



# Motor Diagnostic and Motor Health Study

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In this presentation, we shall cover the Motor Diagnostic and Motor Health Study.

BJM Corp is a submersible pump and motor test equipment manufacturer. Established in 1983, BJM introduced the first motor circuit analysis instruments in 1985. The instruments are hand-held, simple to use and cost effective showing immediate ROI's in virtually any application.

Dr. Howard W. Penrose is the General Manager of BJM Corp's ALL-TEST Pro Division with 20 years in the electric motor system industry from motor repair to advanced research in electric motor systems.

# Electric Motors In Industry

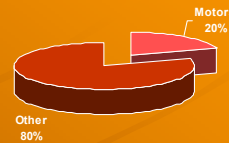
## ◆ Motor Systems Use

- 20% of all energy
- 57% of electrical energy
- 70-90% of Process Industry Energy

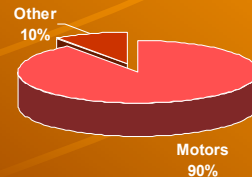
## ◆ Motor Population

- 1.2 billion in USA
- 96% are <5 hp
- 2.5% are 5 to 25 hp
- 1.5% > 25 hp and uses 60% of motor energy

% of All Energy in USA Consumed by Motors



Motor Energy in Process Industries

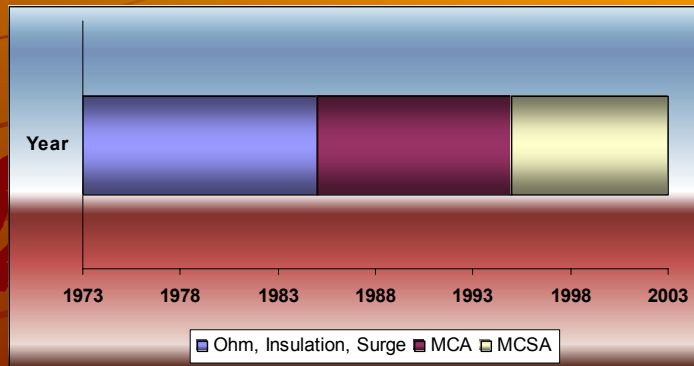


How important are electric motors?

Electric motors are the prime movers of industry in any industrial country. In North America, electric motors consume about 20% of all energy used in the USA, 57% of all energy generated and over 70% of the electrical energy in manufacturing. Motors in most process industries consume approximately 90% of the electricity used by the plant.

In 1997, there were over 1.2 Billion motor in the USA. 96% were under 5 horsepower, 2.5% are from 5 to 25 horsepower, and the remaining 1.5% are over 25 horsepower. The motors over 25 horsepower consume approximately 60% of motor energy.

# History of Motor Diagnostics



Prior to 1985, several methods were commonly used to evaluate the condition of electric motors: Insulation resistance testing – troubleshooting and periodic testing; High potential testing and surge comparison testing for manufacturing and repair; Ohm testing for phase resistance balance. The primary focus was to evaluate the insulation to ground condition of the insulation system with limited testing between conductors.

In 1985, off-line motor circuit analysis technologies were made available with the presentation of the ALL-TEST II analog device. It was designed to detect winding shorts as well as insulation to ground faults in AC and DC electric motors. Other technologies followed, however none included test capabilities that were similar to the ALL-TEST's phase angle and current-frequency response test.

The 1990's provided for the introduction of on-line motor current signature analysis machines. These were designed for testing low voltage systems while they were operating and, originally, were set up for evaluating the condition of electric motor rotors only. As the 1990's progressed, additional work in the area of the detection of power quality, mechanical and driven load expanded the capabilities of these MCSA devices. In 2003, ALL-TEST introduced the ALL-TEST Pro MD™ system which includes the award-winning off-line ALL-TEST MCA instruments, the on-line ALL-TEST Pro OL™ MCSA system and the EMCAT MD™ software package.

