APPLICATION NOTE

ELECTRIC MOTOR PERFORMANCE TESTING AND RELIABILITY ASSESSMENT

Hugh Falkner, Fred Nelson & Geoff Parry

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Author(s):	Hugh Falkner, Fred Nelson & Geoff Parry (Atkins)
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EXECUTIVE SUMMARY

At the heart of a Motor Management Reliability Programme (MMRP) is the use of cost effective Condition Monitoring. This is the process of monitoring motors in order to detect conditions that may lead to a failure, and to predict when such a failure is likely to occur. The benefits are that this:

- reduces the risk of unexpected or premature failures;
- facilitates maintenance to be scheduled at the most appropriate and least disruptive times; and
- helps minimise the cost and impact of unnecessary maintenance interventions.

This report explores how the cost of condition monitoring can be optimised through careful examination of the overall value of each test performed; weighing up the costs and benefits. Condition monitoring of a motor can range from undertaking occasional but regular tests to continuous real-time monitoring. Central to determining what level of condition monitoring, is appropriate is the need to understand the criticality of each motor – what is the likelihood of failure, and how severe are the consequences? The starting point for this is a careful review of each motor on site, from which an appropriate condition monitoring programme can be developed. Related to this is the question of what to do when a motor fails; should it be replaced or repaired? There are several factors that need to be considered:

- Criticality of the motor – how quickly does it need replacing?
- What energy savings could be made by replacing the failed motor with a new higher efficiency motor?
- How might energy consumption be increased due to poor repair?
- Does it have any unusual features that will make finding or fitting a replacement hard?
- What are the costs (capital and storage) of holding spare stocks on site?
- How quickly can stockists supply replacement motors to site?

This report also considers how the many benefits of condition monitoring and maintenance should be balanced against the increased failures that may occur due to the infant mortality of replacement components, or from the mistakes that might occur during any intrusive intervention.

The second part of this Application Note acts as a guide to the selection of equipment and monitoring methods, and the frequency at which they should be employed. The tests reviewed include temperature monitoring, vibration monitoring, oil analysis and various electrical tests. This allows the selection of test equipment and methods in line with budget and in house skills.

No matter how well established a site condition monitoring regime is, changes in motor duties, site operations or just learning from past motor failures, means that periodic reviewing of condition monitoring activity is always worthwhile.

Devising Cost Effective Condition Monitoring Schedules

Motor criticality

Treating every motor on a site with the same degree of condition monitoring is neither necessary nor practically or financially realistic. The Reliability Centered Maintenance (RCM)[1] method uses the answers to seven basic questions to help determine the best maintenance tasks to implement in a maintenance plan. These questions provide useful pointers to identifying the most cost-effective strategy for a Motor Management Reliability Programme (MMRP); which are:

1. What are the functions of the asset?
2. In what way can the asset fail to fulfil its functions?
3. What causes each functional failure?
4. What happens when each failure occurs?
5. What are the consequences of each failure?
6. What should be done to prevent or predict the failure?
7. What should be done if a suitable task cannot be found?

The risks identified from these considerations can then be defined in terms of *Criticality*, which may be qualitatively expressed as:

Criticality = Likelihood of failure x Severity of the consequences of failure

The value of the Criticality for each combination of Likelihood and Severity of failure is often illustrated using a variation of the diagram in Figure 1. This makes clear that it is the combination of these two factors that is important. For example, if the Likelihood of failure was high (D or E) and the Severity of the consequences was very low (1), then the overall Criticality would be “Medium”.

SEVERITY	A	B	C	D	E
5	Medium	High	Very High	Very High	Very High
4	Medium	Medium	High	Very High	Very High
3	Low	Medium	Medium	High	Very High
2	Low	Low	Medium	Medium	High
1	Low	Low	Low	Medium	Medium
	LIKELIHOOD				

Figure 1 – Criticality as a function of likelihood and severity of failure.

[1] Reliability-Centered Maintenance (RCM) is a phrase coined in the late 1970s by F. Stanley Nowlan and Howard F. Heap in their report *AD A066-579, Reliability-Centered Maintenance,* to describe a cost effective way of maintaining complex systems (http://www.everyspec.com/DoD/DOD-General/AD-A066579_18228/).

The starting point of implementing a Motor Management Replacement Policy (MMRP) is to collect data and information in order to understand the current condition of the plant, and hence the criticality of each motor. This involves identifying all motors in operation or kept as spares, and includes information on their size, condition, age and past maintenance history. For this initial compilation, even small or apparently inconsequential motors should be included, as the wider impact of failure may not be immediately apparent.

For critical services, there will ideally be redundancy of plant, for example water pumps or air compressors, which will allow for testing and even repair of plant without causing inconvenience. For critical processes, any form of testing that involves cessation of work is going to itself carry a significant cost, and so must be carefully justified. In developing an MMRP, cases for introducing greater redundancy may well be identified.

