In this presentation, we shall cover how to create success using a Multi-Technology Approach to Motor Management

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.

Presentation Overview

- What is a Motor System?
- Technology and Component Fault Detection
- System Breakdown – Faults and Detection
- Common Approaches
- Case Studies
- Return on Investment
- Considerations for Selection
- Application Opportunities
- ALL-TEST Pro™ Equipment

The overall presentation shall include:

•Defining the motor system

•What equipment is used to detect what kind of motor system component faults

•A breakdown of each motor system component and what is used for fault detection.

•Common approaches to using multiple technologies in motor systems – Which are the best combinations

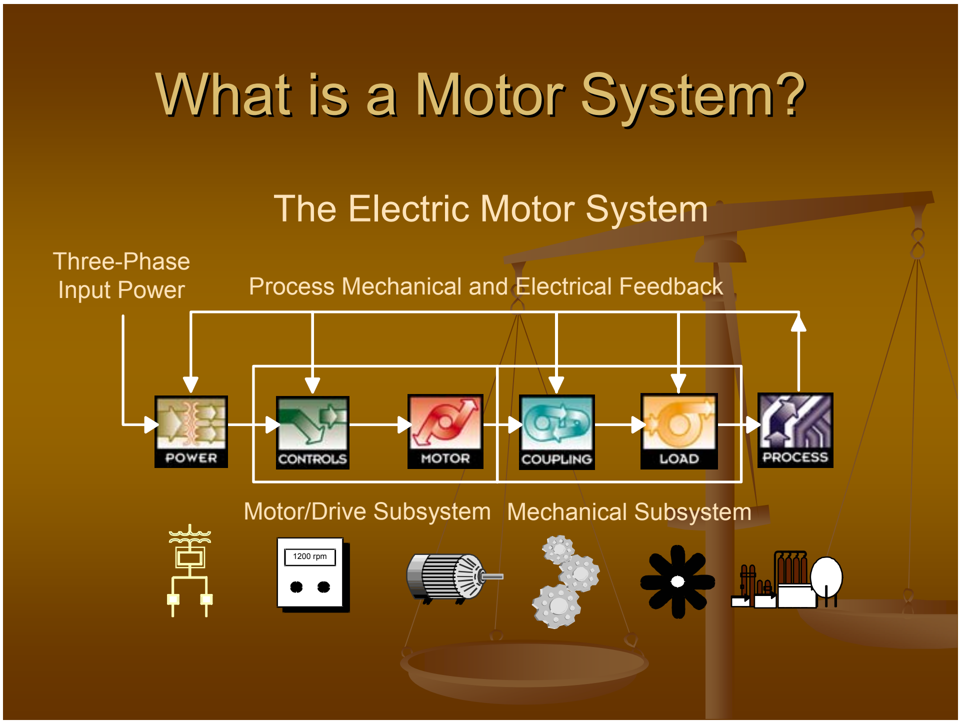
•Several multi-technology case studies

•A return on investment example

•Additional considerations for selection of equipment to diagnose motor systems.

•Motor system application opportunities

•An overview of ALL-TEST Pro instruments and software for motor management



The motor system includes the power distribution system; the motor starting, control, and drive system; the motor; the mechanical coupling; the mechanical load; and the process.

The facility power distribution system includes components such as in-plant wiring and transformers.

The starting, control, and drive system includes the motor starter and adjustable speed drives.

The motor itself – in this outline is an induction motor.

The mechanical coupling refers to components like v-belts and power transmission devices.

The mechanical load refers to the driven equipment, such as a pump, fan, compressor, or conveyor.

The process is what is being accomplished, such as water pumping, mixing, or aeration.

Most users look at motor systems from the component level and try to evaluate or troubleshoot.

The systems approach is a way of looking at the reliability of the entire system and the relationship and synergy of the components.

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	-	-	-	-	-	-	-
MCSA	X	X	L	-	L	X	X	L	-	X	X	X	L

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

This table represents each of the common technologies used to evaluate components within an electric motor system and their common test capabilities. Note, for instance, that high potential testing, insulation to ground testing and polarization index testing each only evaluate the insulation system and must be performed with the equipment de-energized. Surge testing can only evaluate the first couple of turns into the stator windings and an ohm or milli-ohm meter can only detect severe or late-stage winding faults or poor connections. Both high potential and surge testing are potentially harmful to the health of the motor should there be any issues such as aged insulation or contamination.

Motor circuit analysis provides a more definitive view of these components, and more.

The on-line tests can provide a broader view of the overall system, assuming the system is able to operate.

When the motor system is viewed, overall, motor current signature analysis provides a broader overview with only a few limitations.

Aside from an overview of component test ability, a few more things need to be considered…

Management Considerations

Test Method	Estimated Pricing	Non-Destructive	Requires Experience	Dedicated Personnel	Included Software	Other Applications
			Off-Line Test			
High Potential	$10,000 +	Potentially Destructive	High	Recommend	No	No
Surge Test	$25,000 +	Potentially Destructive	High	Recommend	Some	No
Insulation Tester	$1,000 +	(NDT) Non-Destructive	Some	No	No	Yes
Ohm Meter	$500 +	(NDT)	Some	No	No	Yes
PI Tester	$2,500 +	(NDT)	Medium	No	Some	No
MCA	$1,000/ $9,000 +	(NDT)	Some	No	Yes	Yes
			On-Line Test			
Vibration	$10,000 +	(NDT)	High	Recommend	Yes	Yes
Infrared	$10,000 +	(NDT)	High	Recommend	Yes	Yes
Ultrasonics	$10,000 +	(NDT)	High	Recommend	Some	Yes
Volt/Amp	$500 +	(NDT)	Some	No	No	Yes
MCSA	$16,000 +	(NDT)	High	Recommend	Yes	Yes

A few additional considerations have to be reviewed by managers prior to obtaining motor system diagnostic equipment:

•What is the general cost for the equipment? Note that the costs presented here are estimates.