## Motor Diagnostic and Motor Health Study

### ◆ Collaboration

- NetExpressUSA: Reliabilityweb.com and MaintenanceBenchmarking.com
- ALL-TEST Pro, BJM Corp
- SUCCESS by DESIGN Publishing

### ◆ Respondents = 2% of emailed requests

### ◆ Included studies starting in 1995

The MDMH study was a joint effort of the ReliabilityWeb.com web site and MaintenanceBenchmarking.com web site, both of NetExpressUSA, Inc., SUCCESS by DESIGN Publishing and BJM Corp's ALL-TEST Pro division. SUCCESS by DESIGN performed the literature review and co-developed the questions with NetExpressUSA. NetExpressUSA provided the means to perform the motor owner survey online. NetExpressUSA and ALL-TEST Pro provided the email lists to prompt motor owners to perform the survey. SUCCESS by DESIGN compiled the study and performed detailed analysis of the survey with overview from NetExpressUSA and ALL-TEST Pro.

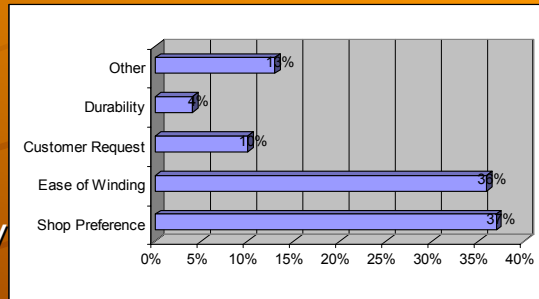
The survey respondents made up an exceptional 2% of the emailed requests, 2-8 times the average survey response. The literature review was a compilation of US Department of Energy, Academic and Utility research projects starting in 1995.

These included:

- A review of the electric motor repair industry by Bonneville Power Administration in 1995
- Electric motor system market transformation strategies by the US Department of Energy in 1996
- Motor Management program development by KWU in 1997
- Industrial motor system market opportunities by the US Department of Energy in 1998
- In service motor testing by Washington State University in 1999
- Industrial assessments for improved energy, waste stream, process and reliability by KWU in 2000
- Electric motor performance analysis tool demonstration project by PG&E in 2001
- EPRI Advanced Electric Motor Predictive Maintenance Project reviewed by the MDMH study in 2003

# Review of Electric Motor Repair Industry: BPA and WSU 1995

- ◆ 81% of shops change windings
- ◆ Possible Increased I<sup>2</sup>R losses and reduced reliability
- ◆ Commission repaired motors

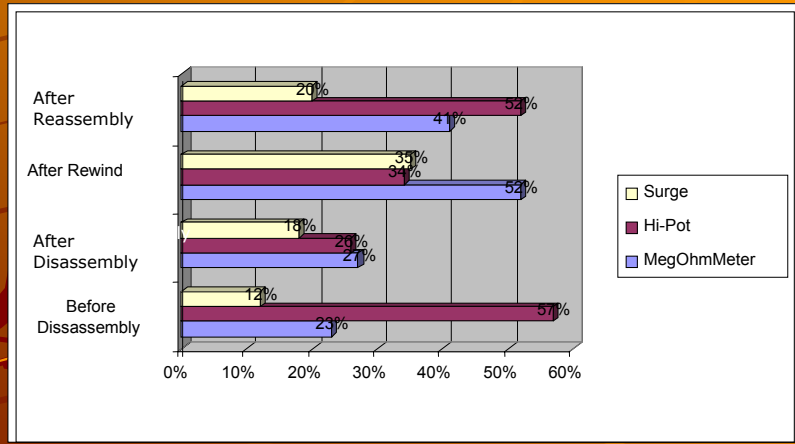


We shall cover a few of these studies in this presentation. The complete MDMH study is available through [ReliabilityWeb.com](http://ReliabilityWeb.com).

In the first review, it was found that 81% of the motor repair centers changed the winding configuration from the original. 37% changed the windings due to shop preference and 36% for ease of winding with only 4% modifying winding design for reliability.

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 (I<sup>2</sup>R losses) 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.

# Before and After Verification from Repair Shops



Surprisingly few electric motor repair shops perform winding analysis, let alone insulation to ground testing through repair. The best way to ensure that the testing is being performed, is specify testing as part of the repair. An excellent base-standard can be found on the Electrical Apparatus Service Association website, [www.easa.com](http://www.easa.com) – the ANSI/EASA R100-1998 standard. It will provide a guideline in which you may want to specify additional pass/fail requirements and reporting requirements. Additional information relating to quality motor repair practices and EASA member shops in your area can also be found there.

