Predictive Maintenance Techniques

Applying Predictive Maintenance Techniques to Utility Systems

by Padraig Liggan and David Lyons

Introduction

Pharmaceutical production is one of the most heavily regulated industries. With such an emphasis on product quality within the industry and with such economic and health consequences due to machine failure, the maintenance team plays a crucial role in the success of the product. It is the maintenance department’s responsibility to ensure equipment is kept to its maximum operating condition. It must predict and prevent failures and repair any problems which may already have led to a failure, while adhering to the rules and procedures set out by the respective regulatory bodies. In addition, critical GMP utility systems supporting production are qualified and associated documentation is needed to prove that equipment serves its function consistently as per the design.

This often leads to maintenance departments performing more work than is necessary to increase assurance of equipment reliability, even if these extra precautions do not necessarily provide any additional benefits.

During the qualification of these systems, the maintenance program is developed and put in place. To change the content of maintenance after this can prove difficult as strict change control procedures often need to be followed and full documented justification needs to be provided. This can sometimes lead to maintenance programs being left as is and the opportunity for continuous improvement missed.

In recent year’s, regulatory agencies such as the US Food and Drug Administration (FDA) and the Irish Medicines Board (IMB) have become more supportive of emerging modern maintenance techniques. Tools such as Reliability Centered Maintenance (RCM) and the use of the many sciences involved in Predictive Maintenance (PdM) are seen as a way of improving the maintenance function. This is allowing pharmaceutical companies to become more cost competitive while still ensuring utmost quality to the pharmaceutical products end user: the patient.

What is PdM?

Most modern industries are moving toward a 24/7 production schedule; the supporting equipment and systems availability need to keep up. No longer do maintenance departments have the luxury of extended periods of available equipment downtime in order to carry out maintenance, instead the maintenance function is moving toward a more predictive approach. This is where the modern technologies of PdM are now predominately being used to effectively monitor performance of equipment and plan maintenance interventions in a timely manner.

PdM is a group of emerging scientific technologies that can be employed to detect potential failures that may not be evident through a preventative maintenance program. If the failure characteristics of the equipment are known, PdM can detect the failure well in advance and appropriate actions can be taken in a planned manner. The use of condition based maintenance has dramatically reduced non-value added maintenance by eliminating the need to unnecessarily shutdown equipment for maintenance checks.

Some of the main technologies currently used in industry are listed below:

- Thermography – infra-red imaging to detect abnormal temperatures or hot spots.
- Vibration monitoring – accelerometer instruments can be used to detect abnormal or high vibration particularly in bearings.
- Oil analysis – sampling of oil (which is then analyzed) can detect the deterioration or breaking down of an internal equipment part.
Predictive maintenance Techniques

PdM Technique | Applications
--- | ---
Vibration Analysis | Rotating Equipment/Drive Systems, Structural Vibration, Motors, Fan Balancing
Oil Analysis | Component Wear and Tear, Oil Degradation, Water Ingress in Oil, Equipment Overheating
Ultrasonic Detection | Steam Trap Testing, Leak Detection, Electrical Arcing, Valve Integrity
Thermal Imaging | Electrical Overheating, Steam Trap Testing, Mechanical Overheating, Insulation Checks

Table A. Typical utility system applications for PdM.

- Ultrasonic measurement – use of ultrasound technologies to detect leaks or blockages on utility systems.

PdM is a relatively new science and has clear benefits in the industry; however, there is a danger of relying too much on these technologies. There must be a fine balance between PdM and conventional maintenance practices.

"Is predictive maintenance a burden or benefit?" PdM will give maintenance personnel ample warning of a potential failure, but may take the focus away from the actual root cause of the failure. For a truly effective predictive maintenance program, a balanced cost (based on the risk and consequence of equipment failure) should be spent on PdM, but also it should only be used as a first step into determining why the equipment being monitored is starting to fail and what are the possible contributions. This is where the experienced maintenance professionals are still an important part of the maintenance process.

This article will present four of the main types of PdM that can be applied to the maintenance program for GMP critical utilities and also highlight the results an organization can hope to achieve.