•Is the equipment potentially destructive or non-destructive. For the purpose of this demonstration – any instrument that can potentially change the operating condition of the equipment through mis-application or finish-off weakened conditions shall be considered potentially destructive.

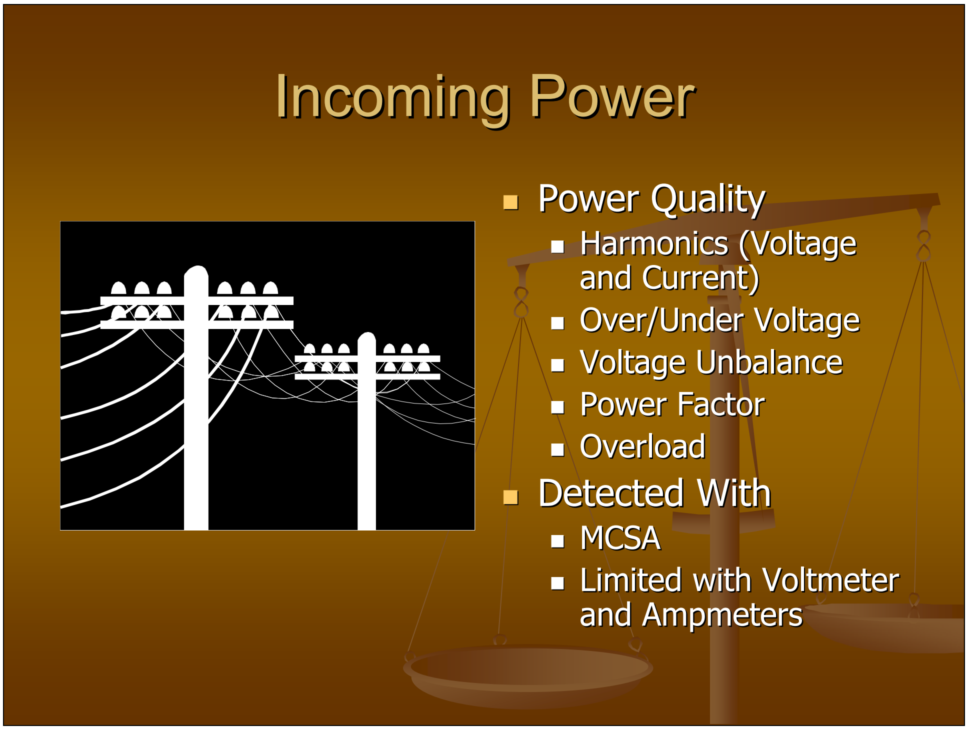
•How much experience is required to operate the equipment? Does it require a specific discipline?

•Does the equipment and software require dedicated personnel in order to get full use of it?

•Does it include software?

•How much training is required?

•Can the instrument be used to test equipment other than motor systems?



The first area of the motor systems' potential reliability issues is power quality. The most common problems include:

•Voltage and current harmonics. Current is potentially the most harmful.

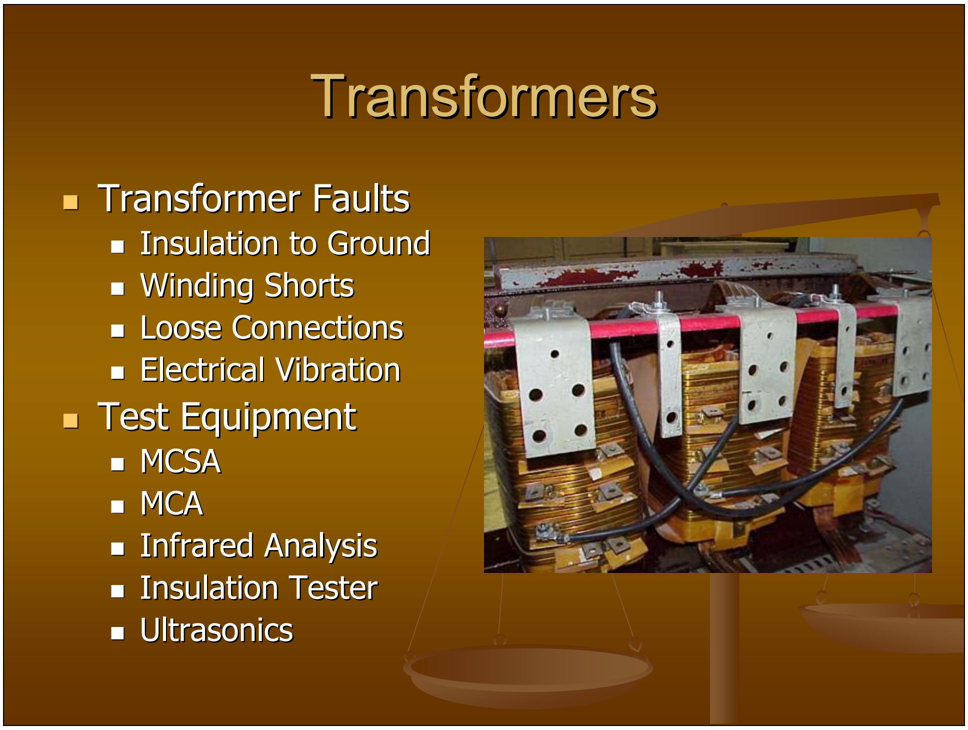
•Over and under-voltage conditions. Electric motors are designed to operate no more than 10% high or low from the motor nameplate value. The preferred range is +/- 5% of the nameplate value.

•Voltage unbalance is the difference between phases. The relationship between voltage and current ranges from a few times to many times current unbalance as related to voltage unbalance based on motor design (can be as high as 20 times).

•Power factor of the system. The lower the power factor from unity, the more current the system must use to perform work.

•Overloaded system – based upon capabilities of the transformer, cabling and motor – detected as current related to nameplate values.

Each of these problems can be easily detected using voltage and current-based motor current signature analyzers. Volt and Amp-meters provide limited capability to detect problems.



Transformers are one of the first critical components of the motor system. In general, transformers have fewer issues than other components of the motor system. However, one transformer usually takes care of multiple systems both in the electric motor as well as other systems.

