Chapter 6 Predictive Maintenance Technologies

6.1 Introduction

Predictive maintenance attempts to detect the onset of a degradation mechanism with the goal of correcting that degradation prior to significant deterioration in the component or equipment. The diagnostic capabilities of predictive maintenance technologies have increased in recent years with advances made in sensor technologies. These advances, breakthroughs in component sensitivities, size reductions, and most importantly, cost, have opened up an entirely new area of diagnostics to the O&M practitioner.

As with the introduction of any new technology, proper application and **TRAINING** is of critical importance. This need is particularly true in the field of predictive maintenance technology that has become increasingly sophisticated and technology-driven. Most industry experts would agree (as well as most reputable equipment vendors) that this equipment should not be purchased for in-house use if there is not a serious commitment to proper implementation, operator training, and equipment monitoring and repair. If such a commitment cannot be made, a site is well advised to seek other methods of program implementation—a preferable option may be to contract for these services with an outside vendor and rely on their equipment and expertise.

Table 6.1.1 below highlights typical applications for some of the more common predictive maintenance technologies. Of course, proper application begins with system knowledge and predictive technology capability – before any of these technologies are applied to live systems.

Table 6.1.1. Common predictive technology applications (NASA 2000)

Technologies	Applications	Pumps	Electric Motors	Diesel Generators	Condensers	Heavy Equipment/ Cranes	Circuit Breakers	Valves	Heat Exchangers	Electrical Systems	Transformers	Tanks, Piping
Vibration Monitoring/Analysis		X	X	X		X						
Lubricant, Fuel Analysis		X	X	X		X					X	
Wear Particle Analysis		X	X	X		X						
Bearing, Temperature/Analysis		X	X	X		X						
Performance Monitoring		X	X	X	X				X		X	
Ultrasonic Noise Detection		X	X	X	X			X	X		X	
Ultrasonic Flow		X			X			X	X			
Infrared Thermography		X	X	X	X	X	X	X	X	X	X	
Non-destructive Testing (Thickness)					X				X			X
Visual Inspection		X	X	X	X	X	X	X	X	X	X	X
Insulation Resistance			X	X			X			X	X	
Motor Current Signature Analysis			X									
Motor Circuit Analysis			X				X			X		
Polarization Index			X	X						X		
Electrical Monitoring										X	X	

6.2 Thermography

6.2.1 Introduction

Infrared (IR) thermography can be defined as the process of generating visual images that represent variations in IR radiance of surfaces of objects. Similar to the way objects of different materials and colors absorb and reflect electromagnetic radiation in the visible light spectrum (0.4 to 0.7 microns), any object at temperatures greater than absolute zero emits IR energy (radiation) proportional to its existing temperature. The IR radiation spectrum is generally agreed to exist between 2.0 and 15 microns. By using an instrument that contains detectors sensitive to IR electromagnetic radiation, a two-dimensional visual image reflective of the IR radiance from the surface of an object can be generated. Even though the detectors and electronics are different, the process itself is similar to that a video camera uses to detect a scene reflecting electromagnetic energy in the visible light spectrum, interpreting that information, and displaying what it detects on a liquid crystal display (LCD) screen that can then be viewed by the device operator.

Because IR radiation falls outside that of visible light (the radiation spectrum to which our eyes are sensitive), it is invisible to the naked eye. An IR camera or similar device allows us to escape the visible light spectrum and view an object based on its temperature and its proportional emittance of IR radiation. How and why is this ability to detect and visualize an object's temperature profile important in maintaining systems or components? Like all predictive maintenance technologies, IR tries to detect the presence of conditions or stressors that act to decrease a component's useful or design life. Many of these conditions result in changes to a component's temperature. For example, a loose or corroded electrical connection results in abnormally elevated connection temperatures due to increased electrical resistance. Before the connection is hot enough to result in equipment failure or possible fire, the patterns are easily seen through an IR imaging camera, the condition identified and corrected. Rotating equipment problems will normally result in some form of frictional change that will be seen as an increase in the component's temperature. Faulty or complete loss of refractory material will be readily seen as a change in the components thermal profile. Loss of a roof's membrane integrity will result in moisture that can be readily detected as differences in the roof thermal profile. These are just a few general examples of the hundreds of possible applications of this technology and how it might be used to detect problems that would otherwise go unnoticed until a component failed and resulted in excessive repair or downtime cost.