Another consideration is the prevention of failure by ensuring that a motor is appropriately protected. In practice, this decision is usually driven only by the value of the motor itself, but should in fact be influenced by the entire criticality of the system that it is serving. Protection options range from fuses and simple overload protection for non-critical small low voltage (LV) motors, to very sophisticated multifunctional motor protection relays for large high voltage (HV) motors.

FREQUENCY OF CONDITION MONITORING

Condition monitoring of a motor can range from undertaking occasional but regular tests, to continuous real-time monitoring. The frequency of monitoring that is appropriate should primarily be determined by the criticality of the motor. However, criticality is not necessarily the whole story; a non-critical motor, for example, might be expensive to repair or replace, in which case the cost-effective frequency of monitoring may be higher than would otherwise be the case. Figure 2 illustrates the factors to be considered when determining the appropriate frequency of monitoring.

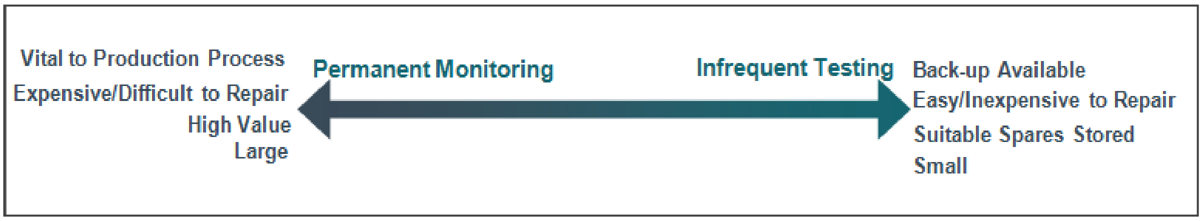


Figure 2 – Factors influencing the frequency of condition monitoring for each motor.

ON-LINE CONDITION MONITORING

The usefulness of spot condition monitoring of equipment is limited by the time intervals between tests. On-line condition monitoring overcomes this constraint by giving continuous information on machinery status.

Major and critical plant will usually be offered by the manufacturer with built in sensors, most commonly power/current monitoring, temperature or vibration sensors. Such on-line monitoring not only allows for real-time viewing of machinery status, but more importantly shows trends over time. With care it is then possible to follow the condition of the machine as a function of plant operations, allowing identification of plant operations most likely to accelerate wear.

Should a sudden failure occur or a particular condition be reached (e.g. level of vibration or temperature), then the immediacy of the alert can prevent further damage.

Another advantage of on-line monitoring is that it avoids the risk with portable monitoring equipment of small differences in sensor position or firmness of mount (vibration monitoring) giving misleading readings.

Whilst on-line condition monitoring is the ideal way of detecting developing problems before they lead to failure, it is unlikely to be cost effective for less critical plant.

Spares Management

Deciding for which motors to keep spares is always a balancing act; as too few will result in increased downtime and reduced production, but too many represents an unnecessary high financial outlay. Furthermore, in addition to the cost of purchasing and maintaining a spares inventory, there is a hidden cost in that it slows down the ability to use the latest designs of motor.

Motors that are kept in stores for any length of time also require attention to ensure that they do not deteriorate, which represents a further cost. These actions are dependent on the motor and storage conditions, with the following seen in the well run spares department:

- Occasional turning of the shaft to avoid brinelling of bearings.
- Use of embedded resistance heaters to drive off condensation.

In answer to these issues, distributors can effectively operate as the organisation's spares department, offering guarantees of rapid delivery of new parts, with local stocks influenced by the requirements of their customers.

However, the final decision on which motors to keep in stock, and which to rely on trusted local distributors for, is highly site dependent. Key considerations will include the location of possible distributors, and the availability of in house personnel with the knowledge and time to properly care for motors kept in stock.

When should a motor be replaced?

Another important issue in developing an MMRP is deciding on the conditions determining whether on failure a motor should be repaired or replaced. This entails balancing factors such as the cost of the motor, price to repair/replace, money lost from outage, any special mounting requirements, operational conditions, estimated performance and actual measurements recorded. Further information on this is given in ECI publication Cu0104 "Electric Motor Asset Management".

Assessing motor efficiency

Ideally the maintenance engineer would like to be able to compare actual efficiency with that of the original condition. Unfortunately the formal test procedures (IEC60034-2-1, Standard on Efficiency Measurement methods for low voltage AC Motors) involve a large investment in testing equipment; not even every West European country has a laboratory capable of undertaking these tests. Even if it was possible, the need to remove the motor from site to a test lab incurs a large cost, and so it is not a practical proposition.

On a small number of sites with large numbers of motors, personnel might actually undertake simple dynamometer testing. Even if this is not to the letter of the above test standard, it can be sufficiently accurate to give a very good indication of efficiency. However, the following two tests are a very useful indicator of motor condition that require no expensive apparatus, and are particularly appropriate for checking the condition of a motor following repair:

- The stator resistance gives a clear indication of the amount of copper used – showing clearly the use of conductor with a reduced cross sectional area.