Common transformer problems include:

•Insulation to ground faults.

•Shorted windings.

•Loose connections, and,

•Electrical vibration

Test equipment for evaluating the condition of transformers include:

•Motor current signature analysis

•Motor circuit analysis for grounds and shorts

•Infrared analysis for loose connections

•Ultrasonics for looseness and severe faults

•Insulation tester for insulation to ground faults

The motor control or disconnect provides some of the primary causes of motor system problems. The most common for both medium and low voltage systems are as follows:

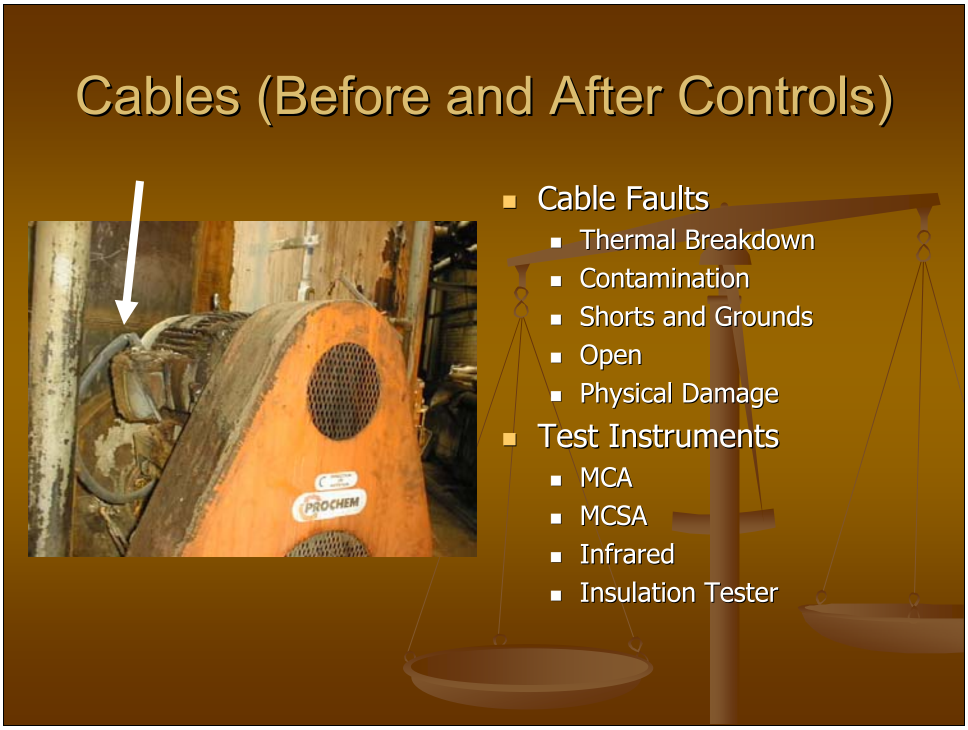
•Loose connections

•Bad contacts including pitted, damaged or worn.

•Bad starter coils

•Bad power factor correction capacitors

The test methods for evaluating the control systems are fairly numerous with MCA, Infrared and MCSA providing the most accurate evaluations.



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.

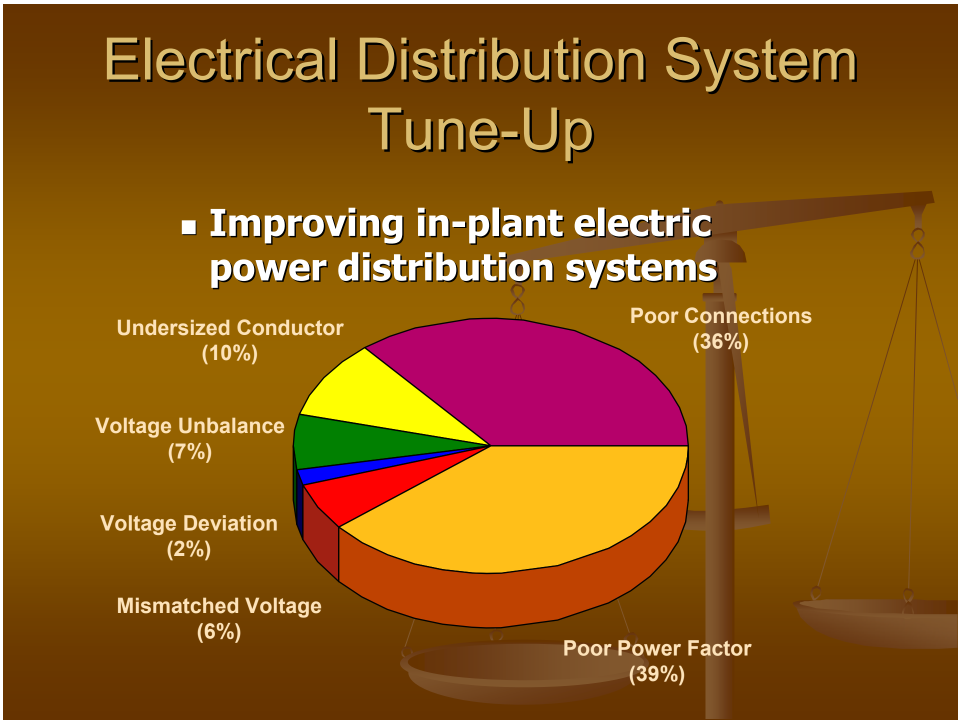
•Contamination which can be even more serious in cables that pass underground through conduit.

•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.