One of the primary methods for evaluating winding condition by electric motor repair shops is the surge test. This test uses twice the nameplate voltage plus a thousand volts pulsed out to the winding and reads the 'ringing' reflection on a scope. Windings are compared and unlike sine-waves identify a fault. Surge testing is similar to doubling the compressed air in your compressed air system, it will find faults, but may cause a few in the bargain. Additionally, per the 2003 EPRI AEMPM study, surge testing will only detect winding faults approximately three coils into each phase (there is usually at least twelve), placing most of the electrical stress there, and will not detect resistive faults such as high resistance joints or broken wires. It is quite potentially destructive as noted in studies, papers and observations by experienced electric motor personnel.

The study did find that de-energized MCA testing was able to test far deeper into the winding while providing additional information, such as the condition of the rotor. MCA will provide some mechanical response, but requires at least 30% load to get an accurate measurement. The recommendation of using MCA, MCSA or both as a final test will go a long way to ensure the reliability of your repaired electric motors whether performed by the repair shop or part of your acceptance commissioning program.

# Motor System Maintenance and Management Project

## ◆ Areas requiring additional research:

- Circuit testing reliability
- Motor life estimation through risk assessment
- Motor system component life estimation
- Effects of various control systems on reliability

## ◆ Opportunities Evaluated

- Combined PM and PdM programs have profitable ROI
- Partnerships amongst motor stakeholders including all departments, suppliers and repair centers
- Use of a combination of instrument technologies allow a more complete view of the tested system
- A variety of business cost factors are impacted by equipment reliability, including production and energy

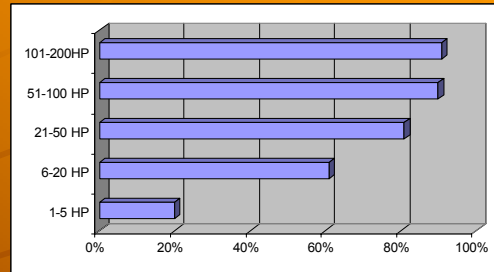
The motor management program project reviewed motor circuit testing reliability, motor and component life estimation, and the application of motor maintenance and reliability centered maintenance within industrial plants. It determined that motor management programs that combine preventive and predictive maintenance 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.

In virtually every case, the proper selection and implementation of motor diagnostic equipment will yield very profitable ROI's. In order to ensure increased success in the program, partnerships amongst motor stakeholders including all departments, suppliers and repair vendors are a must.

Electric motor reliability will have a significant positive impact on production availability and energy costs.

# US Industrial Motor Systems Market Opportunities Assessment

- ✦ Purchase and maintenance decisions are made at plant level
- ✦ Noted limited resources for motor system monitoring and maintenance



Percentage of Motors Rewound

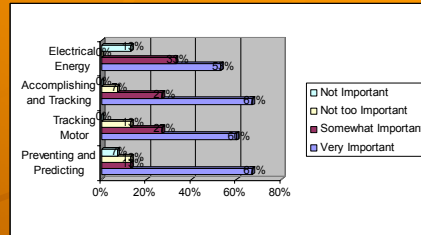
The electric motor system market opportunities assessment determined the general level of purchase and motor system decision making was at the plant level. This included responsibility for motor energy and reliability.

It also found that the primary resource that was lacking was not funding or budget, but manpower. This particular sentiment was reflected by almost every research study cited by the MDMH as well as the survey.

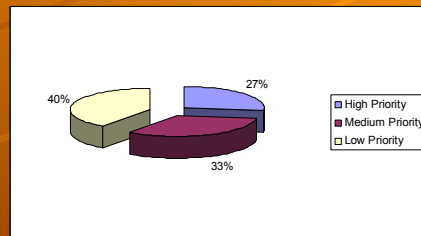


# In Service Motor Testing Project

- ◆ 73% of motor sites perform motor testing in-house
- ◆ Highly Invasive test methods are not desired
- ◆ Test Instruments:
  - Non-Invasive
  - Simple and hand-held
  - Reasonable and accurate
  - Cost Effective



Motor Management Practices

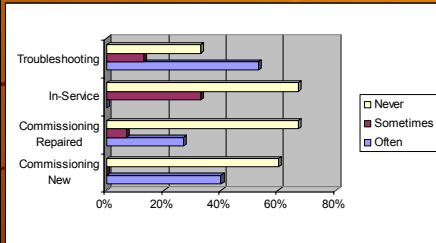


Test for Condition and Reliability

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 the 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/physically 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.