- With the motor mechanically disconnected but energised, the no load active power can be measured, which will increase if the motor laminations are damaged.

While measuring the actual efficiency of an electric motor is difficult and costly, simple tests to check for deterioration in performance after repair are useful as part of tracking the motor condition over its lifetime.

RISKS OF EXCESS CONDITION MONITORING AND MAINTENANCE ACTIVITY

For engineers the maxim "You can't manage what you can't measure" is deeply engrained, but what it doesn't consider is how the measurement process itself may be a problem, not just because of the risks inherent in the measurement process itself, but also from the consequences of unnecessary intervention.

The modern motor vehicle offers a good example of how the increased use of sensors gives a much better controlled and efficient machine, and provides improved fault diagnosis capability. On the other hand, the sensors, cables, connectors and electronic management system are in themselves new sources of vehicle malfunction. Motor manufacturers have to strike a balance between the collection and processing of operating data and the costs of doing so, including the inherent risks of increased system complexity.

True non-intrusive condition monitoring will not in itself accelerate wear, but even where the action itself is not going to cause damage, there is a risk of mistakes during testing itself leading to further problems, such as:

- Dropping of a tool, fastener or other item into the machinery.
- Tripping out of the electrical supply by the incorrect fitting of probes or disturbing of failed insulation.
- Injury to personnel through electric shock.
- Fasteners not being re-tightened correctly.

Similarly, some inspection procedures might be more intrusive than they appear. For example, opening up white metal bearings for observation can cause damage during reassembly that would not have occurred had they been left intact.

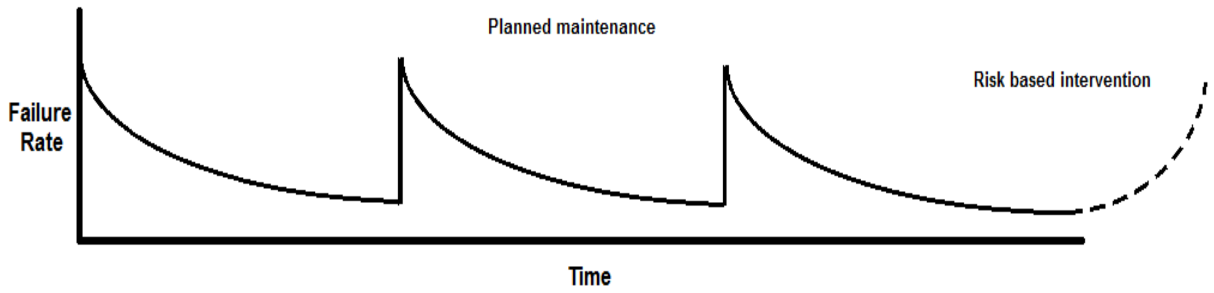


Figure 3 – Failure rate and maintenance intervention

For every motor, there will become a point at which excessive maintenance interventions will actually increase the chance of failure. Figure 3 shows how each time a new part is fitted, the risk of failure due to infant mortality and disturbance during the intervention might actually increase the risk of failure in the short term.

Figure 4 illustrates the relationship between maintenance spend and the probability of motor failure. Understanding where a particular motor is on this curve gives an indication of the potential for either saving costs or increasing reliability through additional maintenance expenditure.

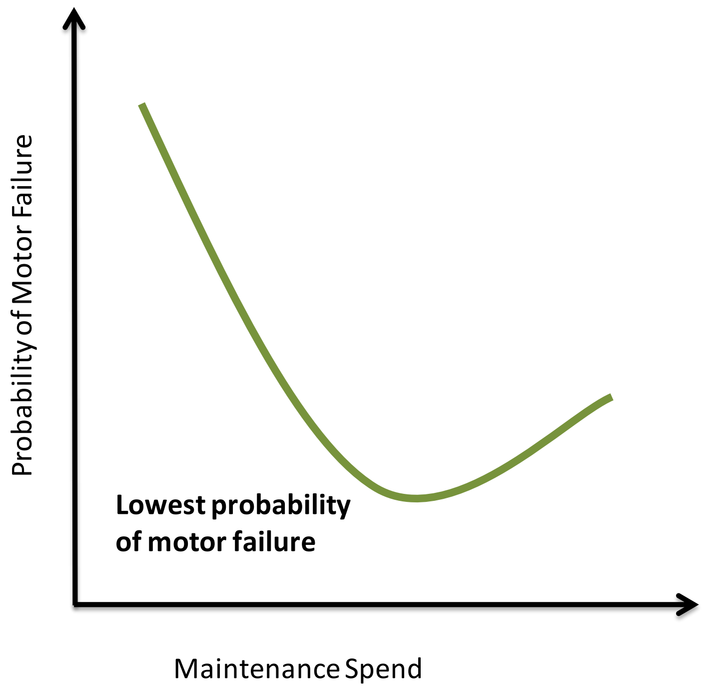


Figure 4—Risk of failure and maintenance spend – the cost of excessive maintenance.