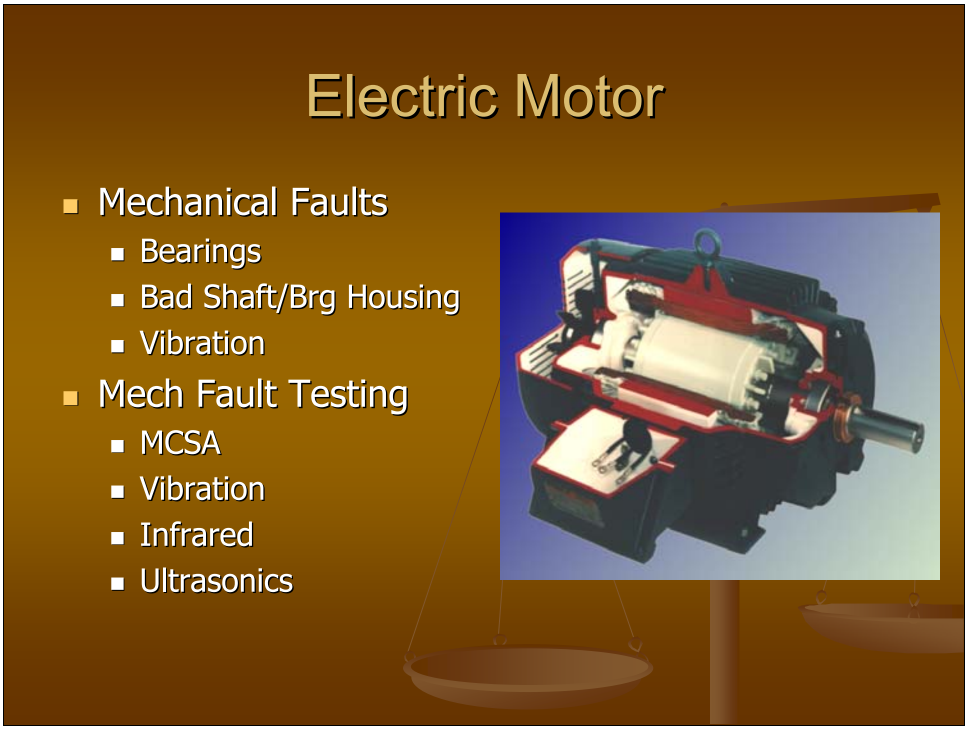
Test instruments include motor circuit analysis, motor current signature analysis, infrared and insulation to ground testing.



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 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

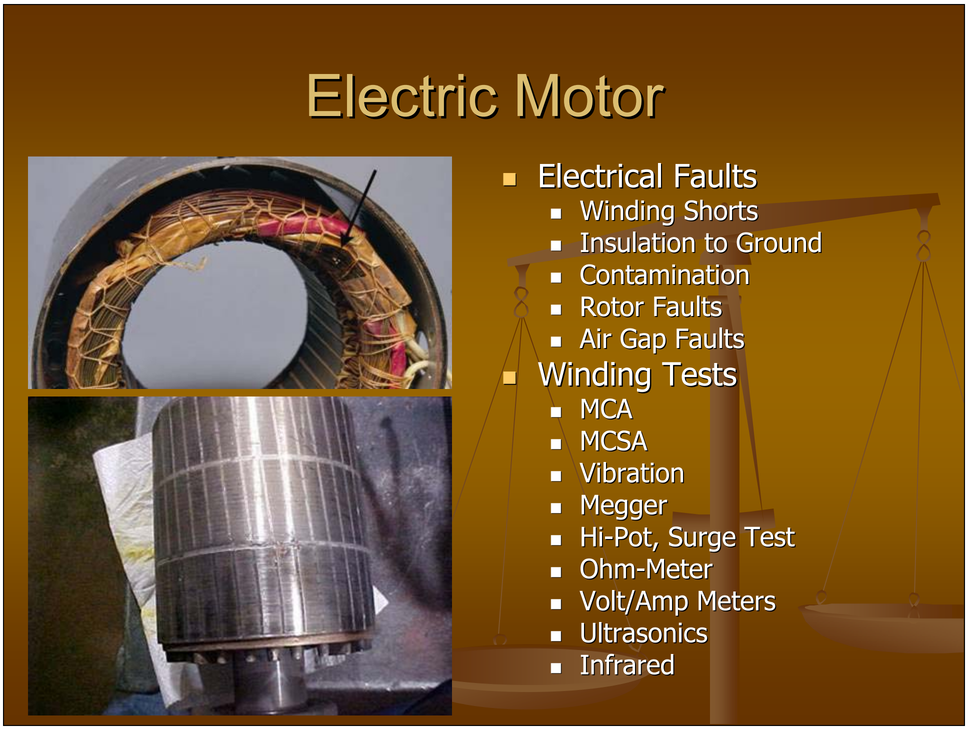
Each of these can be detected using:

•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



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:

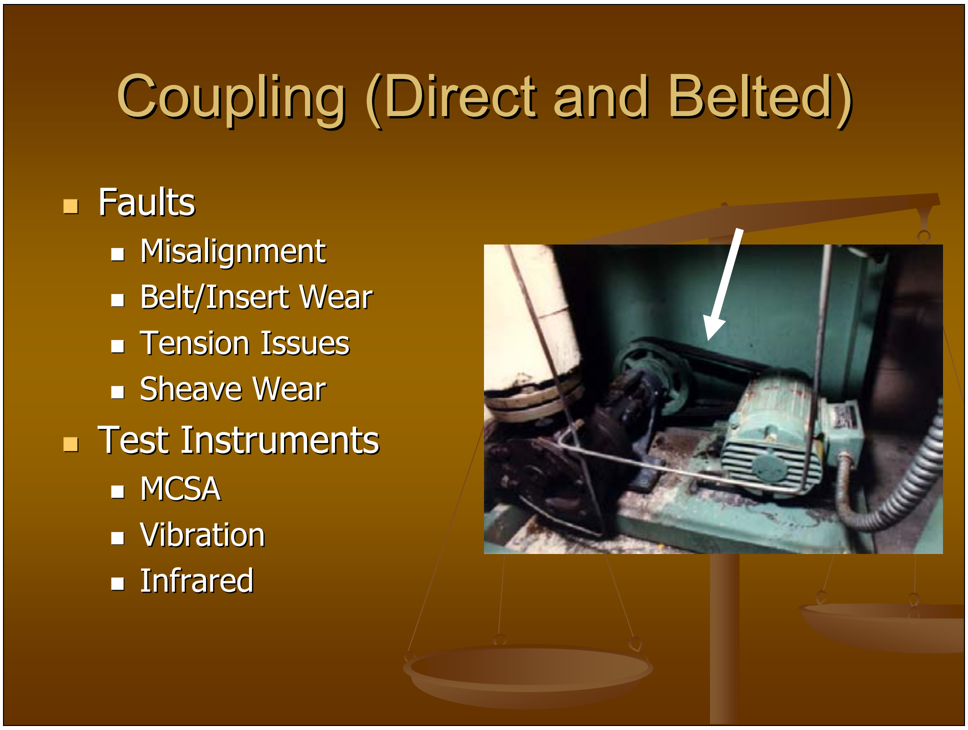
•MCA and MCSA will detect all of the faults

•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.



