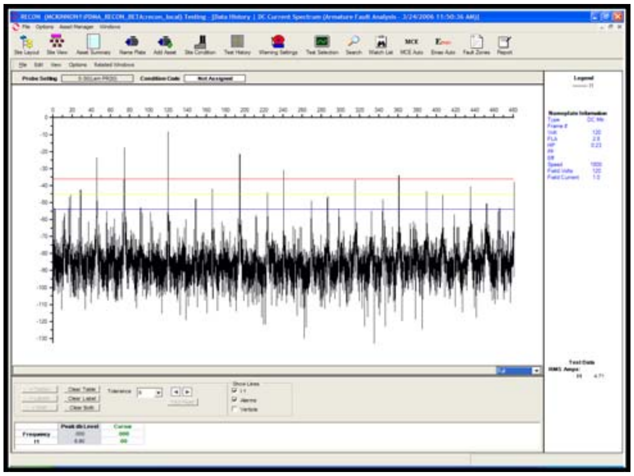

Figure 6 – Coil group short - full load, full speed, and brushes at zero.

C. *Coil to Coil Short*

Figure 7 shows the time domain of a fault operating condition in which two coil groups are shorted together. Notice the increase in modulation as compared to the coil group short shown in Figure 5. Figure 8 is the Frequency Spectrum produced by this fault.

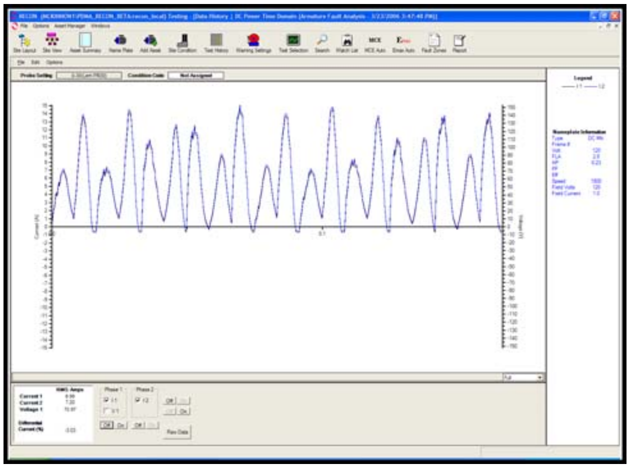

Figure 7 – Coil to coil short - full load, full speed, and brushes at zero.

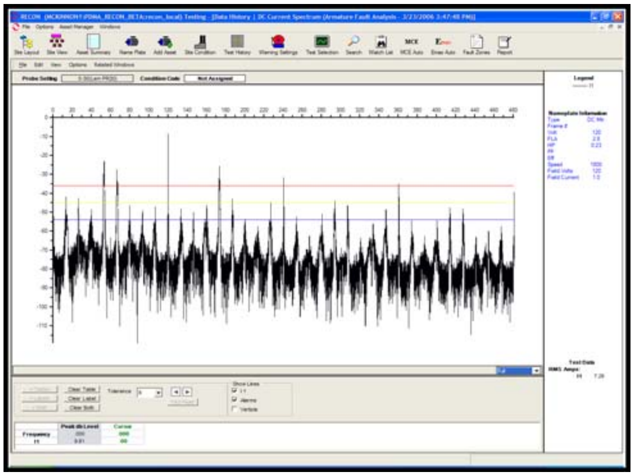

Figure 8 – Coil to coil short – full load, full speed, and brushes at zero.

D. *Brush Position*

Detecting when the brushes are off the magnetic neutral axis can be difficult, especially if the motor is inaccessible during operation. Using voltage analysis in the time domain makes the job of properly setting the brushes for the desired load much easier. The voltage waveforms in Figure 9 appear to be clean (i.e., without noise). When the brushes are off the magnetic neutral axis, the voltage waveforms in the time domain have a lot of hash as shown in Figure 10.

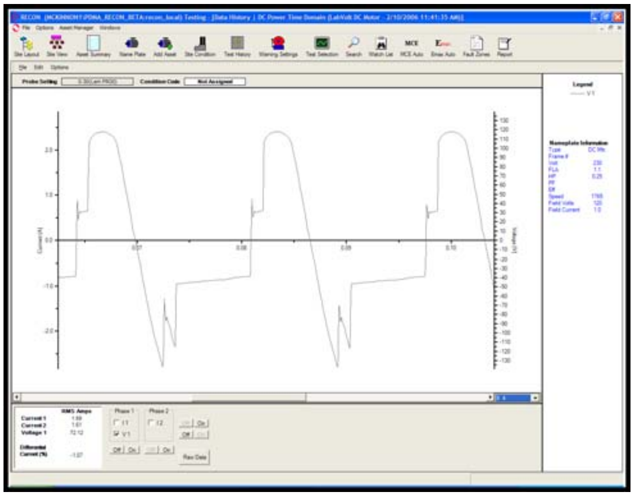

Figure 9 – Brushes precisely on the magnetic neutral axis.