LEARNING FROM MOTOR FAILURES

When a motor fails, it can be considered as an opportunity to investigate the cause of that failure, from which changes can be made to reduce the likelihood of similar failures in the future. For example, it may be possible to adjust the maintenance procedures, operating conditions or condition monitoring of similar motors in order to reduce the risk of recurrence of the same faults on other motors. Preventative actions might include the use of soft starters to reduce starting torque shocks, larger or more efficient motors to give an improved temperature margin, or more attention to the fitting of bearings and shaft alignment.

TECHNIQUES FOR CONDITION MONITORING OF MOTORS

INTRODUCTION & OVERVIEW

For the purposes of this section, we distinguish between motors by their operating voltage. Low voltage (LV) motors are usually classed as motors that run at less than 1,000 V, and will have randomly wound copper windings that are insulated with enamel. High voltage (HV) motors operate at voltages above 1,000 V, with windings formed into a regular shape to achieve the optimum voltage gradient between the conductors and earth, and have mica based insulation.

LV motors are usually smaller than HV motors for the same rating, and due to their simpler winding arrangement are generally less expensive. Due to the difference in the way HV and LV motors are wound, the methods of testing differ and will affect the design of an MMRP. Some tests are common to both, others are specific to HV.

The gradual improvements in operating temperature margins resulting from the use of improved wire insulation mean that the most common source of motor faults is the bearings, which consequently should be the main focus of attention in an MMRP. Fortunately, simple tests are available to quickly identify the condition of bearings, and so this will often be at the top of the list of monitoring techniques to use.

The following are summaries of what can be achieved by different types of condition monitoring and tests applied to motors. For more detailed descriptions of these techniques, see the bibliography for further reading.

MOTOR MONITORING METHODS

TEMPERATURE MONITORING

Understanding what exactly is a safe or normal operating temperature is essential but not always that easy. It will be influenced by several factors:

- Design of motor
- Ambient (local) temperature
- Load factor
- Ventilation method
- Voltage supply (voltage level, balance and distortion)

Even so, understanding when there is a temperature related problem is difficult, and so looking at the motor temperature history, or comparing with similar motors can be very helpful. Several potential problems should be looked for:

- Bearing over-heating, especially of the hotter Drive End, (the Non Drive End or NDE has the advantage of forced cooling).
- Local hot spots on the casing, identifying a stator winding fault (less frequent).
- For motors with VSD control there may be additional temperature stress due to both the higher harmonic content of the supply and the reduction in forced cooling if operating at low speeds with high torque loads.

For larger machines, consideration should be given to installing permanent monitoring devices to continuously monitor critical areas such as the bearings and the stator windings. Options for sensors are resistance temperature detectors or thermocouples.

In a low voltage motor, an option is to fit thermistors that can be built in to trip the motor when the temperature increases above a certain point.

It is essential to regularly clean the motor to keep the ventilation paths clear, especially on open ventilated motors (Figure 5). Blocked ventilation is one of the most common causes of overheating of the machine due to restricted cooling.

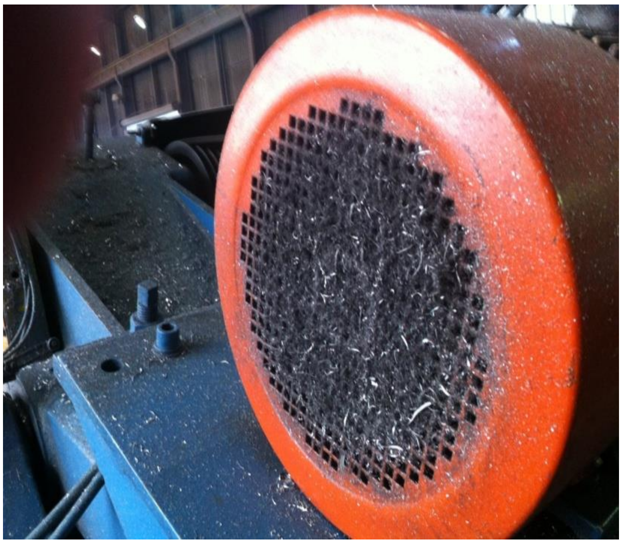


Figure 5 – Partially blocked fan on an induction motor in a metal processing plant. (Atkins)

Figure 6 – Thermal imaging is non-intrusive and so safe and quick to use. (Atkins)

Infra-red thermography (Figure 6) is ideal for quick monitoring, showing temperature across a whole motor very quickly. Spot measurement using infra red thermometers is much less costly than proper thermal imaging cameras, but is considerably more time consuming and it is much harder to spot anomalies that may occur in unexpected places.