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

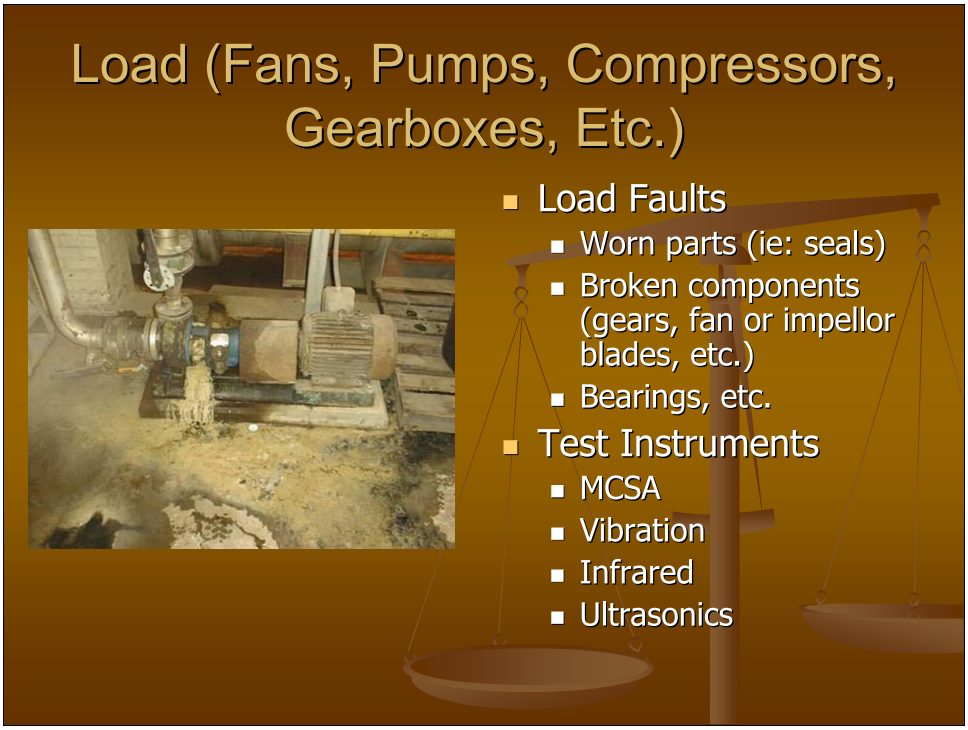
•Belt or direct drive misalignment

•Belt or insert wear

•Belt tension issues are more common than most think and usually result in bearing failure.

•Sheave wear

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



The load can have numerous types of faults depending upon the type of load. The most common are:

•Worn parts

•Broken components

•Bearings

Test instruments capable of testing load problems include:

•MCSA

•Vibration

•Infrared Analysis, and

•Ultrasonics

Common Approaches

	PQ	Cntrl	Conn	Cable	Stator	Rotor	Air Gap	Brgs	Ins	Vibe	Align	Load	VFD
Insulation Resistance and PI	-	-	-	L	-	-	-	-	X	-	-	-	-
Infrared and Vibration	L	X	X	L	L	L	L	X	-	X	X	X	-
Surge and Hi-Pot	-	-	-	-	X	-	-	-	X	-	-	-	-
MCA and MCSA	X	X	X	X	X	X	X	X	X	X	X	X	X
MCA and Infrared / Vibe	L	X	X	X	X	X	X	X	X	X	X	X	L

- Many select mechanical approach (vibe and infrared) if applying a reliability program.
- Most use Insulation and PI testing with limited results
- New approach has been a combination of the MCA and/ or MCSA with a vibration and infrared program for multi-technology approach to confirm findings. Uses combination of electrical and mechanical.

There are several common approaches within industry and several new approaches. The best use a combination of energized and de-energized testing. It is important to note that energized testing is usually best under constant load and trended in the same operating conditions each time.

One of the most common approaches has been the use of insulation resistance and/or polarization index. These will only identify insulation to ground faults in both the motor and cable, which represent under 1% of the overall motor system faults (~5% of motor faults).

Infrared and vibration are normally used in conjunction with each other with great success. However, they miss a few common problems or will only detect them in the late stages of failure.

Surge testing and high potential testing will only detect some winding faults and insulation to ground problems.

The following two approaches have become more common over the past decade:

Motor circuit analysis and motor current signature analysis support each other and detect virtually all of the problems in the motor system. This accuracy requires MCA systems that use resistance, impedance, inductance, phase angle, current/frequency response and insulation to ground and MCSA systems that include voltage and current demodulation.

The most common approach is vibration, infrared and motor circuit analysis. The strength of this approach is that there is a combination of electrical and mechanical disciplines involved in evaluation and troubleshooting. As found in the motor diagnostic and motor health study, 38% of motor system testing involving only vibration and/or infrared see a return on investment. This number jumped to 100% in systems that used motor circuit analysis along with vibration and/or infrared.

