Time To Failure Estimation Using Motor Circuit Analysis Predictive Measurements: Part 2

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Abstract: In the first paper, the keys to the implementation of a technology for predictive maintenance and reliability and the ability to esimate how much time is left prior to equipment failure was outlined. The first part of the study was to establish a baseline for electric motor life time estimation using motor circuit analysis techniques was presented. In the second part of the study, variations of operating conditions including environment, load, cycling, and others are evaluated to fine-tune the estimation. The focus of the study is low voltage, random wound machines in a variety of environments. Additional studies are in progress for medium voltage rotating machinery.

INTRODUCTION

Electric motor winding failure occurs over time based upon a variety of conditions. In the first paper, the baseline for estimating time to failure was determined for a standard motor condition. In this paper, several of the general causes for adjustments to the time to failure esimations will be included.

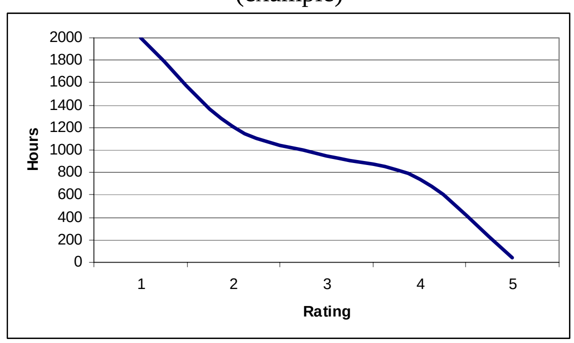
Considerations include: Environmental conditions; Load; Load variations; Severity of fault; Power supply condition; and, Mechanical condition. Estimations are based upon a survey of tested motors, and changes to condition over time, that have identified faults using MCA. In this paper, we will review the environmental conditions, load and load variations with the remainder coming in following papers.

Motor Circuit Analysis (MCA) involves low voltage measurements of resistance, impedance, inductance, phase angle, current:frequency response and insulation to ground testing. Winding condition is determined by comparing similar windings, such as one phase to another in a three phase motor, with variations identifying defects. Resistance is used to identify loose or broken connections, impedance and inductance are compared in order to identify winding contamination or overheated windings, phase angle and current:frequency are used to identify inter-turn insulation degradation, and insulation resistance is used to indentify insulation to ground faults.

WINDING CONTAMINATION

Winding contamination is identified by comparing the pattern of impedance and inductance. Impedance will decrease, and fall towards inductance, as the insulation system begins to degrade due to contamination. However, in most cases, the insulation life may be extended by removing from service, cleaning, dipping and baking (re-insulating) for a limited time after detection. As the fault progresses, it will graduate to an insulation to ground fault or winding short. The progress is, normally, insulation degradation, changes to phase angle or I/F, then failure.

Table 1: Winding Contamination Rating to Hours (example)



The ambient environment effects the progression of winding contamination degradation. Table 1 identifies a rating system applied to the detection of winding contamination when testing monthly. Statistically, it was found that the mean time to failure after fault detection progressed by a simple natural log multiplier:

Equation 1: Winding Contamination Multiplier

$$e^{-m} * Hb$$

where m = multiplier and Hb = Base Hours

The multiplier was based upon the ambient conditions (See Table 2) and the base hours on the base rating tables in Paper 1.

Table 2: Ambient Conditions

Condition	m	Description
1	0	Clean and dry. Ambient temperature < 25C.
2	0.5	Clean factory environment. Conditioned air with ambient temperature < 25C (ie: Assembly plants)
3	0.75	Medium factory environment. Variable ambient temperatures and humidity.
4	1	Harsh factory environment. Variable ambient temperatures and humidity. Enclosed motors in exterior environments.
5	N/A	Harsh environment. High humidity, high ambient and/or Acidic/basic environment. Includes motors mounted in cooling towers.

WINDING SHORTS

A variety of conditions effect the time to failure following the detection of winding shorts. Statistically, the variations in time to failure followed a simple logarithmic scale. The dominant conditions include, for the purpose of this paper:

- ✓ Motor loading
- ✓ Start/Stop cycling

Equation 2: Log Scale Used

$$M = e^{-b}$$

Where M = multiplier and b = condition variable

Motor Loading

In Paper 1, the load was based upon an average of 75%. Conditions vary, depending upon the application of the electric motor. For instance, many fan and pump applications are only loaded to about 50% of load. In other cases, the manufacturer may have included the service factor in the design of the equipment. The average motors evaluated were NEMA Design B, 1.15 service factor, TEFC.