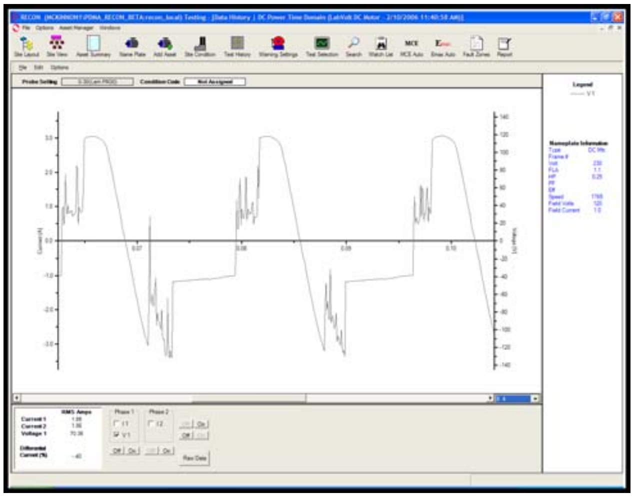

Figure 10 – Brushes off magnetic neutral axis.

E. *Field Ground*

To detect field winding grounds, the time domain waveform of the line to neutral voltage should be analyzed for anomalies. Under no fault conditions, the field voltage will be of significant amplitude as shown in Figure 11. When there is a field ground, the voltage will be very low as shown in Figure 12.

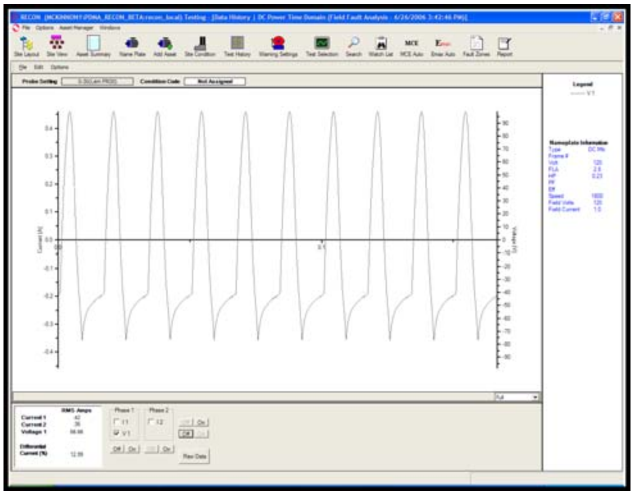

Figure 11 – No field ground, tester grounded at drive.

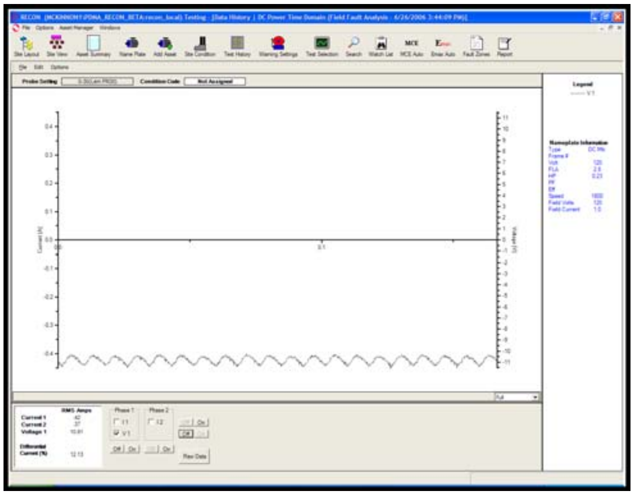

Figure 12 – Field grounded to tester ground.

F. *Brush Ground*

Brush grounds are very similar to field grounds. To detect a grounded brush, analyze the time domain of the line to neutral voltage waveform. Under no fault conditions, the field voltage will be of significant amplitude as shown in Figure 13. When there is a grounded brush, the voltage will be very low as shown in Figure 14.

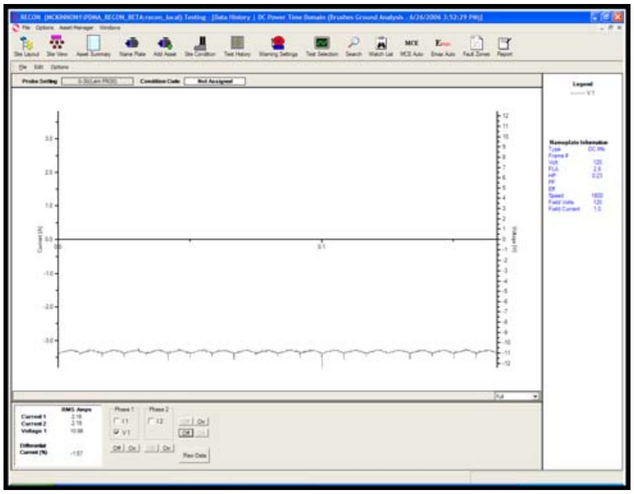

Figure 13 – Brush grounded to tester ground.

