Motor Diagnostic and Motor Health Study
Executive Summary

Howard W. Penrose, Ph.D.
ALL-TEST Pro, A Division of BJM Corp

Terry O'Hanlon, CMRP
ReliabilityWeb.com

Introduction

Electric motors are the prime movers of all industrial nations. Electrical energy can be relatively simple to generate, efficient to distribute, and safe to transform to other types of energy such as heat and torque. The reliability and efficiency of electric motor systems is directly related to the condition of the electric motor electrical and mechanical systems.

Until the mid-1980's, few technologies were capable of evaluating the condition of electric motor windings and rotors. New electronic instruments became available to perform energized and de-energized evaluation of electric motor condition with each of the manufacturers providing different capabilities and price ranges. Through the 1990's, several of the de-energized technologies became obsolete and several energized systems were added. Energized testing came to be known as Motor Current Signature Analysis (MCSA), de-energized testing as Motor Circuit Analysis (MCA) and both were presented under the umbrella term of Motor Diagnostics.

The motor diagnostic technologies, MCA and MCSA, are actually two completely different technologies with different focus'. In addition, the different MCA and MCSA technologies, themselves, are not similar to each other and have different strengths and capabilities. Initial costs vary dramatically, and have little relation to the capabilities of one technology over the other.

With each manufacturer presenting their technology in their own light, marketing as opposed to technical capability became the primary driver for the application of the technologies. No direct research had been performed as to the end-users' perception of technology. This has created confusion and misunderstanding between the manufacturers and end-users. It became readily apparent that research needed to be performed and a roadmap developed, to continue the penetration of motor diagnostic technologies within the industrial environment.

The purpose of this paper is to provide an overview of the study and its implications to the marketplace. It is not the goal or aim of the study to select the 'best' equipment, but to provide information to promote the implementation of motor diagnostics within industry. The study, itself, consists of a literature review of related third-party field studies, a survey of end-user perceptions, conclusions and a Motor Diagnostic Technology Roadmap to assist motor owners in the implementation of motor diagnostic technologies.

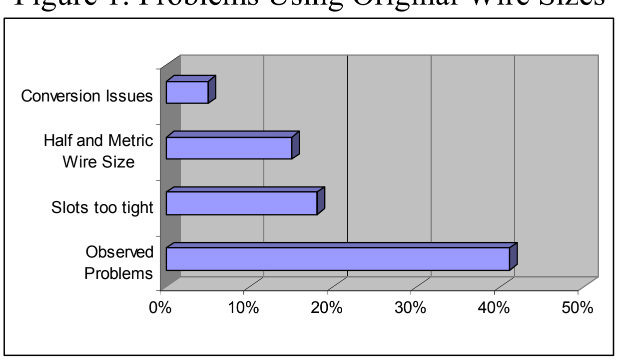
The project was a joint effort of the Reliabilityweb.com web site and MaintenanceBenchmarking.com web site, both of NetExpressUSA, Inc., SUCCESS by DESIGN Publishing (SBD) and BJM Corp. SBD performed the literature review and co-developed the questions with NetExpressUSA. NetExpressUSA provided the means to perform the motor owner survey online. NetExpressUSA and BJM Corp provided the email lists to prompt motor owners to perform the survey. SBD compiled the study and performed detailed analysis of the survey with overview from NetExpress USA and BJM Corp. The survey respondents made up an exceptional 2% of the emailed requests. The literature review was a compilation of US Department of Energy, Academic and Utility research projects starting in 1995.

