Electronic Motor Diagnostics

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ABSTRACT

This paper will review electric motor diagnostic applications, including motor circuit analysis and motor current signature analysis. In particular, the paper will focus on how the data is used, what capabilities are available, and how the technologies work with infrared analysis. Several case studies showing how these technologies work together will be included.

Keywords: motor diagnostics, motor current signature analysis, motor circuit analysis

INTRODUCTION

Electric motor diagnostics (EMD) is a term for test methods and instruments designed for electric motor electrical and mechanical non-destructive analysis. These instruments are used for all motor system related analysis from the generator and prime mover, through the transmission and distribution system, to the electric motor and driven load. These technologies, for the purpose of this paper, will include motor circuit analysis (MCA), a de-energized test method; and electrical signature analysis (ESA), a more advanced method of motor current signature analysis (MCSA).

One of the more complex systems to test is the AC salient pole alternator, which we will refer to as a generator for the purposes of this paper. In order to fully explore the capability of EMD, we will discuss the application on a marine generator from fault, to troubleshooting, to estimating time to failure, and ending with the repair and related repair issues.

MOTOR CIRCUIT ANALYSIS

MCA is a low-voltage method for testing electric motor cables, connections, windings, and rotor for developing faults. The technique involves individual readings of DC resistance (R), impedance (Z), inductance (L), phase angle (Fi), current/frequency response (I/F), and insulation to ground (megohm) testing. Resistance is used for detecting loose connections and broken conductors, insulation to ground is used for detecting ground faults, Z and L are matched to evaluate the insulation condition for winding contamination, Fi and I/F are used to detect winding shorts. One of the key aspects of MCA is the ability to detect early winding defects that can be trended over time, allowing estimation of time to failure..

Following are the pass/fail limits for the analysis:

- R: 3% from the average.
- Z and L: Should follow a pattern (actual values are not important). If the patterns match (i.e., high, low, medium values for both) the insulation system is clean and dry; if not, then the winding is breaking down (dry and brittle, contamination or overheated).
- Fi and I/F: Should both be +/- 1 from the average test results. If not, a winding short exists.
- Megohm: 5 megohms or greater for motors under 600 V and 100 megohms for motors over 600 V.

ELECTRICAL SIGNATURE ANALYSIS

ESA (electrical signature analysis) utilizes readings of both voltage and current in order to produce demodulated current, voltage and current FFTs, and full-power quality and data logging capabilities. ESA consists of two distinct strengths: current FFTs and demodulated current are used to detect electrical and mechanical faults downstream (towards the motor and load); voltage FFTs are used to analyze supply-side electrical and mechanical faults. For instance, when testing from the motor control center, dominant voltage is used to evaluate problems towards the transformer, while dominant current is used to evaluate problems towards the motor and driven load.

The current signature analysis (CSA) portion of the analysis uses the rotor and motor air gap for analysis. CSA will detect electrical and mechanical problems, including the rotor bars, air gap, mechanical unbalance, shorted windings, loose coils, bent shaft, belt issues, gear issues, fan and pump impellor issues, and more. Details on the analysis for motor system defects are too numerous for this discussion and will not be outlined within this paper.

INTRODUCTION TO GENERATOR CASE STUDY

A marine generator on board a military vessel was experiencing increasing over-air-temperature faults during operation. These occurred within 24 hours of operation and gradually worked towards occurring every 6 hours of operation during the course of eight months. The engine and cooling temperatures were evaluated and found to be operating satisfactorily.

Figure 1. Generator

The generator had been installed on the vessel following eighteen years of storage in an uncontrolled environment. It was determined that EMD would be used to evaluate the condition of the system.

Figure 2. Switchgear test points

Testing was performed at the switchgear using MCA. The first set of data identified a problem in the circuit (Table 1). A second set of tests were performed in the connection box at the generator (Table 2), which identified both a winding short and poor insulation condition (unmatched Z and L).

	T1-T2	T1-T3	T2-T3
Resistance	0.0208	0.0189	0.0373
Impedance	1	1	1
Inductance	0	0	0
Fi	22	21	20
I/F	-28	-30	-35
Insulation	750 Megohms		

Table 1. MCA test at switchgear

	T1-T2	T1-T3	T2-T3
Resistance	0.0445	0.0348	0.0542
Impedance	1.60	1.64	1.63
Inductance	0.317	0.320	0.323
Fi	20	20	20
I/F	-33	-35	-36
Insulation	750 Megohms		

Table 2. MCA at generator

As it requires removal of the generator through a hole in the hull of the ship, additional testing was performed using ESA over a period of 30 minutes.