Vibration Monitoring

Full bandwidth vibration monitoring is a powerful way of understanding the condition of a motor, and can often be used to pinpoint the precise cause of the vibration by linking the frequency to the different moving components. It is even more valuable when considering vibration in complex systems where there may be a transmission and pump, fan or other driven component in the assembly. Both mechanical and electrical faults can be detected using this method of monitoring. Issues such as: bearing fluting, air gap variation, broken rotor bars and misaligned couplings can all be identified and remedied.

Permanent fixtures such as displacement probes and accelerometers may be attached to the motor in order for the vibration levels to be monitored at all times.

Low cost amplitude only vibration monitoring can quickly assess for overall condition, and is particularly successful at identifying bearing wear.

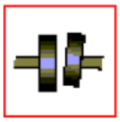
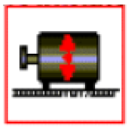
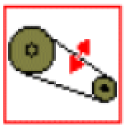
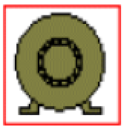
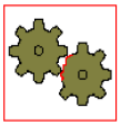
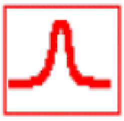
POSSIBLE CAUSE	DOMINANT FREQUENCY	DIRECTION	COMMENTS
Unbalance 	1 x rotational frequency	Radial for dynamic unbalance; possibly axial	Vibration amplitude proportional to unbalance & rpm causes severe vibration.
Misalignment 	2 x rotational frequency	Radial & axial	Severe axial vibration and 2^{nd} harmonic; best realigned using laser.
Bearing defects 	High frequency vibration	Radial & axial loaded position if possible	Use bearing enveloping diagnostic techniques or shock pulse to determine damage severity.
Machine Foundations 	Typically at one or more natural frequencies (transient vibration)	Radial	Natural resonant frequency of foundation or machine base-plate.
Belt vibration 	1 x rotational frequency	Radial	A strobe can compare pulley rotational speed and belt speed in order to identify belt slippage.
Blade pass frequency 	Number of vanes or blades x fundamental frequency	Radial	Vibration frequency represented by the number of blades multiplied by the shaft rotational frequency.
Electrical 	Line frequency, 50Hz or 60 Hz & multiples thereof	Radial & axial	Side bands may also occur at multiples of the rotational frequency. Vibration ceases when power is turned off.
Gear mesh defect 	Gear frequency equal to the number of teeth x rotational frequency of the gear in question	Radial & axial	Side bands occur from modulation of the gear-teeth meshing vibration at the rotational frequency, e.g. the input and output shaft speeds of the gearbox.
Component resonance 	Component's natural frequency	Radial & axial	A component's natural frequency coincides with an excitable frequency.

Table 1 – Using a full frequency vibration analyser it is possible to identify precisely which component is the source of vibration, (Pruftechnik – An Engineer's Guide to Condition Monitoring Alignment and Dynamic Balancing http://www.pruftechnik.com/fileadmin/user_upload/COM/Machinery_Service/PDFs/EngineersGuide2012.pdf).

The standard, ISO 10816 *Mechanical vibration -- Evaluation of machine vibration by measurements on non-rotating parts*, gives definitive values of vibration criticality, making it easy to get a snapshot of performance without a pre-history of the machines vibration profile. Examples of these are shown below, where the Zone boundary corresponds to the vibration limit applicable to different frequency bands.

Table A.1 — Classification of vibration severity zones for machines of Group 1: Large machines with rated power above 300 kW and not more than 50 MW; electrical machines with shaft height $H \geqslant$ 315 mm

Support class	Zone boundary	r.m.s. displacement µm	r.m.s. velocity mm/s
Rigid	A/B	29	2,3
	B/C	57	4,5
	C/D	90	7,1
Flexible	A/B	45	3,5
	B/C	90	7,1
	C/D	140	11,0

Table A.2 — Classification of vibration severity zones for machines of Group 2: Medium-sized machines with rated power above 15 kW up to and including 300 kW; electrical machines with shaft height 160 mm $\leqslant H <$ 315 mm

Support class	Zone boundary	r.m.s. displacement µm	r.m.s. velocity mm/s
Rigid	A/B	22	1,4
	B/C	45	2,8
	C/D	71	4,5
Flexible	A/B	37	2,3
	B/C	71	4,5
	C/D	113	7,1

Table 2 – ISO10816 - Examples of Vibration criticality tables

Oil Sampling and Analysis of bearing lubrication

Bearing selection varies with motor size:

- Small motors commonly use sealed ball and roller bearings, where no monitoring is possible.
- Medium motors commonly contain greased ball and roller bearings, supplemented with additional grease where required.
- Large motors may also have ball and roller bearings, either lubricated with grease or oil, but high speed and large mechanical forces may require the use of white metal oil lubricated bearings.

On oil lubricated motors, the presence of metal or other particles in the oil indicates excessive wear. By analysing the particles found in the sample, the exact component that is deteriorating and leaving particles in the oil can be easily identified, making it easy to schedule a repair. The sample can also show whether the oil is still effective as a lubricant, whether too little oil is flowing, or if the oil is still to the correct specification.

