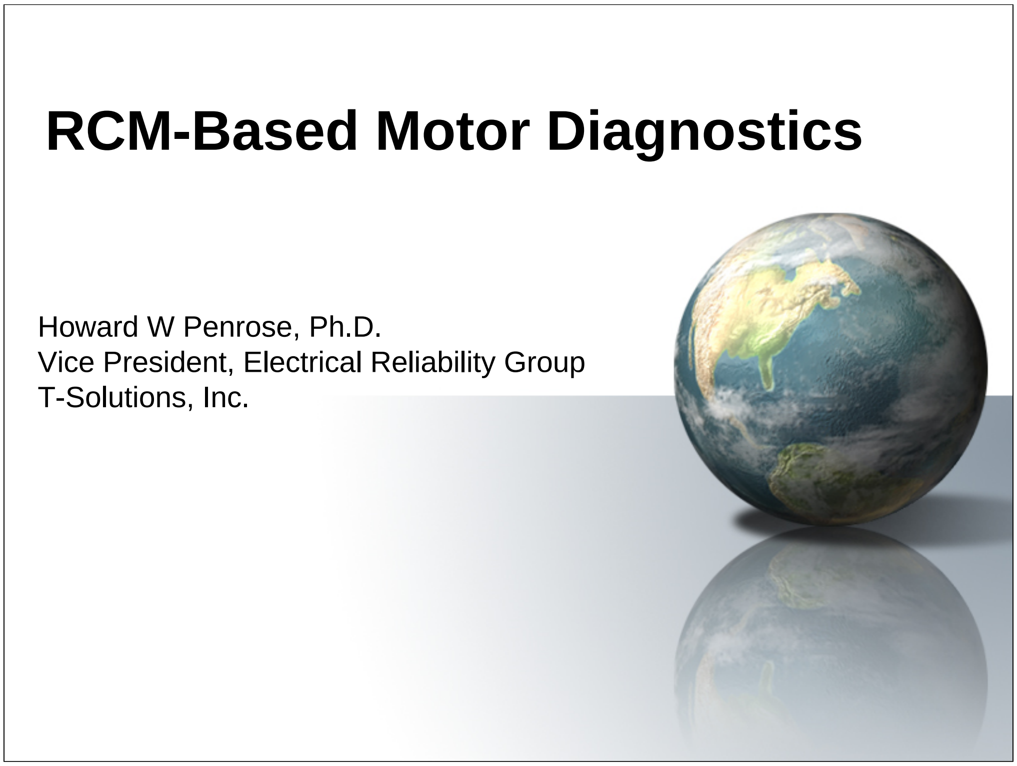


Unfortunately, due to changes in schedule resulting from weather in the Northeast, I was unable to attend this years Thermal Solutions conference.

However, I feel that the concepts behind this presentation are important our industry and industrial competitiveness in the United States.

The title of this presentation is RCM-Based Motor Diagnostics presented by Dr Howard Penrose, the vice president of the T-Solutions, Inc. Electrical Reliability Group. Dr Penrose has over twenty years in the electric motor and reliability industry from electric motor repair through advanced concepts in time to failure estimation and diagnostic techniques. T-Solutions is a military consultant for reliability and maintenance with primary clients being the US Navy and US Coast Guard, amongst others.

Importance of Motor Systems in the United States

- Energy Consumption
  - 3,848 Billion kWh of electricity in 2003
  - ~2,270 Billion kWh consumed by motor systems
  - Over 70% of energy in manufacturing and over 90% in process facilities
  - Application of basic maintenance = ~45.4 Billion kWh and ~$6.8 Billion USD nationally
  - Application of reliability program = ~317.8 Billion kWh and ~$47.7 Billion USD nationally
- Potential reduction of approximately 3000 to 5000 Mega-Tons of Combined Greenhouse Gasses

The potential impact of reliability and maintenance within the United States cannot be ignored, even from an energy and environmental consideration.

In 2003, there were 3,848 Billion kWh of electricity generated. Of this, approximately 2,270 Billion kWh were consumed by electric motor systems. Over 70% of the electrical energy in manufacturing and over 90% in process facilities.

Based upon US DOE estimates, it can be extrapolated that there is a potential of a reduction in 45.4 Billion kWh in energy and $6.8 Billion in cost reduction in energy by industry.

The application of reliability-centered programs, this potential, in energy alone, can increase to 317.8 Billion kWh and $47.7 Billion annually.