The Literature Review

The literature review consisted of seven US Department of Energy, Academic and Utility field research studies. These parts consisted of:

- ✓ A review of the electric motor repair industry – Bonneville Power Administration (1995)
- ✓ Electric motor system market transformation strategies – US Department of Energy (1996)
- ✓ Motor Management program development – KWU (1997)
- ✓ Industrial motor system market opportunities – US Department of Energy (1998)
- ✓ In service motor testing – WSU (1999)
- ✓ Industrial assessments for improved energy, waste stream, process and reliability – KWU (2000)
- ✓ Electric motor performance analysis tool demonstration project – PG&E (2001)

Figure 1: Problems Using Original Wire Sizes



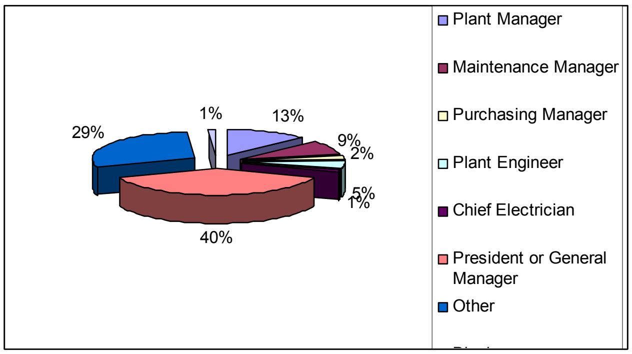
In the first review, it was found that 81% of the motor repair centers changed the winding configuration from the original. 37% of the repair shops changed the windings due to shop preference and 36% for ease of winding. Not all of the changes will have a negative impact on efficiency and reliability. However, reducing wire size or incorrect re-design will change the losses of the motor which will reduce the reliability of the motor through increased current and temperature during operation. It is important to have MCA readings of the motor when it is in good condition to compare to the post-repaired windings to determine if negative changes have occurred. This is termed as commissioning the repaired electric motor. By finding issues prior to re-installation or storage, warranty issues can be addressed without the lost time related to installation and removal.

The market transformation strategy study provided evidence that process improvements and efficiency directly relate to reliability. However, the study was a review of energy efficient motor systems and did not identify reliability as the primary driver of a motor system program.

The motor management program project reviewed motor circuit testing reliability, motor and component life estimation, and the application of motor maintenance and reliability centered maintenance within industrial plants. It determined that motor management programs that combine PM and PdM programs will provide profitable returns on investment. One of the key findings that relates to the MDMH was that use of a combination of instrument technologies support the strengths of each allowing for a more complete view of the system being tested.

The electric motor system market opportunities assessment determined the general level of purchase and motor system decision making. It also found that the primary resource that was lacking was not funding but manpower. Most maintenance and reliability programs have a limited focus on energy. The priority of facilities management and maintenance staff was to ensure continuity of mechanical operations. During the study, it was very difficult for facility management to provide personnel for the study.

Figure 2: Person Who Makes Motor System Decision (US DOE Study)



The in-service motor testing study assessed the general interest in on-site motor testing with an emphasis on motor efficiency. However, the requirements were parallel to requirements for general diagnostic equipment:

- ✓ The test should be non-invasive and convenient. Invasive was determined as being required to de-energize equipment for a significant period of time or uncoupling/disconnecting equipment.
- ✓ Equipment must be simple/easy to use and hand-held.
- ✓ It must provide reasonable, accurate results, and,
- ✓ The equipment must be cost effective.

Another comment on the study was that when the industrial sites stated that they were unable to shut down equipment prior to the site visits, no work was performed. It was assumed that the ‘unable to shut down’ perception was correct.

The industrial assessments study found that the perception that 24/7 operation meant no access for testing and evaluation was incorrect. In general, system redundancies and periods where the equipment was not required for production was found in all cases for testing purposes. Equipment ease of use and ease of interpretation was determined as necessary for actual successful application due to manpower and training limitations. Plant reliability was found to have a tremendous impact on the profitability of the company. Recommended motor-system related technologies included: Vibration analysis; Infrared technologies; and, Motor circuit analysis.