Table 3 indicates the condition variable value applied to Equation 2 for motor loading. For instance, if a motor is loaded at 25% of nameplate rating, the resulting multiplier (M_L) would be $M_L = e^{-(-0.5)} = 1.64$.

Table 3: Load Conditions (Condition Variables)

Load	Condition Variable (b)
25%	-0.5
50%	-0.25
75%	0
100%	0.75
115%	2

Motor Start/Stop Cycling

The number of starts and stops that a motor is capable of sustaining in an hour is primarily based upon the rotor design. In the case of estimating time to failure, the start/stop frequency is based upon the stresses to the winding, both mechanically and electrically. The majority of motors reviewed in this survey were random wound. While the impact did appear to vary by motor size, for time and simplicity, we will consider a conservative cycling at 50 horsepower in an across the line starting condition.

Table 4: Start/Stop

Number Start/Stops per hour (average)	Condition Variable (b)
0.25	0.25
0.5	0.75
1	1
2	1.5
4+	2

Other Conditions

A variety of other conditions exist that create variations in the time to failure estimation. These conditions will be included in future papers.

Winding Short Multiplier

Using the days/hours found in Paper 1 as the base system (1 year = 4000 hours), an estimated time to failure can be calculated.

Equation 3: Winding Short Formula

$$M = M_L * M_S * Hours$$

Where M_L is the Motor Loading multiplier and M_S is the Motor Starting/Stopping multiplier.

Using this algorithm, a time estimation can be considered for trended equipment, in various loads and stop/start cycling environments, that has identified winding shorts using MCA.

TEST CASES

Following are several test cases using the system described in this paper.

Winding Contamination (10 horsepower)

A 10 horsepower motor in a plywood application (screen motor), operating 6,000 hours per year in a damp environment tested monthly. Winding contamination indicated in February of 2003. Applied a condition of 3 from Table 2.

Monthly time to failure estimation from Figure 1 of the first time to failure paper shows a potential life of 2000 hours. Applied to Equation 1, the estimated life of this application was:

Example 1: Winding Contamination

$$e^{-0.75} * 2000 = 945 \text{ hours}$$

The motor was removed, cleaned, dipped and baked during the following month. Winding contamination was visually confirmed.

Winding Short (150 horsepower)

A 150 horsepower motor in a paperboard application tested quarterly. A turn to turn short developed with both phase angle and I/F changing by more than 3 points between tests. The motor is started and stopped approximately twice per hour and is running at about 50% load. The motor had been tripping off-line randomly. Operates 4,000 hours per year. The base hours, from Table 3 of Paper 1 shows 335 hours as a baseline.

Example 2: Winding Short

$$e^{-(-0.25)} * e^{-1.5} * 335 \text{ hours} = 96 \text{ hours}$$

The effective time to failure was estimated to occur in just over 1 week. The motor catestrophically failed in operation within 3 weeks.

Winding Contamination (100 horsepower)

Winding contamination detected in a 100 horsepower motor which is tested every six months. The motor operates 2,000 hours per year and the insulation resistance dropped to 45 MegOhms. Ambient conditions indicated a condition 2 environment.

Example 3: Winding Contamination

$$e^{-0.5} * 1{,}000 \text{ hours} = 606 \text{ hours}$$

The motor remained in operation for close to one year prior to being removed for rewind repair.

CONCLUSION

Time estimation of electric motor life following the detection of winding contamination or developing shorts, using motor circuit analysis measurements of resistance, impedance, inductance, phase angle, current/frequency response and insulation to ground can be performed. Evaluation must be based upon averages with multipliers that indicate operating conditions.

The purpose of the estimation is to allow the diagnostic user to plan shutdowns, repairs and/or replacements. The estimation should be considered as the average time to failure and any action should be taken well within the estimated period.

ABOUT THE AUTHOR

Howard W Penrose, Ph.D., CMRP, is the President of SUCCESS by DESIGN, a reliability and maintenance services consultant and publisher. He has over 20 years in the reliability and maintenance industry with experience from the shop floor to academia and manufacturing to military. Dr. Penrose is a past Chair of the Chicago Section of the Institute of Electrical and Electronic Engineers, Inc. and is presently the Founding Executive Director of the Institute of Electrical Motor Diagnostics. For more information, or questions, related to this article or SUCCESS by DESIGN services, please contact Dr. Penrose via phone: 860 575-3087 or email: howard@motordoc.net.

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BIBLIOGRAPHY

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