This relates to a potential reduction of 3000 to 5000 Mega-Tons of combined greenhouse gasses related to electrical energy generation annually, alone. This is all in addition to the bottom-line cost benefit to the application of a reliability-centered program.

Classical RCM Approach*

1. Set boundaries
2. Functional block diagram and partitioning
3. Functional Failure Analysis
4. Additional Functionally Significant Items
5. Failure Modes and Effects Analysis
6. Decision Logic Tree
7. Servicing and Lubrication Analysis
8. Maintenance Requirements
9. Maintenance Procedures Evaluation
10. Maintenance Task Definition
11. Inactive Equipment Maintenance
12. Unscheduled (Corrective) Maintenance
13. Development and Preparation of Procedures
14. Continuous Improvement (Backfit RCM Process)

*Navy MIL-P Std

The flavor of RCM Program that is used for an RCM-Based approach to Motor Diagnostics is the Classical RCM concept put forward by the fathers of RCM, Nowlan and Heap. This program has been adopted by the US Navy as the MIL-P-24534A, which has been in place since 1985. This standard outlines a process for the implementation of RCM. The basic steps of the standard are:

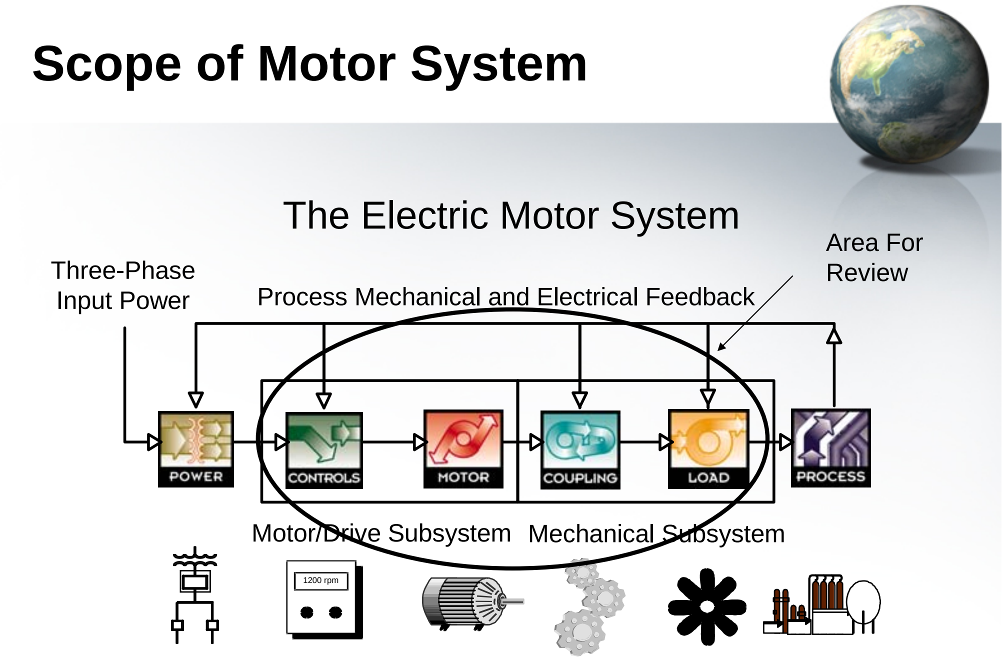
1. Set boundaries for the system being reviewed
2. Generate a functional block diagram and partitioning of the system under review
3. Determine functional failure analysis
4. Determine functionally significant items of the system
5. Perform a failure modes and effects analysis
6. Go through a logic tree in order to determine the effectiveness of maintenance tasks for the FMEA
7. Determine servicing and lubrication analysis
8. Set maintenance requirements
9. Draft and evaluate maintenance procedures
10. Define the maintenance tasks
11. Determine tasks for inactive equipment
12. Develop corrective maintenance processes and specifications
13. Develop and prepare procedures and specifications
14. Utilize continuous improvement of the RCM process, such as the Backfit process.

Case: Pump System

Due to the magnitude of the RCM process, we will be focusing on just the selection of technologies to evaluate a pump system. The result of this presentation represents the findings of the process as it relates to a condition based monitoring function of an RCM-based program. It is not meant to represent the steps of the process. However, the findings represent my personal experience with general pump systems.

It is also assumed that the pump system to be reviewed is a critical system to the process.