6.2.2 Types of Equipment

Many types of IR detection devices exist, varying in capability, design, and cost. In addition, simple temperature measurement devices that detect IR emissions but do not produce a visual image or IR profile are also manufactured. The following text and pictures provide an overview of each general instrument type.

Figure 6.2.1. Typical IR spot thermometer

Spot Radiometer (Infrared Thermometer) – Although not generally thought of in the world of thermography, IR thermometers use the same basic principles as higher end equipment to define an object's temperature based on IR emissions. These devices do not provide any image representative of an object's thermal profile, but rather a value representative of the temperature of the object or area of interest.

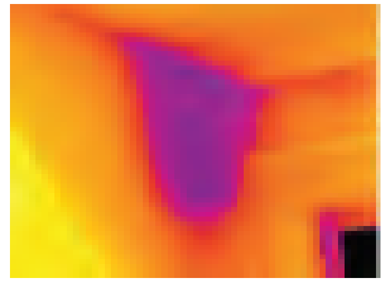


Figure 6.2.2. Internal house wall. Note dark area indicating cooler temperatures because of heat loss.

Infrared Imager – As indicated earlier, equipment capabilities, design, cost, and functionality vary greatly. Differences exist in IR detector material, operation, and design. At the fundamental level, IR detection devices can be broken down into two main groups – imagers and cameras with radiometric capability. A simple IR imager has the ability to detect an object's IR emissions and translate this information into a visual image. It does not have the capability to analyze and quantify specific temperature values. This type of IR detection device can be of use when temperature values are unimportant and the object's temperature profile (represented by the image) is all that is needed to define a problem. An example of such an application would be in detecting missing or inadequate insulation in a structure's envelope. Such an application merely requires an image representative of the differences in the thermal profile due to absence of adequate insulation. Exact temperature values are unimportant.

IR cameras with full radiometric capability detect the IR emissions from an object and translate this information into a visible format as in the case of an imager. In addition, these devices have the capability to analyze the image and provide a temperature value corresponding to the area of interest. This capability is useful in applications where a temperature value is important in defining a problem or condition. For example, if an image indicated a difference between a pulley belt temperature and an ambient temperature, the belt may have worn, be the wrong size, or indicate a misalignment condition. Knowing the approximate temperature differences would be important in determining if a problem existed.