The electric motor Performance Analysis Testing Tool (PATT) demonstration project was the first project of its type to specifically review motor diagnostics as part of an energy and condition analysis. The study was funded by Pacific Gas & Electric, the initial review and selection of equipment, as well as the program plan, was developed by the University of Illinois at Chicago’s Energy Resources Center (UIC-ERC), the program was then contracted through Flowcare Engineering and, later, Newcomb Anderson Associates. It involved a review of technology for energy data collection, motor diagnostic equipment review, development of a program, field testing of the program and development of training material. The program considerations were, in order of importance:

- ✓ It had to be easy to implement (ease of use)
- ✓ Marketable by program volunteers (repair and field service companies and consultants)
- ✓ The initial cost to implement had to be considered reasonable, including the purchase of tools.
- ✓ It had to be the least invasive approach as possible with the other considerations

The equipment and software considerations were, in order of importance:

- ✓ Initial cost
- ✓ Training requirements
- ✓ Ergonomics (hand-held)

- ✓ Accuracy
- ✓ Least intrusive

Training for the complete program had to be able to be completed within three business days, including use of the selected equipment and software. The equipment selected, to meet the requirements, were:

- ✓ MotorMaster Plus (US Department of Energy) software with maintenance modifications funded by BJM Corp, Dreisilker Electric Motors, Inc. and Pruftechnik.
- ✓ Pruftechnik vibration analyzers – hand held, easy to use and least cost.
- ✓ ALL-TEST IV PRO 2000 motor circuit analyzer – hand held, easy to use and least cost.
- ✓ Fluke 41B and Powersight 3000 – hand held, easy to use and already available through PG&E

Other technologies, including infrared, were considered but, due to constraints, determined to be used in a systems phase of the project as the PATT program was limited to the motor only.

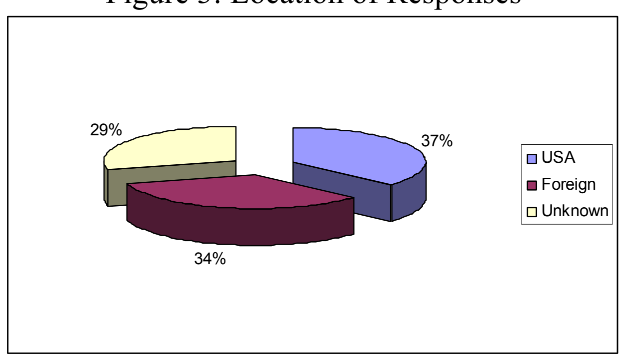
Findings of the PATT project were exceptional. First, a majority of the motors determined to have maintenance issues, had electrical issues with a minority having mechanical issues. Second, it was proven that the concept of not being able to de-energize equipment was incorrect. In all but one case, the 24/7 facilities were able to de-energize equipment on demand or within a few minutes of request during the project when, at the beginning of the project, management was under the impression that the equipment could not be de-energized. A direct correlation between energy and reliability was established and, in plants that had a PdM program in place, 14% of motors had some type of maintenance issue while all other plants had greater than 19% of motors with issues. The incremental cost of a sampling of the motors showed a $297,000 in avoidable unplanned downtime per year for five years.

Through the literature review, the conclusions from each of the studies supported each other. Another common thread was that 'initial cost' was an issue. However, the combined perceived need for testing and reliability far outweighed the cost issue. The 'initial cost' and 'unable to shut down' comments appeared to be used to slow or prevent further action, as was proven in the PG&E and industrial assessment studies. Once past these issues, the programs moved quite easily and with tremendous results. The potential support for a program seemed to be more of the development of a business case to qualify the use of the real currency: Manpower. Is the business willing to invest in manpower to improve product throughput and cost per unit of production?

MDMH Electric Motor Testing Best Practice Survey Findings

Through April and May, 2003, a survey was presented and co-sponsored by: NetExpressUSA; BJM Corp and SUCCESS by DESIGN Publishing. The survey consisted of 23 key questions and a twenty-fourth requesting information on the respondent. The questions were designed to allow closer study of the answers to provide a deeper understanding of motor owner perceptions of motor diagnostics.