Electrical Tests

There are many electrical tests and investigations that can be used to determine the condition of key constructional factors. Some tests can be done while the motor is still in operation, 'online', while some require the motor to not be in use, 'offline'.

Offline testing allows for more comprehensive testing to be done. Tests include surge test, winding resistance/coil resistance testing, meg-ohm test, polarization index testing, high potential test and step voltage test. Testing the state of the windings by the winding resistance and insulation resistance test is a good way to begin, as any other test will be affected by the winding condition.

Online testing is done whilst the motor is operating, and while tests are more limited, they do have the advantage of reflecting real life operating conditions.

Motor Circuit Analysis

Motor Circuit Analysis is the practice of performing a series of low voltage tests to gather some electrical measurements from various points around the motor and then analysing the results to develop an idea of the condition of the motor. A particular benefit of Motor Circuit Analysis is that it only uses a low voltage signal, so greatly reducing the risk of damaging the motor compared with the application of high voltages.

Partial Discharge (electric insulation testing)

A high voltage motor (> 5 kV) can be monitored for the presence of partial discharge, which occurs in the areas of the insulation where there is a void or poor clearances. This test can be done online or offline. If performed online, there are special capacitors that are connected permanently to the motor so that the capacitive coupling of the winding can be monitored, either continuously or periodically. If the test is being done while the motor is offline, a separate power supply is used to energise the windings at a high voltage so that partial discharge can be investigated. A technique called Electrical Scanning can also be carried out using an Ultrasonic Acoustic Monitor to look for and observe arcing and corona discharge throughout the motor.

Winding Resistance Test

A winding resistance test is a quick and accurate way to check the condition of the conductors in the coil; the results can indicate the existence of short circuits, as well as show any imbalances between phases due to turn count differences. The voltage across the coil is measured once a current has been introduced. The value of the resistance is then calculated and assessed using former measurements of the same kind for comparison. Any change to the resistance is an indication of damage within the winding.

Insulation Resistance and Polarisation Index Tests

The Insulation Resistance test (Winding to Earth test) involves measuring the leakage current when a chosen DC voltage is applied to the motor. The resistance is derived from the leakage current measured 60 seconds after the voltage has been applied. This test can identify ground wall insulation damage, and shorted or contaminated windings.

For high voltage motors, if the winding to earth test provides enough evidence to consider the windings to be in reasonable working condition, then a Polarisation Index test may be carried out. This is carried out in the same way as the Insulation Resistance test, but compares a ten minute figure to that given after one minute. It analyses the insulation walls' capability to polarise. A high capability usually indicates good quality insulation, whereas a low capability usually indicates poor insulation quality or contamination such as moisture. Under some conditions the difficulty of measuring the very low leakage currents means that the results of this test may be inconclusive. The Polarisation Index test would not be used on a low voltage machine.

Surge and HiPot Tests

A surge test and a high potential (HiPot) test are similar in that a voltage larger than the operating voltage is applied to the motor to analyse its behaviour.

A surge test is used to determine whether there is damage or faults in the insulation between the turns in the winding. High voltage transients that a motor experiences under normal operating conditions can ruin the motor's insulation. The test works by replicating the effect of these transients. Each phase of the motor is tested using a value of voltage chosen in reference to the standard functional voltage of the system and the results are examined for signs of a defect. Defects can be discovered at very early stages of a fault. Another benefit of this test is that it limits the amount of energy applied with these transients, meaning that the test can be performed without causing additional damage.

After the manufacturing process a motor will be subjected to a High Potential test. By applying a voltage much higher than the standard operating voltage, twice the working voltage plus 1 kV, from the windings to the frame of the motor, faults within the insulation windings can be identified. This test is usually only performed once at full voltage, as it can cause damage if done multiple times. Sometimes, a user will ask for this to be performed following a repair on the motor. After a minute of applying this high voltage to the motor, the leakage current is measured and analysed. An unusually elevated leakage current is a warning of poor insulation – either phase to phase, or phase to earth.

Step Voltage Test

The Step Voltage test consists of applying a range of increasing DC voltages to the motor. The test will reveal any imperfections in the condition of the insulation by showing a reduction in resistance with increasing voltage. The time this test takes is dependent on how many steps are applied. Usually, a minute per voltage step is counted.

Electrical Signature Analysis

Electrical signature analysis uses the measurement of either voltage or current waveform from a motor to determine whether there is a fault. If this is done frequently, trends can be distinguished and faults can be found before serious damage is caused. However, previous values are not necessarily needed to indicate an existing fault; from examining the signatures received it is possible to see where faults may be developing.

Electrical signature analysis while the motor is running allows a number of different parameters to be tracked. Depending on whether you are focusing on current or voltage, a number of parameters will be monitored at various frequency levels including the level of voltage, the level of current, torque, and any unbalances in the voltage and current.