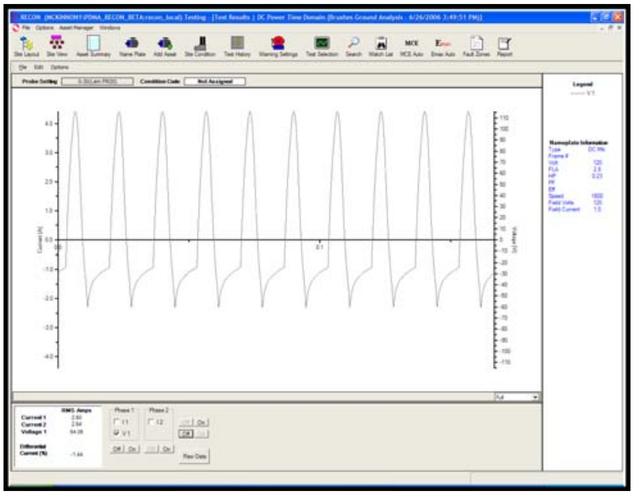

Figure 14 – No brush ground, tester grounded at the drive.

G. *Differential Current*

Differential current may be analyzed by comparing two current waveforms in the time domain. There are two predominant situations where differential current analysis may provide insight to fault conditions that may otherwise be overlooked. One of these is when two or more cables feed a single terminal such as those found in semi-high current situations. Another situation differential current analysis may be used is in comparing the A1 to A2 currents. Situations may occur in which one of the main power cables may have bypass current. Bypass current may occur from the high frequency switching found in DC drives. Differential current may also occur when alternate return paths offer a lower impedance than the primary feed cables.

Numerical analysis is the primary methodology used when analyzing differential current. The deterministic differential will vary according to the application. For our study, we used a 2% differential (1% equipment + 1% minimum differential) to compare two cables feeding a single terminal. One of these cables had a resistance inserted into the line to represent a high resistance connection of one of the cables in a multi-cable situation.

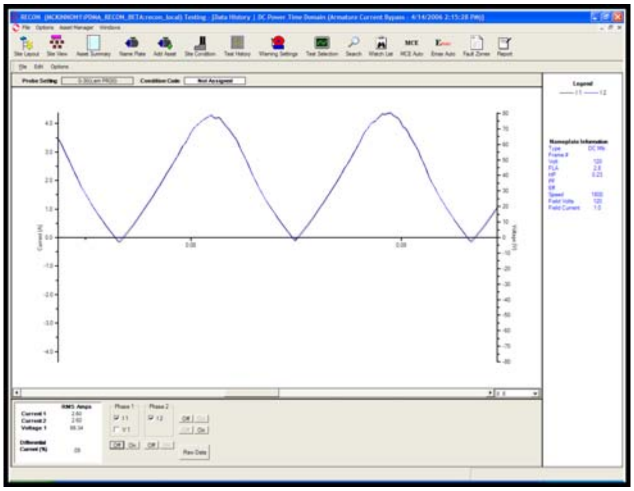

Figure 15 – No fault condition – 0.09% differential current.

Figure 15 shows a situation of balanced currents between two cables connected to A1 terminal. Figure 16 shows a situation in which one of the cables connected to A2 terminal has a high resistance connected in series to simulate a high resistance connection. Note the 2.44% differential current met our established criteria of at least 2% for a fault condition to be deterministic.

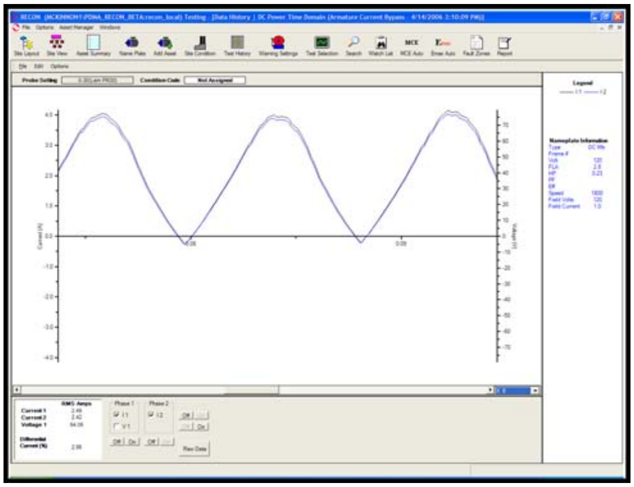

Figure 16 – High resistance fault condition – 2.44% differential current.

III. SUMMARY

Our research has shown the use of current and voltage signature analysis in both the time and frequency domains may provide useful insights to online fault analysis of DC motors. Many common faults such as shorted turns or commutator bars, grounded windings, and off magnetic neutral axis faults may be detected using online current and voltage signature analysis.

Trending these over time may provide an indication of a developing fault in the motor. As with all tests, cross correlation between technologies is imperative in the decision making process.

IV. REFERENCES

1. S. J. Chapman, “Electric Machinery Fundamentals”, McGraw-Hill publishing Company, 1985.

2. S. Smith, “Magnetic Components Design and Applications”, Van Nostrand Reinhold Company, 1985.

David L. McKinnon received his BS in Electrical Engineering from New Mexico State University in 1991 and an MBA from the University Of Phoenix in 2002. He has worked in the field of magnetics for over 14 years. During the past four years, he has worked for PdMA Corporation as a Project Manager for hardware and product development of motor test equipment.