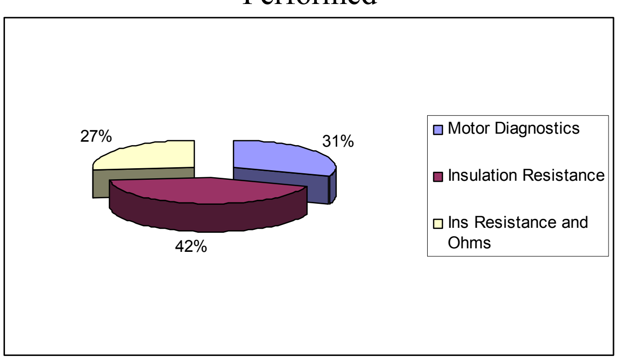
Figure 3: Location of Responses



The initial answers displayed on the MaintenanceBenchmarking.com (used for the survey) website were very interesting. However, once the data was reviewed more closely, the answers changed dramatically. For instance, a majority of the 68% of companies that stated they had a motor diagnostic system in place actually viewed insulation resistance, ohm/milli-ohm readings, voltage and current readings and visual inspections as motor testing. This 68% identified that only 45% of companies applying motor diagnostic technologies were seeing a return on investment. In reality, 19% of the survey were actually using MCA and/or MCSA with an expected return on investment response of over 90%. 78% of the companies not using motor diagnostics were not seeing a return on investment. This means that the 'traditional' methods of motor testing were not cost effective. The survey respondents were made up of virtually every industrial type including the service, consulting, waste water, government and commercial building industries.

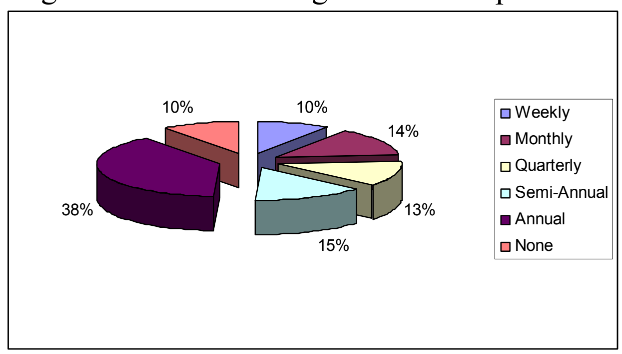
Another key point was the initial cost issue. The minority, 23%, selected initial cost as the only issue preventing the application of motor diagnostic technologies. 28% viewed initial cost and at least one other issue, and 49% viewed other issues, with manpower being the majority in both instances. This supported the findings of the field studies.

Figure 4: Claim Motor Winding Tests Performed



The number of critical motors followed a classic bell curve with the peak covering the 50 to 100 critical motors per plant range with the peak number of facilities having unplanned downtime costs of $10,000 per hour. Of the plants within the survey, the 24/7 operation plants made up 66% with most, 90%, having scheduled shutdowns for maintenance (Figure 5). The shutdown schedules were not specific to any particular industry.

Figure 5: Planned Outages for 24/7 Operations



The perceived need for both on and off-line testing varied by the number of shifts with a majority of each varying between one shift to 24/7 operation. In each case, a combination of on and off-line testing was a majority (73%), of which combined on and off-line technologies are addressed by two of four motor diagnostic manufacturers, most of which use a combination of portable laptop and case and one being hand-held.

Fewer than 2% of the respondents viewed energy as a primary driver for motor diagnostic technologies. This was important as energy was determined to be a good metric as to the success of a maintenance and reliability program in the literature study programs.

A few of the respondents provided advice for companies beginning a motor program. These had some general tendencies with the following noticed:

- ✓ Of those that mentioned specific manufacturers, one stood out as requiring training, dedicated personnel and a long learning curve (portable) and one stood out as not having training, dedicated personnel or a learning curve mentioned (hand held).
- ✓ Pre-planning and equipment selection based upon needs.
- ✓ Stay with the program.
- ✓ Purchase equipment intelligent and simple enough to avoid the need for a dedicated operator.
- ✓ Start with a few critical motors then grow the program.