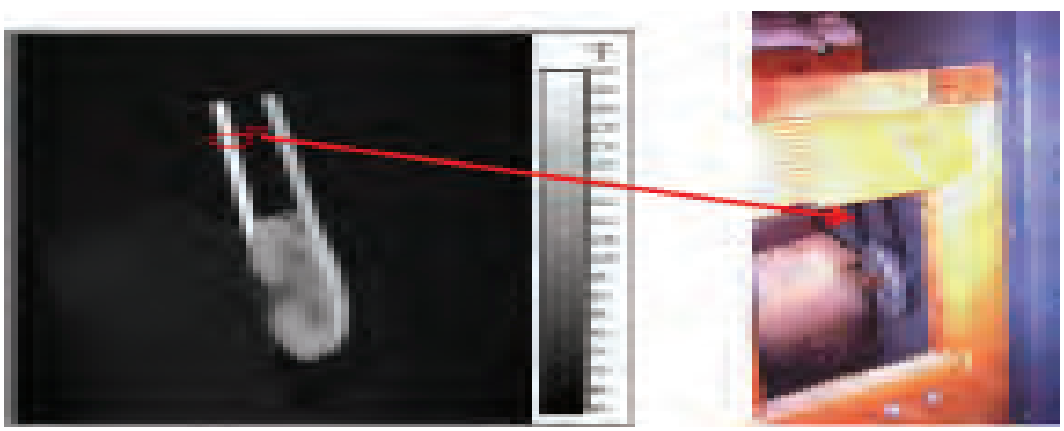


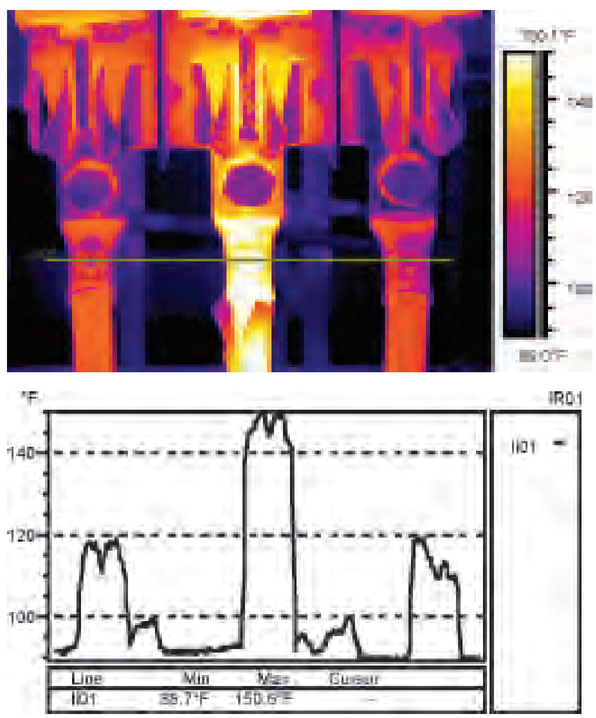
Figure 6.2.3. Temperature is used in defining belt problems. Figure shows a belt temperature of 149°F, and ambient temperature of 67°F for a difference of 82°F. The difference should be trended over time to determine slippage that would be indicated by a higher temperature difference.

6.2.3 System Applications

6.2.3.1 Electrical System Applications

The primary value of thermographic inspections of electrical systems is locating problems so that they can be diagnosed and repaired. “How hot is it?” is usually of far less importance. Once the problem is located, thermography and other test methods, as well as experience and common sense, are used to diagnose the nature of the problem. The following list contains just a few of the possible electrical system-related survey applications:

- Transmission lines
  - Splices
  - Shoes/end bells
    - Inductive heating problems
  - Insulators
    - Cracked or damaged/tracking
- Distribution lines/systems
  - Splices
  - Line clamps
  - Disconnects
  - Oil switches/breakers
  - Capacitors
  - Pole-mounted transformers
  - Lightning arrestors
  - Imbalances
- Substations
  - Disconnects, cutouts, air switches
  - Oil-filled switches/breakers (external and internal faults)
  - Capacitors
  - Transformers
    - Internal problems
    - Bushings
    - Oil levels
    - Cooling tubes
    - Lightning arrestors
  - Bus connections
- Generator Facilities
  - Generator
    - Bearings
    - Brushes
    - Windings
    - Coolant/oil lines: blockage
  - Motors
    - Connections
    - Bearings
    - Winding/cooling patterns
    - Motor Control Center
    - Imbalances
- In-Plant Electrical Systems
  - Switchgear
  - Motor Control Center
  - Bus
  - Cable trays
  - Batteries and charging circuits
  - Power/Lighting distribution panels



Software analysis tools can quantify and graphically display temperature data. As shown above, the middle conductor/connection is a much higher temperature indicating a loose connection.

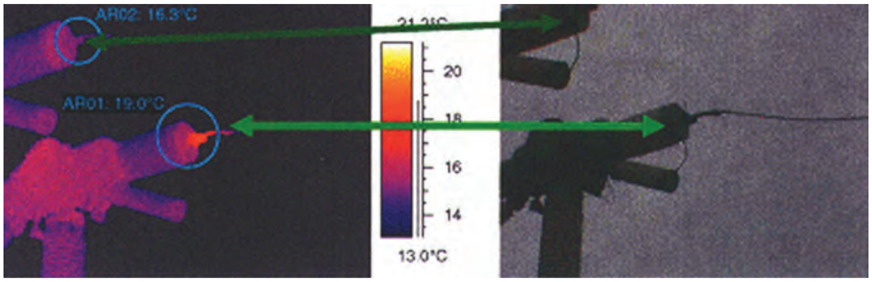


Figure 6.2.4. Air breaker problem. Highlighted by temperature difference between two different breakers. Likely caused by poor connection.