By recording data for a wide range of values, it increases the chance of discovering a fault early on, which may mean that severe damage can be avoided. It is only effective, however, if the results are actually compared with those previously recorded and trends are looked for, and the results are interpreted properly.

Using this method, many faults can be found including:

- Broken rotor bars

- Abnormal levels of air gap eccentricity
- Mechanical problems
- Rotor winding asymmetry
- Mechanically induced current components due to mechanical influences in the drive train

This form of testing has proven to be the most successful method of detecting broken rotor bars, rotor winding asymmetry and air gap eccentricity.

MOTOR MONITORING METHOD FREQUENCY TABLES

This section gives guidance via Tables 1, 2 and 3, on the type and frequency of condition monitoring that should be applied to different types of motors, according to their criticality. It should be considered as the starting point in the development of your motor monitoring strategy, and if nothing else should present questions for consideration. The definition of "criticality" is left deliberately vague, as it should be defined according to the specific needs of each site.

Notes (for tables on following pages)

1. Only applies if the motor is lubricated by oil.
2. This test would usually only be performed once at the beginning of the motor's life, the only time it would be repeated is following a re-wind.
3. This would only be done after the Polarisation index test has been performed with no issues discovered.
4. This test would not be performed on motors less than 6.6kV.

Key: Coding used for the suggested frequency of condition monitoring

High criticality	Medium criticality	Low criticality	Frequency
1	1	1	> Once a Month, continuously
2	2	2	Once a Month - Once Every Six Months
3	3	3	Once Every Six Months - Once a Year
4	4	4	Once a Year - Once Every Three Years
5	5	5	< Every Three Years
6	6	6	Once

Notes and Key for Tables 3 to 5 showing the coding used for the suggested frequency of condition monitoring

Recommended frequency of monitoring		Low Criticality Motors Typical ratings						
		Very Small LV <1 kW	Small LV 1 kW - 100 kW	Medium LV 100 kW - 1 MW	Large LV >1MW	Small HV <1 MW	Medium HV 1 - 5 MW	Large HV > 5 MW
Tests	Temperature Monitoring	3	2	2	2	2	2	1
	Vibration Monitoring	3	2	2	2	2	2	1
	Oil Sampling and Analysis[1]	Unlikely	2	2	2	2	2	2
	Partial Discharge[4]	No	No	No	No	No	No	No
	Winding Resistance	No	No	No	3	No	3	3
	Insulation Resistance	No	No	No	3	No	3	3
	Polarisation Index	No	No	No	No	No	No	4
	Surge Test	No	No	No	No	No	No	5
	High Potential[2]	6	6	6	6	6	6	6
	Step Voltage[3]	No	No	No	No	No	No	No
	Electrical Signature Analysis	No	No	No	No	No	No	No
	Power Quality	No	No	No	No	No	No	No
	Motor Circuit Analysis	No	No	No	No	No	No	No

Table 3 – Motor monitoring frequency guide - Low Criticality Motors.

Recommended frequency of monitoring		Medium Criticality Motors Typical Ratings						
		Very Small LV <1 kW	Small LV 1 kW - 100 kW	Medium LV 100 kW - 1 MW	Large LV >1MW	Small HV <1 MW	Medium HV 1 - 5 MW	Large HV > 5 MW
Tests	Temperature Monitoring	3	2	2	2	2	2	1
	Vibration Monitoring	3	2	2	2	2	2	1
	Oil Sampling and Analysis[1]	Unlikely	2	2	2	2	2	2
	Partial Discharge[4]	No	No	No	No	4	4	4
	Winding Resistance	No	4	3	3	4	3	3
	Insulation Resistance	No	4	3	3	4	3	3
	Polarisation Index	No	No	No	No	4	4	4
	Surge Test	No	No	No	No	5	5	5
	High Potential[2]	6	6	6	6	6	6	6
	Step Voltage[3]	No	No	No	No	4	4	4
	Electrical Signature Analysis	No	No	No	No	No	No	No
	Power Quality	No	No	No	No	No	No	No
	Motor Circuit Analysis	No	No	No	No	No	No	No

Table 4 – Motor monitoring frequency guide - Medium Criticality Motors.

Recommended frequency of monitoring		High Criticality Motors Typical Ratings						
		Very Small LV <1 kW	Small LV 1 kW - 100 kW	Medium LV 100 kW - 1 MW	Large LV >1MW	Small HV <1 MW	Medium HV 1 - 5 MW	Large HV > 5 MW
Tests	Temperature Monitoring	3	2	2	2	2	2	1
	Vibration Monitoring	3	2	2	2	2	2	1
	Oil Sampling and Analysis[1]	Unlikely	2	2	2	2	2	2
	Partial Discharge[4]	No	No	No	No	4	4	4
	Winding Resistance	4	4	3	3	4	3	3
	Insulation Resistance	4	4	3	3	4	3	3
	Polarisation Index	No	No	No	No	4	4	4
	Surge Test	No	5	5	5	5	5	5
	High Potential[2]	6	6	6	6	6	6	6
	Step Voltage[3]	No	No	No	No	4	4	4
	Electrical Signature Analysis	No	5	5	4	5	4	3
	Power Quality	No	5	5	5	5	5	5
	Motor Circuit Analysis	No	5	4	3	4	3	3

Table 5 – Motor monitoring frequency guide - Highly Critical Motors.