Final Considerations

Test Method	Where Can You Test
High Potential Testing	At Motor – Requires disconnect
Surge Test	At Motor – Requires disconnect
Insulation Tester	From MCC
Ohm Meter	At Motor – Requires disconnect
PI Testing	At Motor – Disconnect Recommended
MCA Test	From MCC
Vibration Analysis	At each location tested
Infrared	At each location tested
Ultrasonics	At each location tested
Volt/Amp	From MCC
MCSA	From MCC

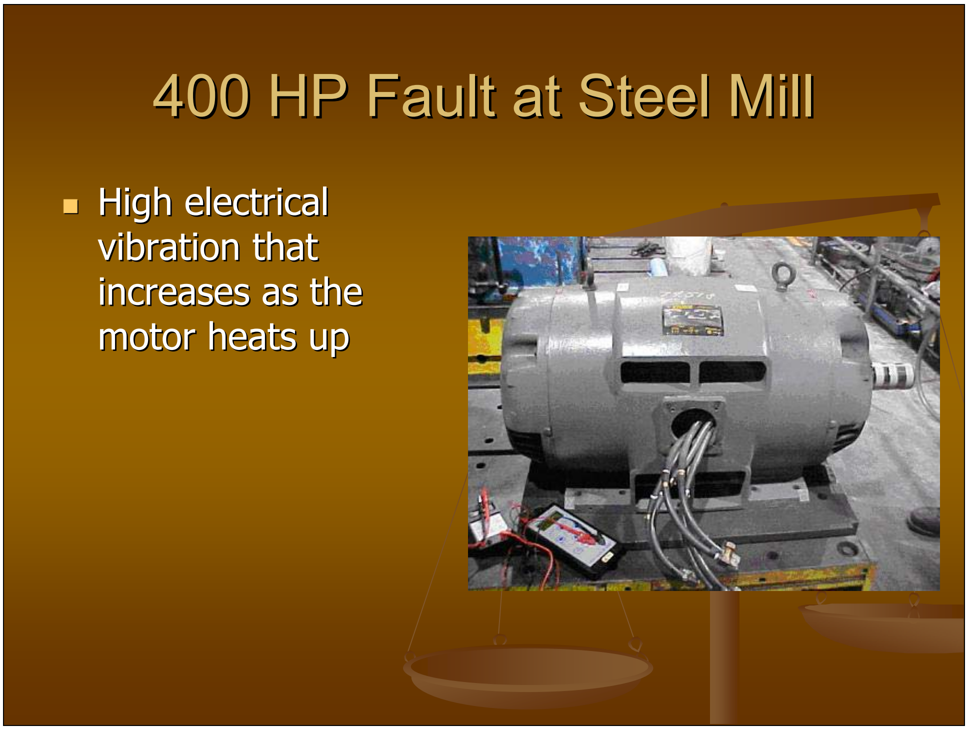
Example of Difference: Testing 20 motors at one site took just over an hour During a survey using MCA testing. Same motors required testing over entire Day using vibration analysis during same survey.

A final consideration when reviewing the systems to use as part of your motor system evaluation is where you have to test and the time involved. For instance, during the PG&E electric motor performance analysis tool study, MCA testing was performed from a motor control center and results found. Vibration analysis on the same motors required the day as testing required traveling to each location.

High potential testing, polarization index and surge testing should be performed at the motor with all cabling disconnected.

Insulation testing, motor circuit analysis, motor current signature analysis and volt/amp testing can each be performed from the MCC.

All of the other tests are usually performed at each location being tested. Is this bad? Not really, one of the benefits of testing at each location is the ability to identify visual problems.



In this first case study, a problem in a 400 horsepower electric motor at a steel mill was identified. This problem had been driving the maintenance and reliability group crazy for about two months. As it was part of a parallel system, this motor was used only as a back-up, which created another problem – an unreliable back up system.

The motor had an electrical vibration that showed some looseness, when the motor was energized. The vibration would continue to increase as the motor's operating temperature increased. The signature would disappear when de-energized. The bearings had been replaced and a number of other symptoms were addressed to no avail. As a high-frequency signature in vibration looked like rotor bars, which were known, with multiple harmonics, it was determined that the fault must be a rotor problem. The motor was sent to a local repair shop who happened to have MCA equipment.

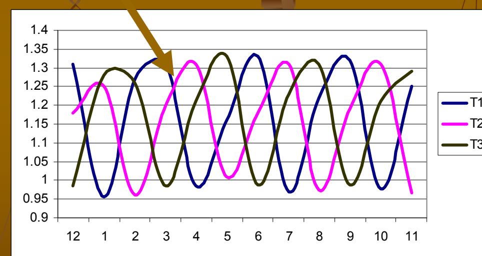
The rotor and stator were tested.

Test Results

Winding Test

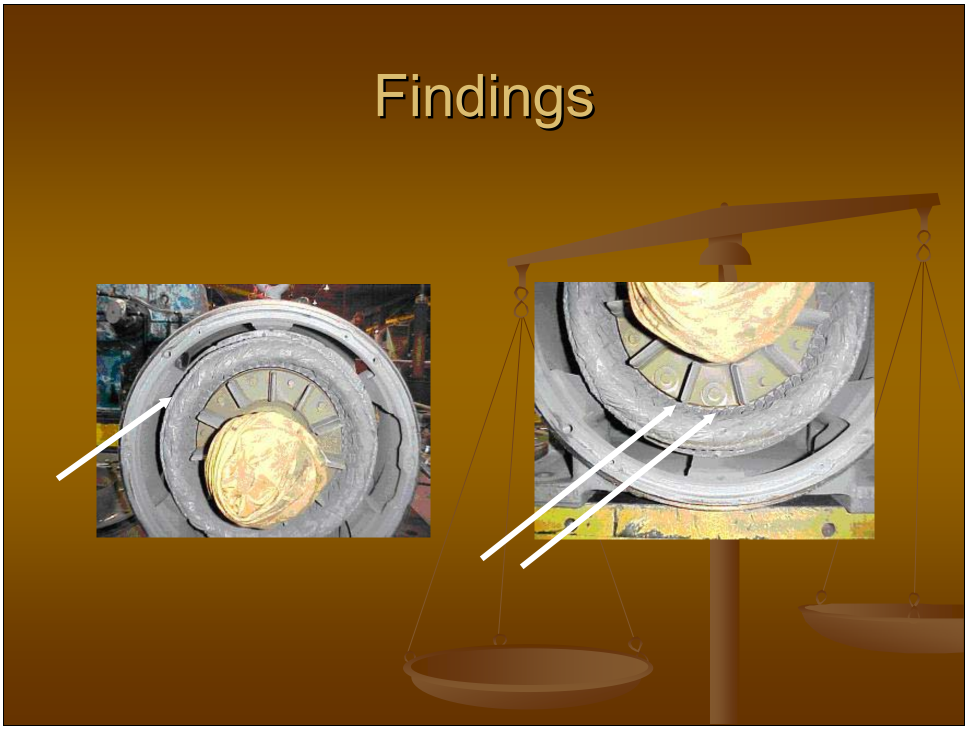
	T1-T2	T1-T3	T2-T3
Resistance	0.009	0.009	0.009
Impedance	6	6	6
Inductance	1	1	1
Phase Angle	53	52	53
I/F	-40	-40	-40
Insulation	#.#		