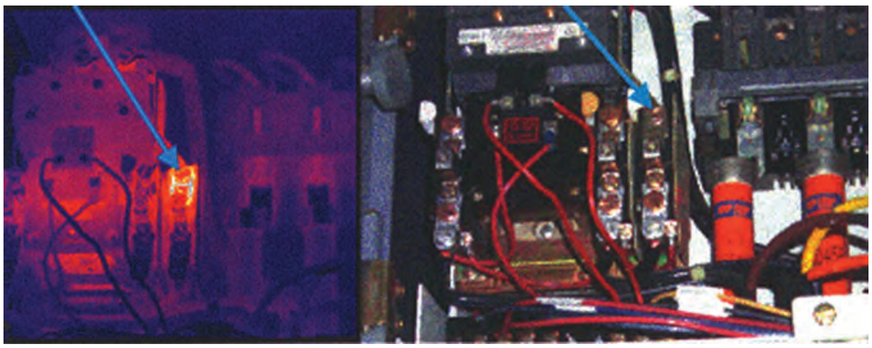


Figure 6.2.5. Overloaded contacts show different temperature profiles indicating one contact seeing much greater load, a potentially unsafe situation.

6.2.3.2 Mechanical System Applications

Rotating equipment applications are only a small subset of the possible areas where thermography can be used in a mechanical predictive maintenance program. In addition to the ability to detect problems associated with bearing failure, alignment, balance, and looseness, thermography can be used to define many temperature profiles indicative of equipment operational faults or failure. The following list provides a few application examples and is not all inclusive:

- Steam Systems
  - Boilers
    - Refractory
    - Tubes
  - Traps
  - Valves
  - Lines
- Heaters and furnaces
  - Refractory inspections
  - Tube restrictions
- Fluids
  - Vessel levels
  - Pipeline blockages
- Environmental
  - Water discharge patterns
  - Air discharge patterns
- Motors and rotating equipment
  - Bearings
    - Mechanical failure
    - Improper lubrication
  - Coupling and alignment problems
  - Electrical connections on motors
  - Air cooling of motors

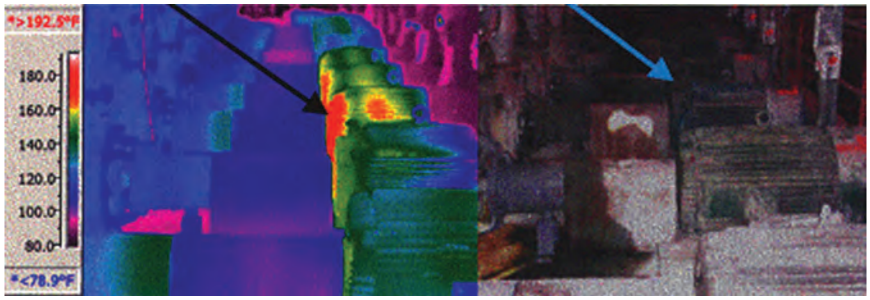


Figure 6.2.6. IR scans of multiple electric motors can highlight those with hot bearings indicting an imbalance or wear problem.

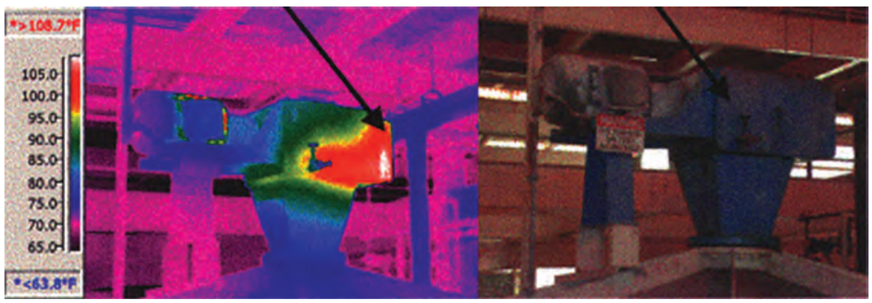


Figure 6.2.7. Possible gearbox problem indicated by white area defined by arrow. Design drawings of gearbox should be examined to define possible cause of elevated temperatures.