**PdM – an Overview of the Applications and Benefits**

Predictive maintenance has become a key part of the modern maintenance department and more and more companies are taking on board these technologies in order to maximize the reliability of their equipment by detecting failures well in advance. Some failure modes cannot be designed out (i.e., mechanical bearings are here to stay, electrical panels will always be an integral part of any system), but if failures can be detected early, the maintenance team can plan the work in an organized manner. Unplanned breakdown maintenance can cost as much as three times that of planned maintenance so PdM is of significant benefit. Detecting a failure early means that the level of damage that can follow an actual failure also can be avoided or reduced. An example would be when a bearing failure occurs on an air handling unit fan, this can have disastrous consequences on the internals of the fan, which may start breaking up and the fan shaft may become damaged beyond repair. If this example was to be presented in terms of cost only:

- Case 1 (with PdM) – potential bearing failure is detected using vibration analysis, replacement cost of bearing ~ $100’s
- Case 2 (without PdM) – no vibration analysis program, catastrophic failure of fan bearing causing fan impellers to break and the shaft is beyond repair, cost of new fan ~ $1000’s + cost of downtime to manufacturing.

Companies often choose to initially outsource predictive maintenance services and then invest over time for internal training on the techniques and the purchasing of equipment. Either way, it is clear that PdM can pay for itself many times over and this is why it is becoming so popular. Table A gives a high-level overview of typical utility system applications for PdM.

**Vibration Analysis**

**Vibration Analysis Principles**

Vibration can be defined as simply the cyclic or oscillating motion of a machine or machine component from its position of rest. It is normal for all machines to have some level of small vibration; however, when this vibration increases or becomes excessive, it usually indicates a mechanical fault of some description. Vibration analysis uses accelerometer instruments to detect these vibration movements, the results of these vibration readings can be plotted (magnitude Vs frequency) using a mathematical representation called Fast Fourier Transform (FFT). The FFT plot will highlight the level of vibration and identify which frequencies they are present in. The frequencies present are related to the machine cyclic movement, such as RPM, and by using this data the origin of the fault can be determined.

Figure 1 shows a typical vibration plot for a motor drive unit, the different frequencies present relate to the different moving components within the drive unit. Each element in the drive system operates at different frequencies and the magnitude of the vibration is used to determine if a fault exists. The vibration levels or magnitude levels also will tell the vibration analyst how severe the vibration is and whether any action is needed. It is common in industry to take a set of

![Figure 1. Typical vibration analysis FFT plot (magnitude vs. frequency).](image-url)
baseline readings when the equipment is first installed, the condition of the equipment can then be trended over time and areas of deterioration can be identified. Vibration analysis is quite a complex subject and takes a lot of mechanical expertise and training in order to become proficient. The vibration analysis plots can often contain multiple fault frequencies and in order to determine their origin, the analyst needs to have detailed knowledge of the operating characteristics of the equipment (such as number of fan blades, RPMs, pulley ratios, bearing types, etc.). For this reason, false diagnosis can sometimes be a problem. With the correct training and mechanical proficiency, the following types of problems can be determined using vibration analysis:

- misalignment of drive systems
- unbalance of rotary components
- mechanical looseness
- bearing deterioration and gear wear
- belt deflection

As mentioned above, accelerometer instruments are used to detect levels of vibration. These instruments can be used in the following ways in order to collect the data:

- The accelerometer instrument is placed manually on the selected equipment location. The data is collected onto a storage device for further analysis using computer software. These storage devices known as “vibration analysis data packs” also allow some basic analysis to be completed at the equipment being measured.
- Accelerometer instruments are fixed to the selected equipment location. The readings are taken at specified intervals and analyzed further. (This is particularly useful for difficult to access locations such as continually operating enclosed drive systems.)
- Accelerometer instruments are fixed to the selected equipment location and are also connected directly to a plant management software system, such as Distributed Control System (DCS). These accelerometers also can be connected to wireless data sending devices which allows remote monitoring and analysis to be carried out.

The following is an example of data that is required to setup an initial vibration analysis program for a complex rotary drive system:

- motor rating (KW)
- RPM
- motor non drive end bearing type
- motor drive end bearing type
- fan/pump drive end bearing type
- fan/pump non drive end bearing type
- driver pulley size
- driven pulley size
- belt length and number of belts
- gearbox ratio
- pump/fan vanes (number of)

### Vibration Analysis – Practical Applications

Table B shows a sample vibration analysis program for a large pharmaceutical manufacturing site and the type of equipment typically covered. Note that for utilities equipment operating 24/7, the vibration analysis inspection intervals for bearings are typically three months. The reason being that, the P-F interval for a bearing (P-F means from the point the failure is detectable to the time of failure) is typically around four months. By inspecting at three monthly intervals, the VA program is more likely to detect bearing failure onset before becoming catastrophic. P-F intervals can vary for different types of components with wear-out operational characteristics; the probability of detecting the onset of a component failure is increased by ensuring the PdM inspection interval is less than the P-F interval.