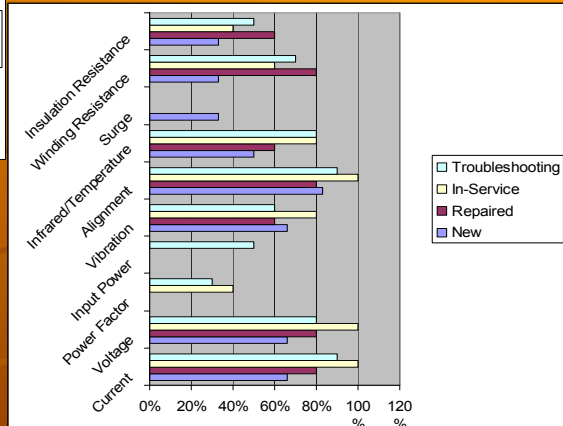
# When are Motors Tested?



## When are Motors Tested

One of the items of note from This study was the concept that 24/7 meant motors could not Be de-energized.

## Kinds of Tests Performed



A key 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.

One of the interesting comments from the study was that most testing was performed only when troubleshooting.

## A Novel Industrial Assessment Study for Energy, Waste Stream, Process and Reliability

- ◆ While the general feeling was that there would be difficulty accessing much of the equipment to be reviewed due to 24/7 operation, it was generally found that system redundancies and break periods were discovered in all instances
- ◆ RCM and the trained use of equipment was critical in all instances
- ◆ Equipment ease of use and interpretation was required.
- ◆ Plant reliability had a tremendous impact on the profitability of the company
- ◆ The result of this study led to additional research

The industrial assessments study found that the perception that 24/7 operation meant no access for testing and evaluation was incorrect. Yes, you heard that right – the perception 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 results of this study directly resulted in the development of the Pacific Gas and Electric's Electric Motor Performance Analysis Testing Tool or PATT project.

# PG&E Electric Motors Performance Analysis Testing Tool (PATT)

## ◆ Study Considerations:

- Evaluate economic benefits of testing methods including MCA
- Evaluation of electric motor maintenance and management programs
- Selection of field efficiency testing and measurement equipment and software
- Develop a strategy that incorporates tools and systems for performing efficiency and load analysis, assessing market requirements, market to industrial and commercial users and training of service providers and motor system users.

The PATT project was the first of its type to specifically review motor diagnostics as part of an energy and condition analysis. The study was funded by Pacific Gas and 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, the program was then contracted to 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.

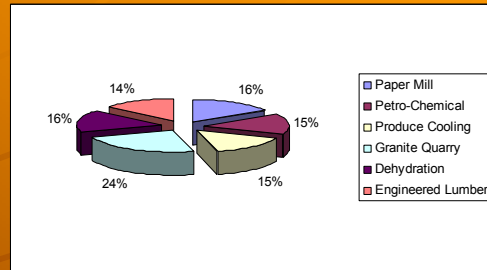
# Equipment and Software Review

## ◆ Market Transformation

- Ease of use
- Marketability
- Initial Cost
- Invasiveness

## ◆ Equipment Selection

- Initial Cost
- Training Requirements
- Ergonomics
- Accuracy
- Least Invasive



Percentage of Motors Evaluated  
And Plant Type

The program considerations were, in order of importance:

- It had to be easy to implement
- Marketable by program volunteers such as 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 other considerations.

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

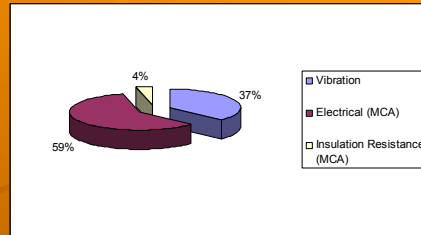
- Initial cost
- Training requirements
- Hand-held
- Accuracy and
- Least Intrusive

# Equipment Selection and Maintenance Issues

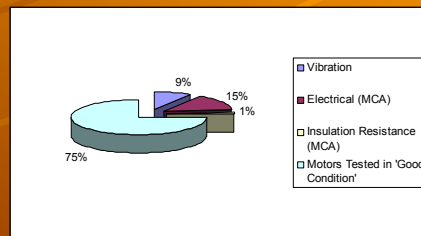
## ◆ Equipment

- Infrared, not selected for this stage
- Vibration (Pruftechnik)
- Fluke 41B and Powersight 3000
- ALL-TEST IV PRO 2000
- Universal Translator
- MotorMaster Plus

◆ Of 20 motors tested, \$297,000 USD over 5 years



Motors with types of issues



Motors reviewed with issues

Training for the complete program had to be able to be completed within three business days, including use of the selected equipment, software and safety.