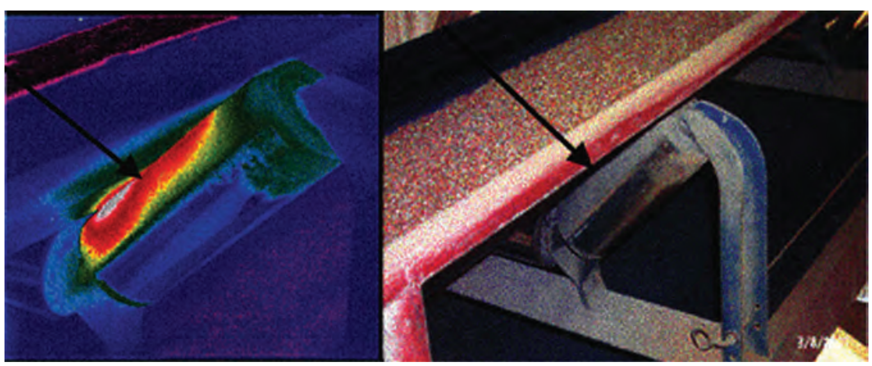


Figure 6.2.8. Seized conveyer belt roller as indicated by elevated temperatures in belt/roller contact area.

Figure 6.2.9. Inoperable steam heaters seen by cooler blue areas when compared to the operating heaters warmer red or orange colors.

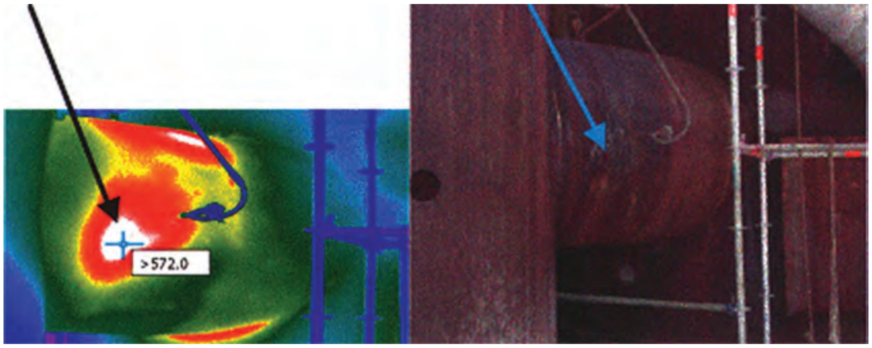


Figure 6.2.10. IR scans of boiler can highlight those areas where the refractory has broken down leading to costly heat loss.

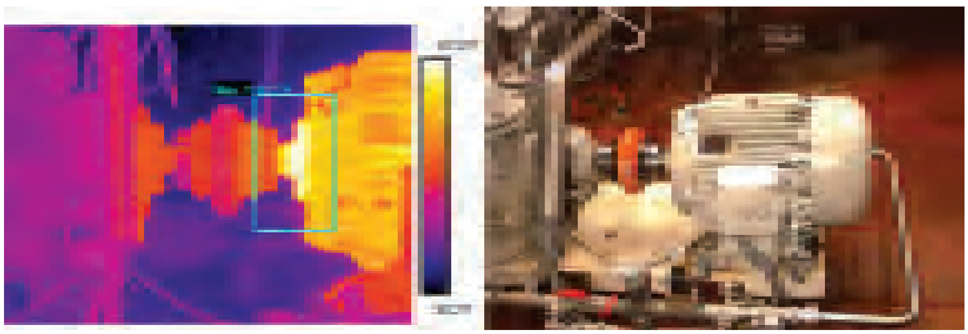


Figure 6.2.11. When trended, IR scans of single bearings provide a useful indicator of wear and eventual need for replacement.