Scope of Motor System



The scope of the analysis will be limited to the MCC bucket through to the Driven load, in this case the pump. Therefore, we will be reviewing the components of the controls, motor, coupling and load, which will also include the cabling between the MCC and motor.

Controls

- Motor Control Centers (MCC's) and Disconnects
  - Starters
  - Overloads
- Cabling

In the MCC, the area being reviewed consists of the starter, overload and cabling supplying the electric motor. As we are focusing on CBM equipment, we will not discuss cleanliness or visual inspection which can be included as part of the data collection process.

Electric Motor

- Electrical Energy
- Mechanical Torque

The primary purpose of the electric motor is to convert electrical energy to mechanical torque. As a result, it has both electrical and mechanical components that must be considered in the evaluation.

Coupling

- Direct Drive

The coupling, in the case of this example will be a direct drive. However, even pumps can be mounted and coupled through belts, such as in this photo.

Load

- Pump

There are a large variety and design of pumps. In this case, we will consider the pump to be of a basic design consisting of a shaft, bearings, mechanical seal, impellor and housing.

MCC – Controls and Disconnects

- MCC/Disconnect Problems
  - Loose Connections
  - Bad Contacts
  - Bad PF Correction Capacitors
- Test Methods
  - ESA
  - MCA
  - Infrared
  - Ultrasonics
  - Volt/Amp Meter
  - Ohm Meter
  - Visual

For the system under review, the following potential problems consist of loose connections, worn contacts and failed power factor correction capacitors. Test methods that can be utilized to review the condition of these components include:

•Electrical Signature Analysis

•Motor Circuit Analysis

•Infrared Analysis

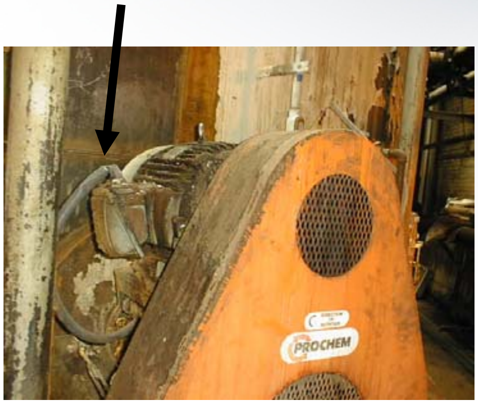
•Ultrasonics

•Volt/Amp Meter testing

•Ohm Meter testing

•Visual inspection

Cables (Before and After Controls)



- Cable Faults
  - Thermal Breakdown
  - Contamination
  - Shorts and Grounds
  - Open
  - Physical Damage
- Test Instruments
  - MCA
  - MCSA
  - Infrared
  - Insulation Tester

System cabling problems are rarely considered and, as a result, provide some of the biggest headaches. Common cable problems include:

•Thermal breakdown due to overloads or age.

•Contamination which can be even more serious in cables that pass underground through conduit.

•Phase shorts can occur as well as grounds. These can be caused by ‘treeing’ or physical damage.

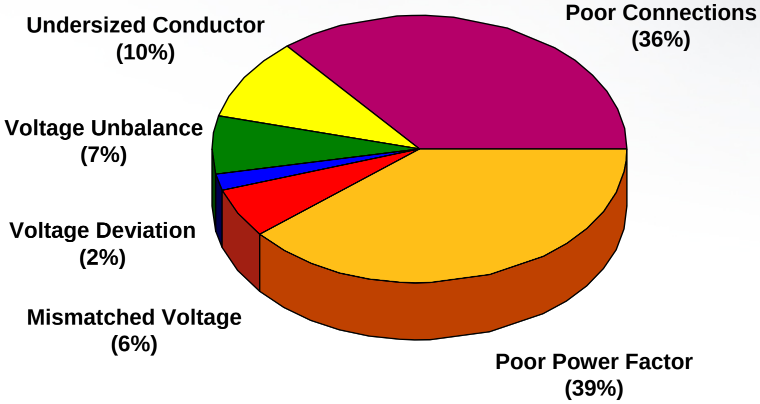
•Opens due to physical damage or other causes.

•Physical damage is often a problem in combination with other cable problems.

Test instruments include motor circuit analysis, motor current signature analysis, infrared and insulation to ground testing.