The equipment selected, to meet the requirements, were:

- The US Department of Energy's MotorMaster Plus software with modifications funded by BJM Corp ALL-TEST Pro, Dreisilker Electric Motors, Inc. and Pruftechnik.
- Pruftechnik vibration analyzers
- ALL-TEST IV PRO 2000 motor circuit analyzers – hand-held, easy to use, accurate, 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.

# Literature Review Conclusions

- ◆ 14% of motors in plants with existing PdM have at least one electrical or mechanical program
- ◆ >19% without PdM programs have at least one problem
- ◆ There is a definite correlation between energy and reliability
- ◆ In all but one case, the motors in 24/7 plants were de-energized upon request
- ◆ Initial Cost and Cannot De-energize found to be excuses to prevent action
- ◆ The actual currency – Manpower: Is the business willing to invest in Manpower to improve product throughput and cost per unit of production?

Findings of the PATT project were exceptional. First, a 63% 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.

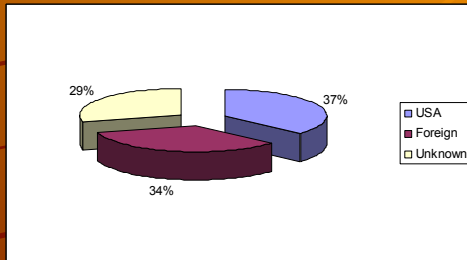
A direct correlation between energy and reliability was established and, in plants that had a predictive maintenance program in place, 14% of motors had some type of maintenance issue. All other plants had greater than 19% of motors with issues. The incremental cost of a sampling of the motors showed a \$296,000 in avoidable unplanned downtime per year for five years.

Throughout 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.

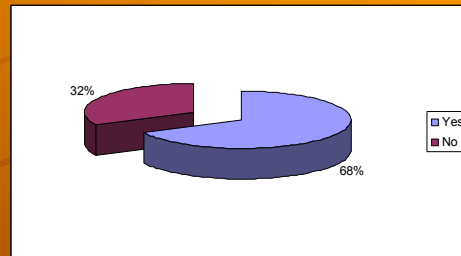
Once past these issues, the programs moved quite easily and with tremendous results. The potential support for a program seemed to be more the development of a business case to qualify the use of the real currency: Manpower.

Is the business willing to invest in manpower to improve product throughput and cost per unit of production?

# Electric Motor Testing Best Practice Survey - 2003



Location of Respondents



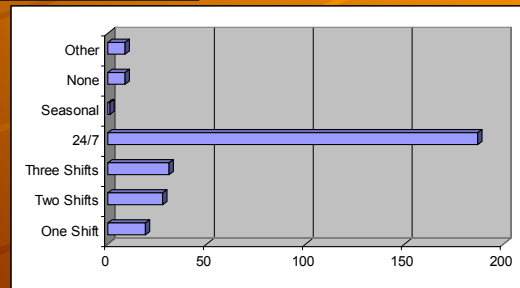
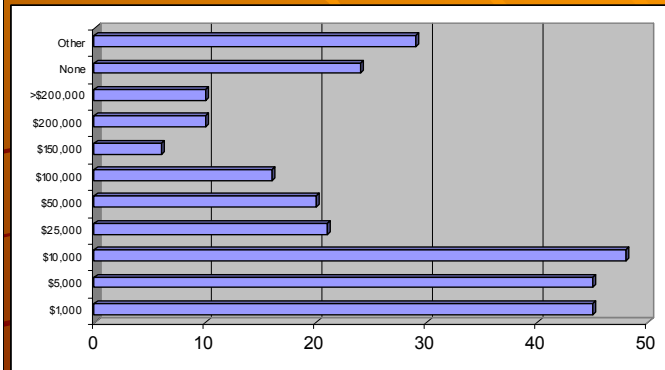
Claim Presently Using Winding Testing

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 which were designed to allow closer study of the answers.

The respondents made up approximately 1/3 United States; 1/3 outside the USA and 1/3 unknown. The response rate was about 2% of the surveyed companies which is an exceptional return.