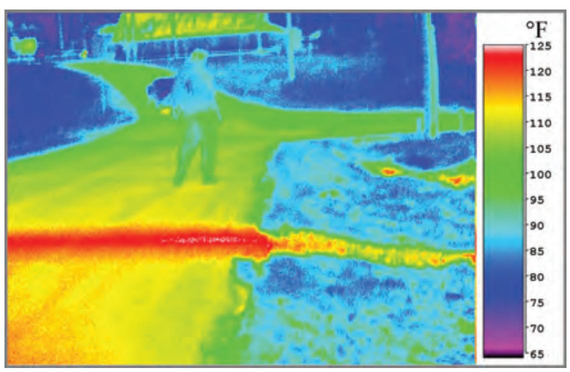
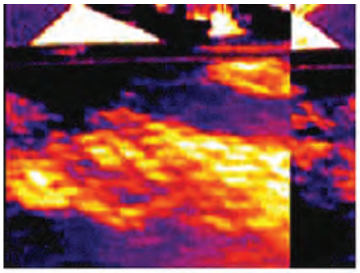
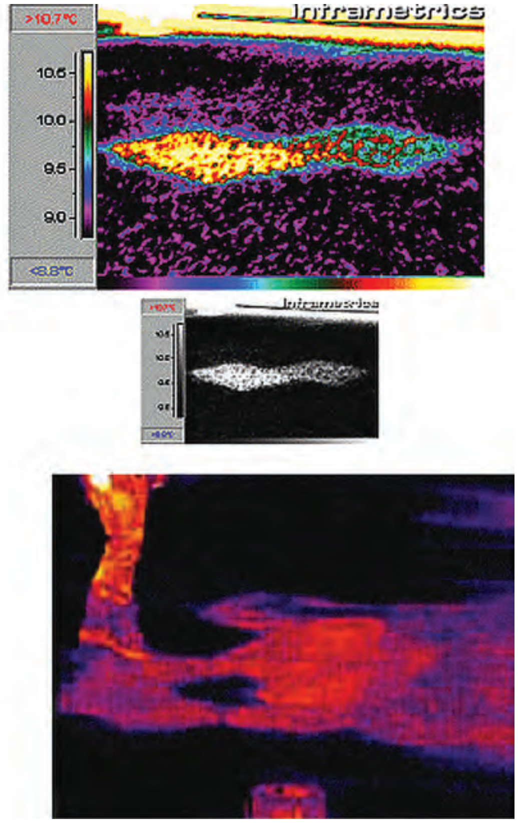


Figure 6.2.12. Steam or hot water distribution system leaks and/or underground line location can be defined with IR.



These images show elevated temperatures of roof insulation due to difference in thermal capacitance of moisture-laden insulation.



IR thermography is a powerful tool for locating roof leaks. As shown in the images, lighter colored regions indicate areas of potential leakage.

6.2.3.3 Roof Thermography

The old adage "out of sight, out of mind" is particularly true when it applies to flat roof maintenance. We generally forget about the roof until it leaks on our computers, switchgear, tables, etc. Roof replacement can be very expensive and at a standard industrial complex easily run into the hundreds of thousands of dollars. Depending on construction, length of time the roof has leaked, etc., actual building structural components can be damaged from inleakage and years of neglect that drive up repair cost further. Utilization of thermography to detect loss of a flat roof's membrane integrity is an application that can provide substantial return by minimizing area of repair/replacement. Roof reconditioning cost can be expected to run less than half of new roof cost per square foot. Add to this the savings to be gained from reconditioning a small percentage of the total roof surface, instead of replacement of the total roof, and the savings can easily pay for roof surveys and occasional repair for the life of the building with change left over.

6.2.4 Equipment Cost/Payback

As indicated earlier, the cost of thermography equipment varies widely depending on the capabilities of the equipment. A simple spot radiometer can cost from $500 to $2,500. An IR imager without radiometric capability can range from $7,000 to $20,000. A camera with full functionality can cost from $18,000 to $65,000. Besides the camera hardware, other program costs are involved.

Computer hardware, personnel training, manpower, etc., needs to be accounted for in the budget. Below is a listing of equipment and program needs recommended by a company recognized as a leader in the world of IR program development:

- Level I thermographic training
- Level II thermographic training
- Ongoing professional development
- IR camera and accessories
- Report software
- Laptop computer
- Color printer
- Digital visual camera
- Personal Protective Equipment (PPE) for arc flash protection

Payback can vary widely depending on the type of facility and use of the equipment. A production facility whose downtime equates to several thousands of dollars per hour can realize savings much faster than a small facility with minimal roof area, electrical distribution network, etc. On average, a facility can expect a payback in 12 months or less. A small facility may consider using the services of an IR survey contractor. Such services are widely available and costs range from $600 to $1,200 per day. Contracted services are generally the most cost-effective approach for smaller, less maintenance-intensive facilities.