Electrical Distribution System Tune-Up

– **Improving in-plant electric power distribution systems**



Problems in the system before the electric motor can be broken down in the following order:

- Poor power factor
- Poor connections
- Undersized conductors
- Voltage unbalance
- Under or over voltage conditions

The most common equipment that covers all of these include motor circuit analysis, motor current signature analysis and infrared analysis.

Electric Motor

- Mechanical Faults
  - Bearings
  - Bad Shaft/Brg Housing
  - Vibration
- Mech Fault Testing
  - MCSA
  - Vibration
  - Infrared
  - Ultrasonics

Electric motors include mechanical and electrical components. The first review is mechanical.

The primary mechanical problems include:

•Bearings

•Bad or worn shaft or bearing housings

•Vibration issues

Each of these can be detected using:

•Motor current signature analysis will detect the more severe problems.

•Vibration analysis will detect the faults earliest but requires a fair amount of experience.

•Infrared will detect problems when they are severe.

•Ultrasonics will detect the more severe problems

Electric Motor

- Electrical Faults
  - Winding Shorts
  - Insulation to Ground
  - Contamination
  - Air Gap Faults
- Winding Tests
  - MCA
  - MCSA
  - Vibration
  - Megger
  - Hi-Pot, Surge Test
  - Ohm-Meter
  - Volt/Amp Meters
  - Ultrasonics
  - Infrared

Electrical faults include:

•Winding shorts including turn to turn and coil to coil

•Insulation to ground faults

•Winding contamination

•Rotor faults including casting voids and broken rotor bars

•Air gap faults including an eccentric rotor

The winding tests to detect these problems include:

•MCA and MCSA will detect all of the faults

•Vibration will detect late-stage faults

•Insulation to ground will only detect ground faults

•Surge testing will only detect winding shorts in the first few turns of the winding

•All other testing will only detect late stage faults.

Coupling (Direct and Belted)

- Faults
  - Misalignment
  - Insert Wear
- Test Instruments
  - MCSA
  - Vibration
  - Infrared

The coupling between the motor and load also has faults due to wear and application:

•Direct drive misalignment

•Insert wear

The most accurate system for fault detection is vibration analysis then motor current signature analysis then infrared analysis.

Load (Fans, Pumps, Compressors, Gearboxes, Etc.)

- Load Faults
  - Worn parts
    - Seals
    - Impellor
    - Bearings
- Test Instruments
  - MCSA
  - Vibration
  - Infrared
  - Ultrasonics

The primary load faults are worn parts such as the seal, bearings and impellor

Test instruments capable of testing load problems include:

•MCSA

•Vibration

•Infrared Analysis, and

•Ultrasonics

Motor System Diagnostic Technology Comparison

	PQ	Cntrl	Conn	Cable	Stator	Rotor	Air Gap	Brgs	Ins	Vibe	Align	Load	VFD
Off-Line Testing													
High Potential Testing	-	-	-	-	-	-	-	-	X	-	-	-	-
Surge Test	-	-	-	-	X	-	-	-	-	-	-	-	-
Insulation Tester	-	-	-	-	-	-	-	-	X	-	-	-	-
Ohm Meter	-	-	L	-	L	-	-	-	-	-	-	-	-
PI Testing	-	-	-	-	-	-	-	-	X	-	-	-	-
MCA Test	-	X	X	X	X	X	X	-	X	-	-	-	-
On-Line Testing													
Vibration Analysis	-	-	-	-	L	L	L	X	-	X	X	X	-
Infrared	X	X	X	L	L	-	-	L	-	-	L	L	-
Ultrasonics	-	L	-	-	L	-	-	X	-	-	-	L	-
Volt/Amp	L	L	L	-	L	L	-	-	-	-	-	-	-
ESA	X	X	L	-	L	X	X	L	-	X	X	X	L

X = Yes; L = Late stage faults/Limited detection; - = No

This table provides an overview of the capabilities of each of the technologies. As noted, some of the technologies provide a broader capability than others. You must also consider that some manufactures of the technologies have greater or lesser capabilities than those listed here.