### Thermal Imaging

**Thermal Imaging Principles**

Thermal imaging uses Infra-Red (IR) technology to identify high temperature areas on the surface of equipment. Thermal imaging is used primarily on electrical panels to identify loose contacts or overheating of cables, but there are other ranges of applications, such as checking for blockages in pipes or carrying out heat surveys in plant rooms. Typical equipment used is an infra-red camera which can range in cost from $10,000-$40,000 and usually comes with a software package to load, store, and compile results. Use of the infra-red camera requires specific training as setting up of the camera and interpretation of results requires a level of expertise. It is better to have an electrically competent person carrying out thermal imaging surveys as the causes of faults particularly in electrical panels can be diagnosed straight away giving the maintenance team useful information before carrying out repair works. It is important to note that infra-red imaging requires a direct exposure to the surface being measured; infra-red cannot penetrate through surfaces, such as glass or plastic, unless specifically designed IR windows are installed. When setting up the IR camera the emissivity factor (ε) is an important parameter. Emissivity is a heat factor which allows for the material type being scanned, its color and the angle of heat being radiated. A true black body would have an emissivity factor of ε = 1 with other surfaces being less ε < 1. Its value is important because if not set correctly, the true temperature reading could be offset; there are ranges of emissivity settings available for common types of material, such as PVC coated cables in electrical panels.
**Thermal Imaging – Practical Applications**

Figure 2 shows a thermal scan of a cleanroom air handling unit electrical isolator taken in 2007, the top left photo shows a normal exposure and the shot on the right is a thermal image. This particular fault was severe with a maximum temperature of 133.2°C (271.8°F).

The fault, found on the incoming cables, was due to internal deterioration of the cable and was creating excessive heat. A condition like this unattended over time would eventually cause the equipment to fail and possibly lead to fire. Once the maintenance team are notified, this fault can be repaired by replacing the cables and ensuring all connections are secure. The repaired panel is then rescanned to ensure that the fault no longer exists.

As mentioned at the beginning of this section, there are other applications that thermal imaging can be used. In 2006, due to concerns of excessive heat in a plant, it was decided to carry out a thermal scan of the area utilities to identify hot spots which could then be insulated and help reduce overall heat levels in the plant room.

Figure 3 shows a thermal scan of a clean water system’s pipework and valves, showing temperatures of approximately...
70°C (158°F). Following lagging of the identified pipework and valves, the temperature was reduced by around 30°C (86°F). This survey was carried out for the entire plant room and identified numerous areas of equipment where excessive heat was being given off and contributing to the overall high temperatures in the plant room. This also led to efficiencies in terms of energy costs.

Thermal imaging can be readily applied to the following general categories of electrical distribution boards:

- small low voltage (220 to 380V) panels (i.e., miniature circuit breaker boards)
- large low voltage (220 to 380V) panels (i.e., motor control centers)
- medium voltage (<1000V) switchgear panels

Table C shows the sample array of equipment on the thermal imaging program for a large pharmaceutical manufacturing site.

### Oil Analysis

#### Oil Analysis Principles

Oils, greases, and other lubricants are commonly used in equipment with moving parts, such as gears and bearings. There are specific grades of lubricants that are suited to different applications. If the grade of lubricant used is known, the chemical properties of the lubricant can be tested. Using oil analysis the quality of the lubricant and material constituents can be tested and compared against the original specification. Oil analysis can be used to determine when an oil change out is required, but also can detect wear of internal components. The following gives some examples of where the oil change would supercede change frequency based on run hours:

- high iron content indicating wear and tear (may require further investigation of the equipment)
- breakdown in the oil additives
- high water content
- changes in viscosity levels

For example, if the gears inside a machine are wearing, fragments of metal are deposited in the oil. When the oil is tested, traces of this metal debris shows up and will give the maintenance team prior warning of a potential failure. The type of metal detected also will give useful information as to its origin (i.e., bearing or gears, etc.). The oil samples are generally taken by technicians in-house and then sent to specialist chemical labs for testing, following which the test results will be issued.