Organising for Effective Motor Management

Employers and Employees

Maintenance programmes may sometimes be weakened through to reduced budgets or staff changes, including loss of key supporters, knowledgeable parties or simply reduced numbers. It is therefore important for senior management to take an interest in supporting and ensuring the success of maintenance programmes, reacting to any organisational changes that might affect performance.

It is also beneficial for the asset management operations to be undertaken separately from daily tasks, as this allows the maintenance team to focus purely on the motors and the longer term outcomes of their decisions. Operators also have a role to play when identifying a change in normal operating conditions such as excess vibration, change in noise or increased temperature. Continuous condition monitoring is used to highlight changes from normal operating conditions to pre-empt failure, thereby enabling the maintenance to be carried out in a pre-planned manner.

Information Management

Finally, reliable and well organised information is indispensible in the operation of an effective MMRP.

One option is to establish a motor database that tracks the work undertaken on each electric motor. It should also incorporate operational data and measurement results to generate an individual record for each motor and an overall record for each site. Key considerations for such a system include:

- How well it performs its main function to store and categorise motor data by location and equipment served;

- The level of experience of the staff who will be using the system, which will influence the choice of proprietary system;
- Integration of the results of previous condition monitoring;
- Whether other tasks can be incorporated, such as maintaining the spare motors inventory.

However, before embarking on what will undoubtedly be a time consuming exercise, very careful consideration must be given to understanding how well it will actually work in practice. Many such computerised systems have fallen into disuse because of the time needed to update details, and the lack of obvious benefit to those responsible for doing so. A computerised maintenance management scheme will not resolve more deeply seated problems of the organisation and management of maintenance.

References

1. Uptime Magazine Aug/Sep 2008: "Electric Motors and Their Management" http://articles.uptimemagazine.com/uptime/motor_testing/
2. EASA/AEMT Whitepaper: "The Results are in: Motor Repair's Impact on Efficiency", 2002, http://www.eemsco.com/Documents/Motor%20Repair%20Efficiency%20Results.pdf
3. Uptime Magazine Dec 2012/Jan 2013: "Improved Reliability through electrical motor testing", pages 22-25 http://www.nxtbook.com/nxtbooks/reliabilityweb/uptime_20131201/#/26
4. SKF – "Maintenance, reliability and asset optimization" http://www.skf.com/files/690979.pdf

Bibliography

- ISO 10816-3:2009 Mechanical vibration – Evaluation of machine vibration by measurements on non-rotating parts -- Part 3: Industrial machines with nominal power above 15 kW and nominal speeds between 120 r/min and 15 000 r/min when measured in situ.
- European Copper Institute – White Paper: Electric Motor Asset Management, ECI No. Cu0104, July 2011
- Uptime Magazine June/July 2012: "Motor Performance Management", Pages 23-26 http://www.nxtbook.com/nxtbooks/reliabilityweb/uptime_20120607/#/28
- Article by the Plant Maintenance Resource Centre (Industrial Maintenance Portal): "Motor PDM", http://www.plant-maintenance.com/articles/Motor_PDM.pdf
- SKF Evolutions Article: 'Electric moves', 2 June 2008, http://evolution.skf.com/electric-moves/
- Baker Instrument Company – "On-Line and Off-Line Testing of Electric Motors", http://www.skf.com/files/692664.pdf
- EASA/AEMT study: "The Effect of Repair/Rewinding on Motor Efficiency", 2003, http://www.iecex.com/dubai/speakers/Day%202C_1100-1200_John_Allen_EASA_Rewind_Study1203.pdf
- Baker Instrument Company – "Testing Theories and Recommendations", http://www.skf.com/files/690979.pdf

- All-Test Pro Whitepaper: “A Review of Polarization Index and IEEE Standard 43-2000”, http://www.alltestpro.com/fileadmin/user_upload/PDFs/A_review_of_polarization_index_and_IEEE_standard_43-2000.pdf
- SKF – “Integrated Condition Monitoring”, http://www.skf.com/binary/12-75560/Interactive-brochure-SKF-Integrated-Condition-Monitoring.pdf
- NETA WORLD, Spring 2008, “Insulation Resistance Testing: How Many Megohms Does it Take to Start a Motor?”, http://www.netaworld.org/sites/default/files/public/neta-journals/NWsp08%20-%20Bishop.pdf
- AEMC Instruments, “Understanding Insulation Resistance Testing”, http://www.powercet.com/uploads/files/AE_Understnd_Insulation_Res_Testing.pdf