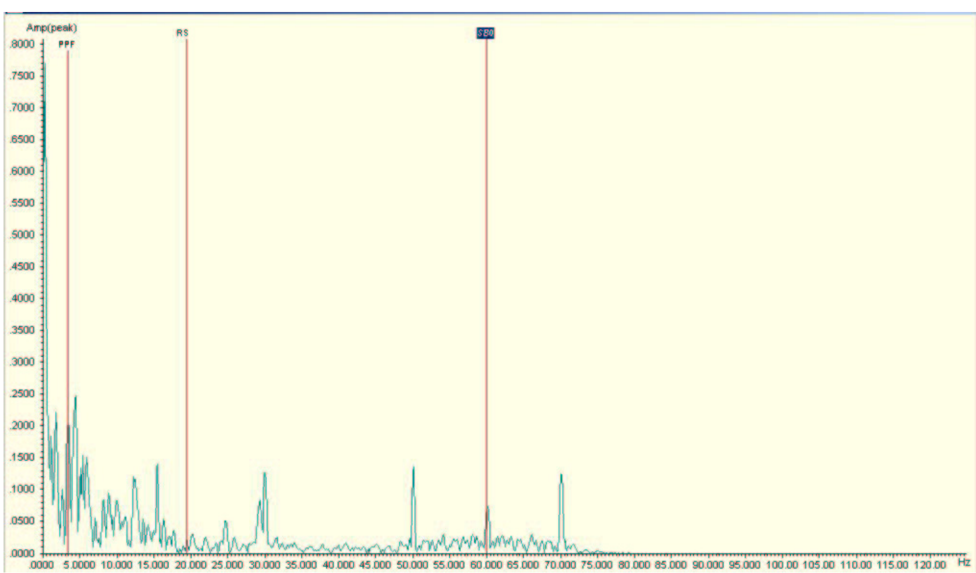

Figure 3. ESA at '0' minutes

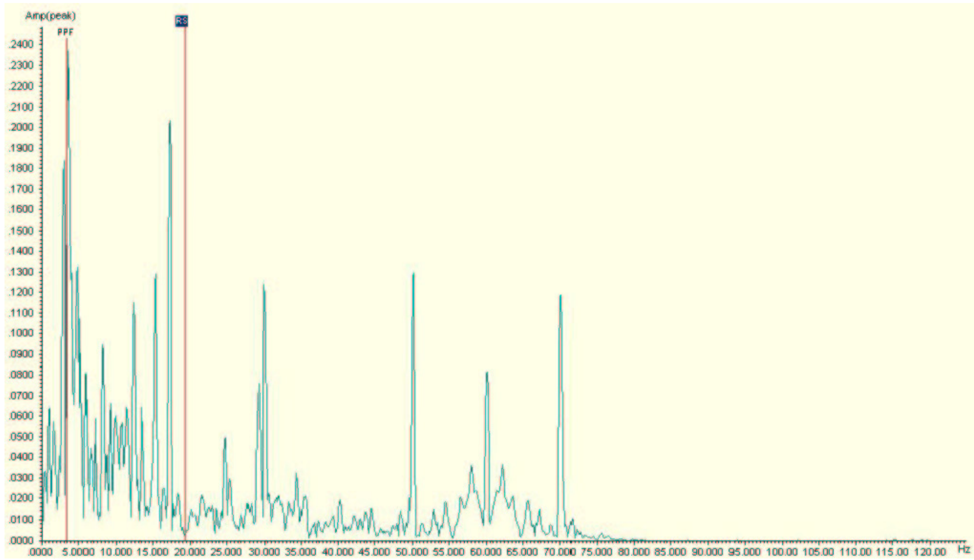

Figure 4. ESA at '10' minutes

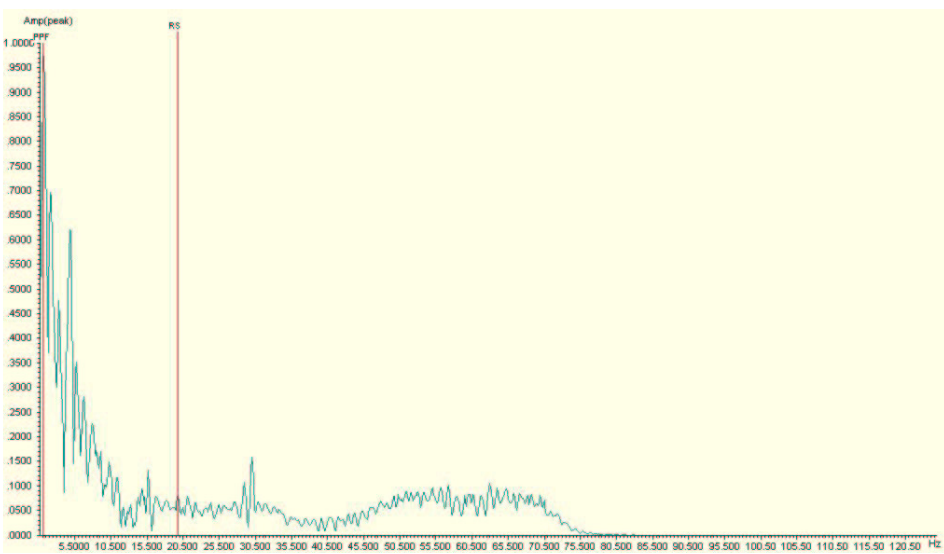

Figure 5. ESA at '20' minutes

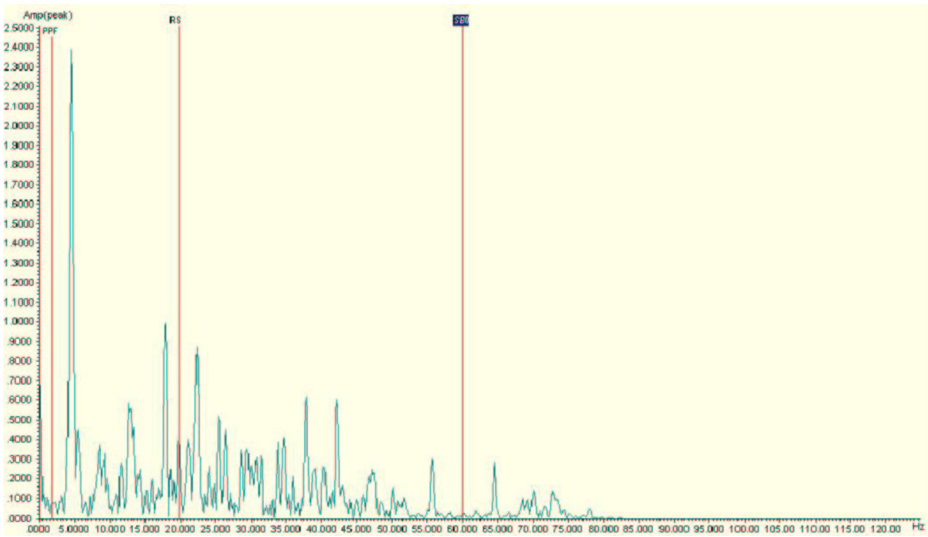

Figure 6. ESA at '30' minutes

At the end of the ESA test period, another set of MCA data was performed while the generator was warm (Table 3).

	T1-T2	T1-T3	T2-T3
Resistance	0.1514	0.116	0.0828
Impedance	1	1	1
Inductance	0	0	0
Fi	20	20	20
I/F	-31	-33	-35
Insulation	55 Megohms		

Table 3. MCA after ESA test

The reduction in insulation resistance from 750 megohms to 55 megohms indicates a temperature rise somewhere in the insulation system of approximately 140°C. In addition, the difference between the results of Table 1 and Table 2 indicated shorted cables.

The vessel was scheduled for work three months following tests; that time included a cruise overseas. The question was whether the generator would be serviceable during this time. If not, the vessel would be unable to perform its mission.

A review of loads and temperatures, including the data from the EMD analysis, was performed. Based upon historical references and estimated time to failure research, it was determined that the generator could be operated in parallel with a second generator at 50% load, or less. Watchstanders were given instructions to observe for variations in current unbalance as an indicator of advanced winding failure. Recommendations were provided to the vessel's shore engineering support group for the storage of rotating machines and generators.