Another issue became very clear through the survey: The definition of motor diagnostics and its sub-groups needed to be determined. Therefore, the following definitions were developed based upon respondent perceptions:

- ✓ Motor Diagnostics: Tools, instruments and software applied to trend or evaluate the condition of an electric motor's electrical and mechanical environment. This definition will be used to cover all methods of rotating machinery testing.
- ✓ Mechanical Motor Diagnostics: Vibration, Infrared and Ultrasonics, for instance, will be covered under this sub-group. Each of these tools detect, primarily, the mechanical condition of the rotating machinery with some ability to detect and identify electrical issues. This definition covers those instruments and software capable of BOTH trending and diagnosis of faults through either a single set of readings (diagnosis) or a series (trending) that is repeatable.
- ✓ Electrical Motor Diagnostics (Termed only as Motor Diagnostics for title of this study): Motor circuit analysis and motor current signature analysis only. These tools are designed to, primarily, detect the electrical condition of the motor's electrical environment either energized or de-energized.
- ✓ Test Motor Diagnostics: Multi-meters, insulation to ground testing, surge comparison testing, and similar testing used to evaluate individual components of the electric motor's condition. These test tools can also include micrometers, growler (rotor) testing, bar to bar tests (DC machines), etc. Generally, equipment used to check the condition of rotating machinery that will not necessarily be trend-able or repeatable.
- ✓ Motor Circuit Analysis (MCA): Electrical Motor Diagnostics of de-energized rotating machinery. At the time of this study, there are two manufacturers of MCA devices that use very different approaches. One is a portable (brief case and lap top) RCL-based instrument, relatively expensive, and provides readings of resistance, inductance, capacitance and a battery of insulation to ground tests. The other is a hand-held impedance based instrument, communicates with computer software, is relatively inexpensive, and provides readings of resistance, inductance, impedance, phase angle, current/frequency response and insulation to ground testing. The portable instrument requires a great deal of training and experience while the hand-held instrument can usually be applied in a few hours of self-training (Findings of UIC-ERC study). The primary benefits of MCA include: Safety of de-energized testing (reference NFPA 70E and OSHA for flash protection in energized systems); The ability to isolate the condition of just the components being tested with little to no interference from the outside environment. This allows the ability to troubleshoot individual components.
- ✓ Motor Current Signature Analysis (MCSA): Electrical Motor Diagnostics of energized rotating machinery. At the time of this study, there are four MCSA instruments on the market. Three are portable (brief case and lap top) and one is hand-held. All are

three-phase instruments but approach the ability to evaluate the condition of equipment differently. All generally range above $23,000 USD, with the exception of the hand-held instrument. The primary difference in the instruments is demodulation. One method relies upon Torque Demodulation, one on Current Demodulation, and the hand-held and other rely upon a combination of Voltage and Current Demodulation. Each tool requires more extensive hardware/software and diagnostic training and safety during data collection is a primary consideration. Several of the manufacturers provide permanently mountable ports that can be located on the door of the MCC/disconnect cabinet.

Additional information on the study and motor diagnostic equipment manufacturers can be found on www.reliabilityweb.com.

Project Conclusions

The conclusions follow three parts: Motor diagnostic equipment manufacturers; End-User/Motor Owner Conclusions; and, Survey conclusions. Each work together to set up a roadmap for implementation of motor diagnostic technologies into industry.

The primary conclusions for motor diagnostic equipment manufacturers, echoed in both the literature review and survey, are:

- ✓ Equipment must be easy to use.
- ✓ Hand-held equipment is preferred.
- ✓ A short learning curve.
- ✓ Accurate.

End-users/motor owners need to plan and review their existing program then select the best technology to fit their needs. In most cases, the most cost effective equipment will pay itself back immediately with the detection of existing electrical defects. There are a number of questions that the end user must review prior to making a motor diagnostic equipment purchase:

- ✓ What are the training requirements? How much time will have to be invested in learning the equipment and software?
- ✓ What is the setup time per motor?
- ✓ What are the annual costs? Is there an annual maintenance fee associated with the equipment? What are calibration and repair costs associated with the equipment?
- ✓ Are there technical support fees? What is the technical/motor system background of the technical support staff (D&B ratings can be very helpful here)?
- ✓ Are there fees for software updates? What are the associated costs? Will the software maintain equipment history from previous versions?
- ✓ Are there fees for equipment updates? What are the associated costs?
- ✓ How much information does the equipment require to perform an analysis? Motor nameplate? Number of rotor bars and stator slots? Load information? Operating speed? No information required? And, How easy is the information to obtain?
- ✓ How long does it take to complete a test? Is the data analysis automated? Are the diagnostic rules straight-forward and applicable?
- ✓ Does the equipment require a constant load during testing? What load? How long must this level be maintained?
- ✓ Can the test be performed from a distance (ie: motor control center or disconnect)? Will it detect cable and other circuit problems?
- ✓ If a suspicious unbalance is detected, does it require rotor testing or more extensive time testing to confirm if a fault exists?
- ✓ Will the equipment operate successfully in the plant electrical environment? Will it allow frequencies other than 50/60 Hertz