Selected MD Technologies to Meet Dominant Failure Modes

- MCC: Infrared and ESA
- Cables: Infrared and MCA
- Motor, Mechanical: Vibration (ESA)
- Motor, Electrical: MCA (ESA)
- Coupling: Vibration (ESA)
- Load: Vibration (ESA)

Following a review of the most effective technologies for the largest areas of consideration of this system, including which technologies are cross-cutting, the following can be determined:

MCC – Infrared and ESA

Cabling – Infrared and MCA

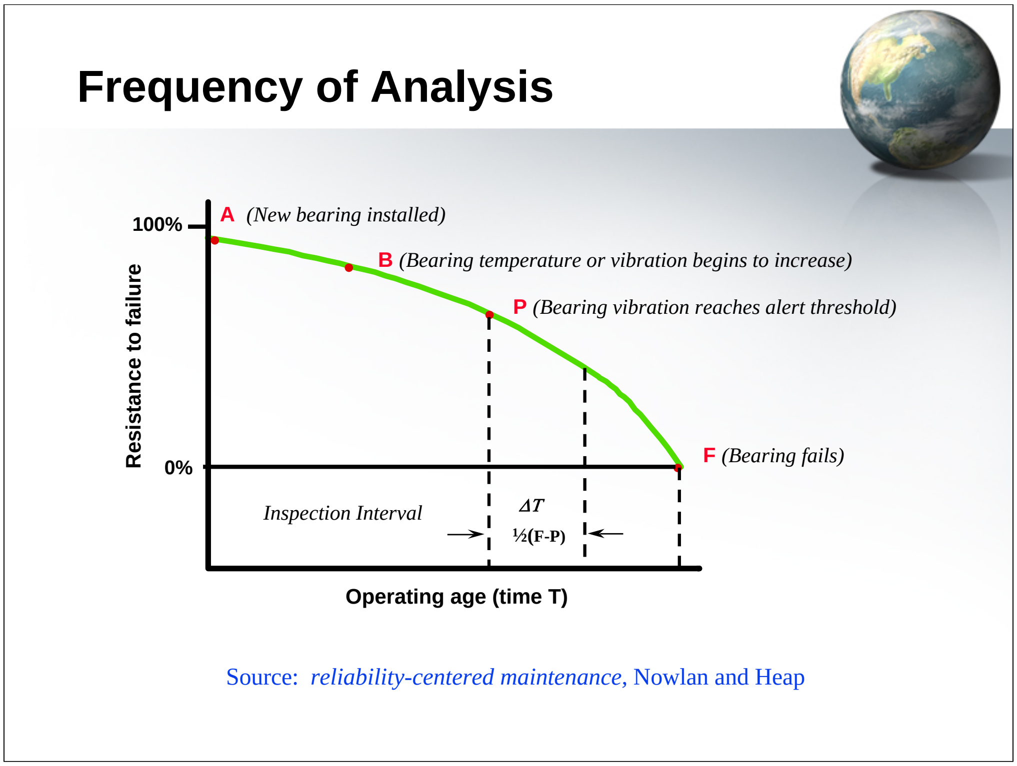
Motor, Mechanical – Vibration and incidental ESA

Motor, Electrical – Vibration and incidental ESA

Coupling – Vibration and incidental ESA

Load – Vibration and incidental ESA

As a result, the optimal instrumentation for reviewing this system are: Infrared, ESA, MCA and Vibration.



The optimal frequency for testing is based upon the time to failure. With a new component, the resistance to failure is very high, in this case, a bearing. As time continues and the bearing begins to break down, the temperature and vibration increases. At some point before failure, the vibration level will reach some threshold.

The optional periodicity is half the detection point to failure point time. If we are unaware of this amount of time, we must consider the detection capability of the technology and average time to failure following fault detection.

Conclusion

- Infrared of Controls and Cabling Connections Quarterly
- ESA from MCC Quarterly
- MCA from MCC Quarterly as equipment can be de-energized
- Vibration on Motor and Pump Quarterly

- Backfit RCM following 18 months

The conclusion from this example would be to perform an infrared inspection of controls and cabling connections quarterly; Perform ESA from the MCC quarterly; MCA from the MCC quarterly, and as equipment can be de-energized; Perform vibration on the motor bearings and pump quarterly. In addition, stagger the tests in such a way to increase the frequency of inspection, should this be a critical or safety related system being tested.

Perform a backfit RCM following about 18 months in order to confirm the effectiveness of the program or to schedule improvements to the program.

T-Solutions, Inc.
135 Hanbury Rd, Suite C-1
Chesapeake, VA 23320

ph: 757-410-0233/0350
fax: 757-410-7809

Website:
http://www.tsoln-inc.com

Howard W Penrose, Ph.D.
Vice President, Electrical Reliability Programs
hpenrose@tsoln-inc.com
Ph/fax: 860-577-8537

Thank you for your time!