GENERATOR REPAIR

The generator was removed for repair (Fig. 6) and shipped to the contracted repair shop.

Figure 7. Generator Removal

Repair requirements included complete rewind of the stator and rotor with approved overtime in order to meet the vessel's shipyard schedule. Acceptance inspections were performed at the repair center's site under load.

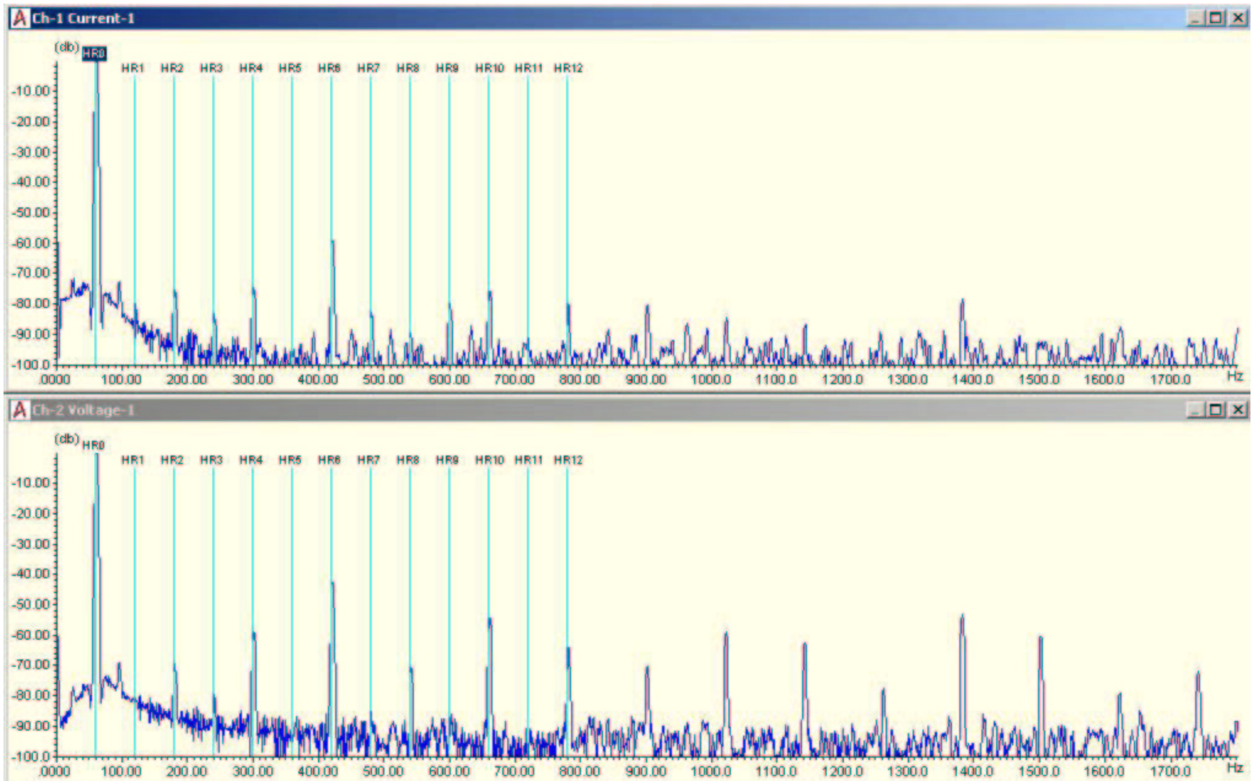

Figure 8. Acceptance ESD Test

Several details on the repair were determined during the inspection:

1. The lead wire was reduced in size. This increases the heat-related losses at the leads and restricts the maximum current capability of the generator.
2. The winding conductors were increased in size. While this allows the generator to operate slightly cooler, it affects the circuit enough that significant tuning was required to be able to synchronize the generator.
3. The rotating fields were not rewound as was determined by the ESA analysis. This results in a reduced reliability in the life of the generator.

CONCLUSION

ESD can be used to evaluate generators and evaluate estimated insulation life. MCA allows for the detection of insulation condition and indicates early winding shorts, while ESA allows for the detection of the electrical and mechanical systems. ESD also allows for the commissioning of repaired electric motors and evidence of proper electric machinery repair.