Rotor Test



As you can see from these readings, the stator winding was in excellent health. The rotor shows a few flat spots in the waveform and a slight arch as you go right to left. These findings indicate small casting voids in the rotor and that there is a little rotor eccentricity. However, neither of these findings indicate a problem as severe as what was being seen.

Time to test, including rotor test: <30 minutes.

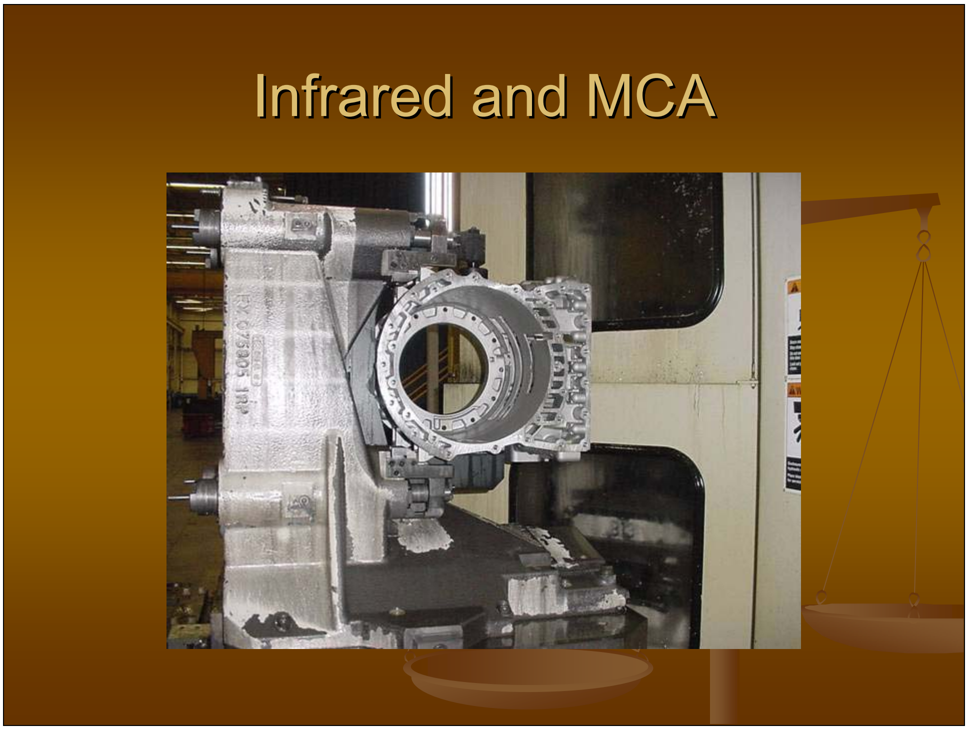


If all of the least likely problems are eliminated, what remains, however improbable, is the fault.

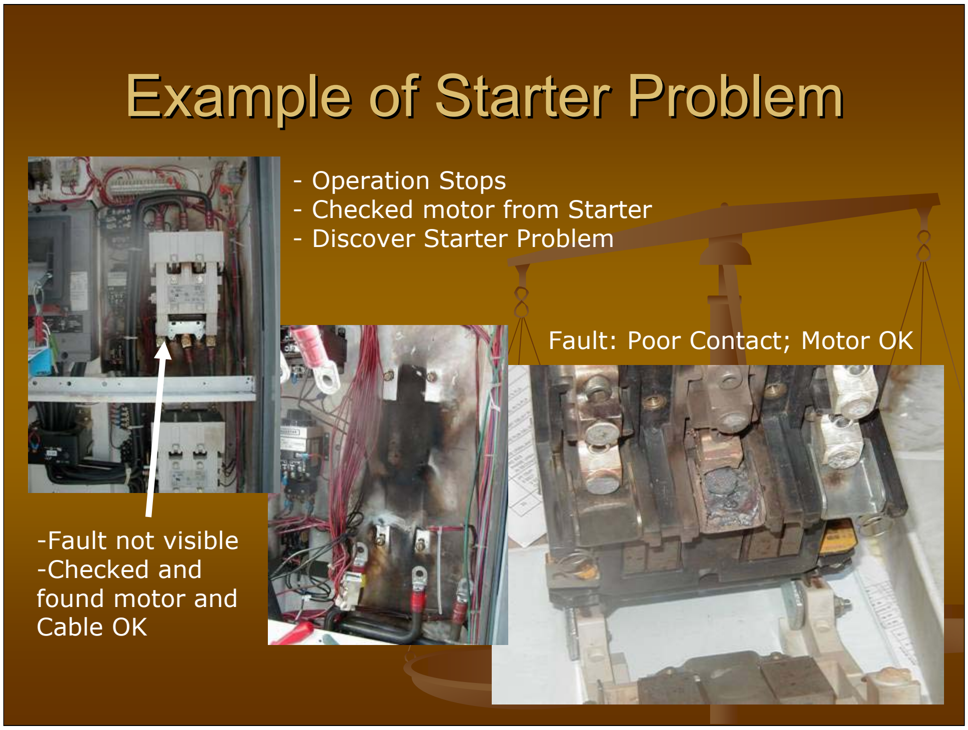
In this case, a single pin from the bottom of the stator housing holds the stator core in place. There are no welds, as they would break during thermal growth. However, the stator was not completely tight within the stator housing and both the stator housing and core are made of two different materials. It appears that the stator housing was growing faster than the stator core, causing the vibration and looseness. Marks on the core and stator housing ribs proved the indication (as well as a slightly visible spacing).