## Cost Per Hour and Operating Profile

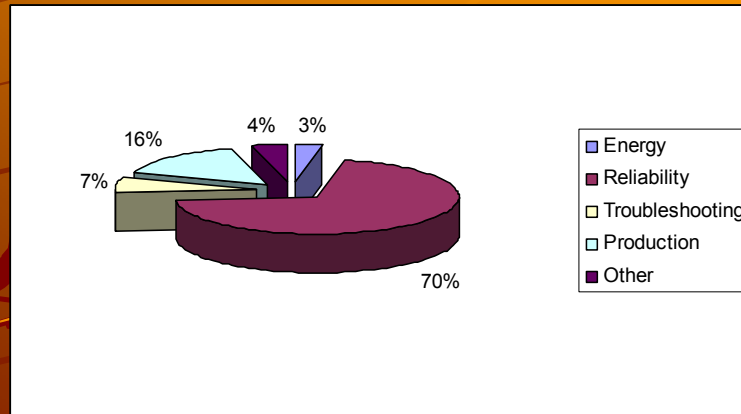


Another key point was the initial cost issue. The minority, 23%, selected initial cost as the only issue preventing the application of motor diagnostic technologies. 28% viewed initial cost and at least one other issue, and 49% viewed other issues with manpower being the majority in both instances. This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

The number of critical motors followed a classic bell curve with the peak covering the 50 to 100 critical motors per plant range and 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 90% having scheduled shutdowns for maintenance.

The perceived need for both off and online testing varied by the number of shifts with a majority of each varying between varying between one shift and 24/7 operation. In each case, a combination of on and off-line testing made up 73% of the responses.

# Primary Driver for Motor Program

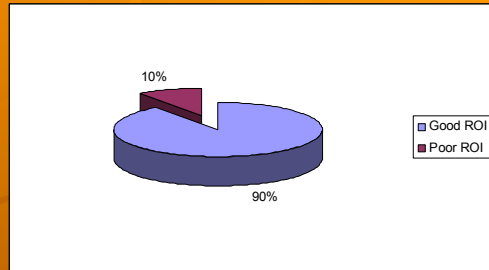


Another item of note was that fewer than 2% of the respondents viewed energy as a primary driver for motor diagnostic technologies. This was important as energy was determined to be a good metric as to the success of a maintenance and reliability program in the literature review study.

The primary driver of the motor diagnostic program was reliability with production taking a close second.

# Data Analysis of MDMH Study

- ◆ A majority of the 68% that claimed motor program in place viewed insulation resistance, ohm, vibration, current and visual inspections as motor testing
- ◆ Of the companies that actually performed motor testing, 91% saw a high ROI

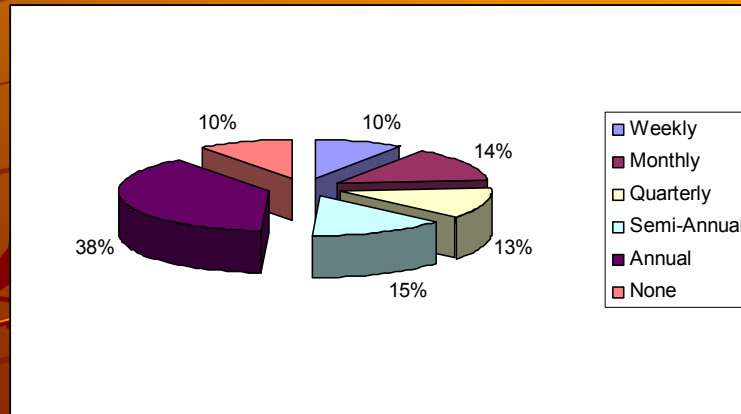


38% of companies using Infrared Or vibration analysis saw an ROI. All 38% were using MCA as part Of the program.

One interesting response was that 68% of those who identified that they had a motor program in place were actually only using insulation resistance, ohm and milli-ohm testing, voltage and current readings, and visual inspections only. Originally, it appeared that only 45% of motor diagnostic programs saw a return on investment. Once the actual data was reviewed, only 19% of the surveyed companies were using MCA or MCSA with an significant return on investment found by over 90% of the companies. 78% of the other companies, including surge test users, were not seeing a return on investment from their motor program.

This identifies that the 'traditional' methods of motor testing are not very cost effective. The survey respondents were made up of virtually every industrial type plus the service, consulting, waste water, government and commercial building industries.