systems to be tested without compromising fault detection?

The actual primary issues to the application of motor diagnostic technologies were training and manpower. Resources must be in place to successfully implement the program.

Another primary driver for the implementation of a program should be new and repaired motor commissioning. This can be performed quickly using MCA technologies before installation or storage saving an average of three hours for each fault detected.

The survey found that the market has less than 19% penetration of motor diagnostic technologies. Maintenance earnings can be very significant through avoiding process downtime related to the motor system. When reviewing motor diagnostic technologies, the following should be considered:

- ✓ Selection of the best MCA equipment to commission new or repaired equipment.
- ✓ Types and variety of equipment that the instrument can test and the repeatability of the test.
- ✓ Plan what equipment will be tested and who will be responsible. Stopping the program while it is in the early stages will destroy the benefits of the program.
- ✓ Determine and schedule training needs.
- ✓ Obtain management and employee buy-in to the program.
- ✓ Partner with your motor repair and new equipment vendors.

Finally, as found in both the literature review and survey, initial cost and being unable to shut down equipment perceptions tend to be methods of stalling the implementation of motor diagnostic technology. In reality, these are not primary factors that should be preventing application of technology. The real question is: If you have access to a technology that will increase product throughput, improve cost per unit of production and reduce maintenance headaches with an immediate return on investment, why have you not implemented a motor diagnostic and motor maintenance program yet?

Bibliography

Penrose, Howard W., Ph.D. and O'Hanlon, Terrance, Motor Diagnostic and Motor Health Study, SUCCESS by DESIGN Publishing, ISBN: 0-9712450-9-6, July 2003.

About the Authors

Howard W. Penrose, Ph.D is the General Manager for the BJM CORP ALL-TEST™ Division, a manufacturer of Motor Circuit Analysis equipment. He has over 20 years in the electric motor and reliability industry starting as an electric motor repair journeyman in the US Navy to leading Motor System Maintenance and Management programs within the industry for service companies, the US Department of Energy, utilities, states, and many others. Dr. Penrose spent several years with the University of Illinois at Chicago teaching Industrial Engineering and performing energy, reliability, waste stream and production industrial surveys in a variety of industrial facilities as part of the UIC Energy Resources Center. Dr. Penrose is the Vice Chair of the Connecticut Section IEEE, a past Chair of the Chicago Section of IEEE, past Chair of the Chicago Section IEEE Power Electronics and Dielectrics and Electrical Insulation Societies, has numerous published research papers and books, and is a trained vibration analyst, infrared analyst, and motor circuit analyst. Additional information on Motor Circuit Analysis, can be obtained by contacting Dr. Penrose at 860 399-5937 or email: hpenrose@bjmcorp.com.

Terrance O'Hanlon, CMRP is the President of NetExpressUSA Inc., a new Media publishing company and the Publisher of Reliabilityweb.com. He is a certified Maintenance and Reliability Professional and is the Director of Strategic Alliances for the Society for Maintenance and Reliability Professionals (SMRP). Mr. O'Hanlon is also a contributing editor for Maintenance Technology Magazine as well as a frequent contributor for other prestigious publications such as Machinery Lubrication, MRO Today, Chemical Processing, Practicing Oil Analysis, Industrial Maintenance (UK) and the Maintenance Journal (Australia). He is the event manager for IMC-2003, www.imc-2003.com the 18th International Maintenance Conference, December 7-10, 2003, in Clearwater Beach, FL.