#### Oil Analysis – Practical Applications

Oil analysis programs allow a condition based approach to oil changes rather than a fixed interval or by equipment run hours.

Results obtained from the oil analysis program can identify optimum frequencies for oil changes and also indicate equipment deterioration and overheating. The oil analysis reports are compiled for the equipment sampled using lab results and circulated to the maintenance area owners giving useful information to act on. Refrigeration compressors, air compressors, standby electrical generator engines, and electrical transformers are among common equipment that oil analysis programs can be applied to.

### Ultrasonic Measurement

#### Ultrasonic Measurement Principles

Ultrasonic measurement is primarily used for leak detection on steam and air systems, but it also can be used to detect leaking valves.

Ultrasonic measurement instruments translate high frequency sounds produced by steam or air leaks into the audible range were users hear them through head phones and can view these sounds on a meter or display. The high-frequency ultrasonic components of these sounds are extremely short wave signals that tend to be fairly directional. It is easy to isolate these signals from background plant noises and detect their exact location. Figure 4 shows an ultrasonic measurement device.

#### Ultrasonic Testing of Steam Traps – Principles

As mentioned at the beginning of this section, ultrasonic measurement is primarily used for checking the operating condition of steam systems traps. Steam traps are used on steam distribution lines to remove unwanted condensate build up. When a steam trap fails, the build up of conden-
Predictive Maintenance Techniques

Table D. 2010 summary of results.

<table>
<thead>
<tr>
<th>Application/Faults Identified</th>
<th>Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal Imaging</td>
<td>Avoidance of equipment faults occurring/overheating/serious incidents.</td>
</tr>
<tr>
<td>— 31 faults found in electrical panels</td>
<td></td>
</tr>
<tr>
<td>Thermal imaging used to survey the insulation of the site steam distribution. Recommendations for insulation repairs and upgrades were issued.</td>
<td>Initial estimates show a potential reduction of the annual cost of steam generation by 3%.</td>
</tr>
<tr>
<td>Vibration Analysis</td>
<td>Level 3 faults are classified as “failure imminent.” For GMP systems feeding production an equipment failure could have severe impact.</td>
</tr>
<tr>
<td>— 26 Level 3 faults requiring bearing changes</td>
<td></td>
</tr>
<tr>
<td>— 25 Level 2 faults requiring belt changes, greasing, or balancing</td>
<td>Level 2 faults are classified as “high vibration.” This maintenance teams have adequate time to plan for remedial action.</td>
</tr>
<tr>
<td>Ultrasonic Inspection</td>
<td>Savings identified based on energy losses due to steam leaking to drain.</td>
</tr>
<tr>
<td>— 16 steam traps found failed and were replaced/repaired</td>
<td></td>
</tr>
<tr>
<td>— Ultrasonic leak inspection program on the site compressed air distribution</td>
<td>Savings identified on manifolds and valves found to be leaking compressed air.</td>
</tr>
<tr>
<td>Oil Analysis</td>
<td>Condition based approach to oil change outs and detection of equipment related wear degradation.</td>
</tr>
<tr>
<td>— Oil change outs on site are condition based</td>
<td></td>
</tr>
<tr>
<td>— A number of oil changes were prompted following oil analysis results</td>
<td></td>
</tr>
<tr>
<td>Laser Alignment</td>
<td>Reduction in seal, bearing wear and energy usage compared with poor alignment.</td>
</tr>
<tr>
<td>— Alignment of 9 motor/pump arrangements to industry standard</td>
<td></td>
</tr>
</tbody>
</table>

**Expected Results**

This section gives an overview of the 2010 summary of results for a mature PdM program applied to utility systems at a large pharmaceutical/biopharmaceutical plant (90 acre site). Table D – 2010 provides the summary of results.

**Summary and Conclusions**

This article has presented in detail the emerging area of Predictive Maintenance (PdM) which has many applications for utility systems in the pharmaceutical industry. PdM is a widely accepted approach to the maintenance strategy for both GMP and non-GMP utilities equipment. The benefits of PdM can be seen and it also promotes a proactive approach to maintenance. Any facility with utility systems should employ some methods of PdM. Initial investment is negligible as PdM programs have been shown to pay for themselves many times over through increased plant reliability and a more proactive approach to maintenance.

**References**


**Further Reading**


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