## Planned Outages for 24/7 Operations



Of those plants that made up the 24/7 operation, 52% had shutdowns every 6 months or less, 38% had planned annual shutdowns and only 10% claimed to never shut down.

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. The ALL-TEST stood out as not requiring training, dedicated personnel nor a learning curve.
- 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, and,
- Start with a few critical motors then grow the program.

# Motor Commissioning

- ◆ 81% of shops modify windings
  - Estimated average downtime \$10,000/hr
  - 3 hours average coupling/uncoupling
  - Average savings \$30,000

The primary benefits of a motor diagnostics program can be found, most immediately, through a motor commissioning program. With 81% of repair shops modifying windings, and average downtime of \$10,000 per hour, an average coupling and uncoupling time of three hours, at least \$30,000 can be immediately saved upon the first detection of a problem.

Motor diagnostic technologies such as motor circuit analysis, provides a much safer method of evaluating the condition of the windings both from a winding and personal protection standpoint. Basically, you do not require live output from the instrument of about 2000 volts in order to test a 480volt motor as you would with traditional turn to turn fault testing.

One other key point is that if the motor vendor is aware that testing is being performed, you are more likely to get more attention. As once put to an automotive manufacturer, "Of course it will work, we know you are watching."

## Other Maintenance Income

- ◆ Assuming a company with a program has 100 critical motors:
  - At least 14 will have mech/elect problems
  - 8 will have electrical issues
  - Assume only 3 of these fail during one year
  - Minimum savings: \$90,000

Through a motor diagnostic program, you have the opportunity to find and take care of the 'hanging' fruit. For instance, assuming a company with a motor program has 100 critical motors, at least 14 will have mechanical or electrical problems. Eight of these will have electrical issues.

Assume that only three of these fail during one year.

Now, again assuming that it takes three hours to couple and uncouple, not including transportation, delivery and physical movement, by detecting the electrical problems with motor diagnostics, you will save at least \$90,000 per year.

Not a bad income for the maintenance department.

# Motor Diagnostics ROI

- ◆ True Investment – Manpower
- ◆ Hand-Held
- ◆ Least Intrusive
- ◆ Most Economical
- ◆ Best Results
- ◆ Quickest Implementation

In order to get the best return on investment from your equipment, the MDMH study shows that the true investment is manpower.

The equipment should be, in order:

- Hand-held
- Least intrusive
- Most economical
- Provides the best results
- Can be implemented with the shortest learning curve.

# ALL-TEST Pro Solutions for Motor Diagnostics

## ◆ Instrument Solutions

- ALL-TEST III™
- ALL-TEST IV PRO 2000™
- ALL-TEST Pro OL™

## ◆ Software Solutions

- Condition Calculator 2.0™
- Condition Calculator PPC™
- TREND 2003™
- EMCAT™

## ◆ Kit Solutions

- ALL-TEST Professional™
- ALL-TEST Pro MD™



ALL-TEST Pro provides multiple solutions to meet all of these needs:

- The ALL-TEST III MCA troubleshooting tool
- The ALL-TEST IV PRO 2000 hand-held motor diagnostic instrument
- The ALL-TEST PRO OL hand-held motor current signature analysis instrument

With the associated software:

- Condition Calculator 2.0 and Condition Calculator PPC for the ALL-TEST III
- The TREND 2003, which comes standard with the ALL-TEST IV PRO 2000
- And the EMCAT option for advanced motor and transformer management programs.

There are several kit solutions:

- The ALL-TEST Professional kit includes the ALL-TEST III, ALL-TEST IV PRO 2000, a training motor, EMCAT software, DC test fixtures and the Motor Circuit Analysis book, and
- The ALL-TEST Pro MD, the complete solution for motor health, which includes the ALL-TEST Professional kit as well as the ALL-TEST Pro OL and two days of training on motor management programs.

Each of the instruments are simple to use, hand-held and provide immediate and definitive answers.





## BJM Corp, ALL-TEST Pro

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Our next presentation will cover how to develop your own successful motor management program using the multi-technology approach.

To obtain your copy of the Motor Diagnostic and Motor Health Study, contact [reliabilityweb.com](http://reliabilityweb.com).

To obtain additional information on motor diagnostic technologies, applications and more, contact:

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Thank you for your time.