You will note balancing weights on the second picture. As an interesting tidbit of knowledge, significant casting voids, because they are missing metal, can usually be found right behind balancing weights on the rotor.

: During a routine IR predictive maintenance route a thermographer determined a motor was operating at an excessive temperature. The motor in question was a 7.5 horsepower coolant pump in a transmission case machining center and, due to its location, additional analysis with IR was difficult. The machining center involved is responsible for critical machining on a key component in the assembly plant. If the cooling pump failed, history revealed that the loss of production would result in assembly plant shutdown. A work order for additional analysis was produced to determine if the trouble was electrical or mechanical. The motor and cabling tested electrically good with motor circuit testing. A bearing fault was detected, using vibration analysis, and a repair versus replace decision was made. The coolant pump motor was replaced during routine downtime and a follow-up IR scan showed the motor operating within normal parameters.



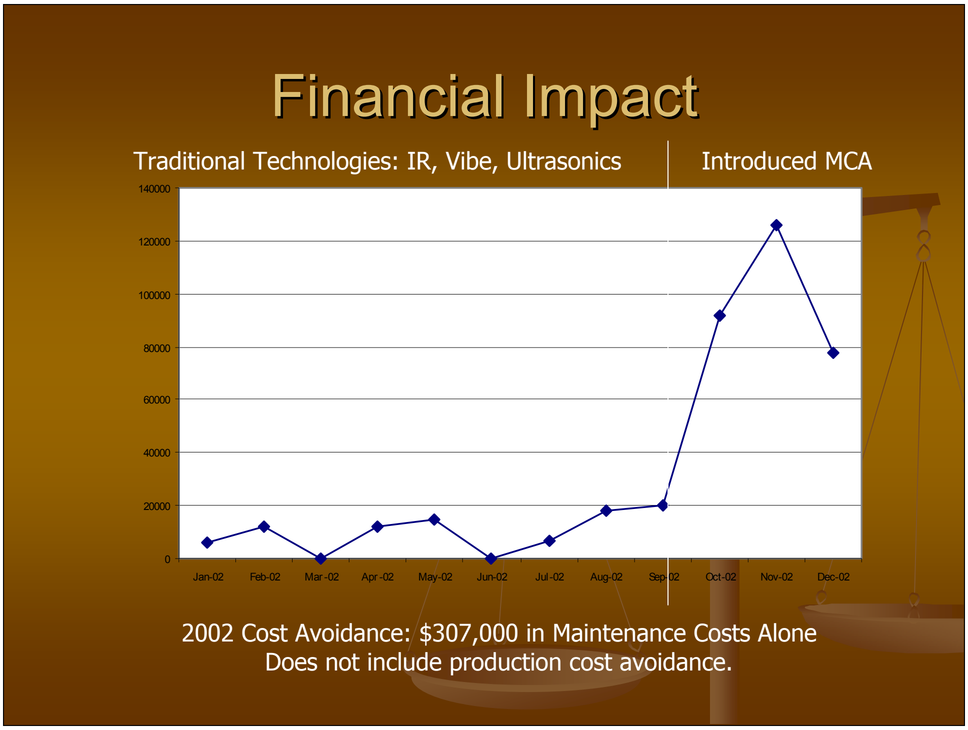
During another routine IR predictive maintenance route, the thermographer identified a critical machine tool motor with a non-specific high stator temperature. The drilling machine was a bottleneck for one process line where it drilled four mounting holes in transmission cases. Loss of the critical motor would shut down the process line. A replacement motor was identified with an estimated three day delivery time. Motor Circuit Analysis was performed and a non-parallel impedance and inductance reading identified winding contamination while an insulation to ground test showed a high MegOhm reading. The electric motor was pulled and sent into an electric motor repair shop for repair and investigation as part of a route-cause-analysis. The motor repair shop discovered fluid in the motor housing, poured a sample and analysis found it to be a mixture of coolant and hydraulic oil. The motor winding was cleaned, dipped and baked, a motor seal replaced, and the leak on the machine tool found and repaired with a turnaround time of less than 24 hours from detection of the problem. If left, the motor would have suffered a catastrophic winding failure most likely resulting in a loss of at least 72 hours production time.



An electric motor trips off line. During the setup to check the electric motor from a starter, a starter fault is detected.

The contacts are checked in the starter and the B phase contacts appear to have exploded. As it turns out, the motor was tested and found to be, electrically, in good condition. The fault was determined to be the result of arcing in the contacts, most likely due to a loose contact.

The starter was replaced and the equipment put back in operation.



What is the financial impact of a combination of infrared, vibration and motor circuit analysis?

In this example, taken from a Midwestern automotive manufacturer, up through September, 2002, findings using infrared, vibration and ultrasonics provided good results. The application of motor circuit analysis, using an ALL-TEST IV PRO 2000, resulted in an increase in maintenance direct cost avoidance of $307,000, which does not include production cost avoidance.

There are three common opportunities for electric motor system testing. These include:

•Commissioning components or the complete system as it is newly installed or repaired. This can usually provide a very immediate payback for the technologies involved.

•Troubleshooting the system. Through the proper application of multiple-technologies, problems can be identified and corrected rapidly.

•Trending of test results for system reliability, again using the proper application of multiple-technologies. Using tests such as motor circuit analysis and vibration analysis, potential faults can be trended over the long term, detecting some faults months in advance.

ALL-TEST Pro provides multiple solutions to meet MCA and MCSA 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.

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

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Thank you for your time.