6.2.5 Training Availability

Training for infrared thermography is available through a variety of system manufacturers and vendors. In addition, the American Society of Non-destructive Testing (ASNT) has established guidelines for non-destructive testing (NDT) (Level I, II, or III) certification (NASA 2000). These three levels are designed to take the student from Level I - where the student is competent with equipment function and use, to Level II – where the student is fully capable and experienced and can complete diagnostics and recommendations, to Level III – where the student is fully experienced to supervise and teach Level I and II students.

6.2.6 Case Studies

IR Diagnostics of Pump

A facility was having continual problems with some to its motor and pump combinations. Pump bearings repeatedly failed. An IR inspection confirmed that the lower thrust bearing was warmer than the other bearing in the pump. Further investigation revealed that the motor-pump combination was designed to operate in the horizontal position. In order to save floor space, the pump was mounted vertically below the motor. As a result, the lower thrust bearing was overloaded leading to premature failure. The failures resulted in a $15,000 repair cost, not including lost production time ($30,000 per minute production loss and in excess of $600 per minute labor).

IR Diagnostics of Steam Traps

Steam trap failure detection can be difficult by other forms of detection in many hard to reach and inconvenient places. Without a good trap maintenance program, it can be expected that 15% to 60% of a facility's traps will be failed open. At $3/1,000 lb (very conservative), a ¼-in. orifice trap failed open will cost approximately $7,800 per year. If the system had 100 traps and 20% were failed, the loss would be in excess of $156,000. An oil refinery identified 14% of its traps were malfunctioning and realized a savings of $600,000 a year after repair.

IR Diagnostics of Roof

A state agency in the northeast operated a facility with a 360,000 square foot roof area. The roof was over 22 years old and experiencing several leaks. Cost estimates to replace the roof ranged between $2.5 and $3 million. An initial IR inspection identified 1,208 square feet of roof requiring replacement at a total cost of $20,705. The following year another IR inspection was performed that found 1,399 square feet of roof requiring replacement at a cost of $18,217. A roof IR inspection program was started and the roof surveyed each year. The survey resulted in less than 200 square feet of roof identified needing replacement in any one of the following 4 years (one year results were as low as 30 square feet). The total cost for roof repair and upkeep for the 6 years was less than $60,000. If the facility would have been privately owned, interest on the initial $3 million at 10% would have amounted to $300,000 for the first year alone. Discounting interest on $3 million over the 5-year period, simple savings resulting from survey and repair versus initial replacement cost ($3 million to $60,000) amount to $2,940,000. This figure does not take into account interest on the $3 million, which would result in savings in excess of another $500,000 to $800,000, depending on loan interest paid.

6.2.7 Resources

The resources provided below are by no means all-inclusive. The listed organizations are not endorsed by the authors of this guide and are provided for your information only. To locate additional resources, the authors of this guide recommend contacting relevant trade groups, databases, and the world-wide web.

FLIR Systems
Boston, MA
Telephone: 1-800-464-6372
Web address: **www.flirthermography.com**

Mikron Instrument Company, Inc.
Oakland, NJ
Telephone: (201) 405-0900
Web address: **www.irimaging.com**

Raytek
Santa Cruz, CA
Telephone: 1-800-227-8074
Web address: **www.raytek-northamerica.com**

Electrophysics
Fairfield, NJ
Telephone: (973) 882-0211
Web address: **www.electrophysics.com**

6.2.7.1 Infrared Service Companies

Hartford Steam Boiler
Engineering Services
Telephone: (703) 739-0350
Web address: www.hsb.com/infrared/

American Thermal Imaging
Red Wing, MN
Telephone: (877) 385-0051
Web address: www.americanthermalimaging.com

Infrared Services, Inc.
5899 S. Broadway Blvd.
Littleton, CO 80121
Voice: (303) 734-1746
Web address: www.infrared-thermography.com

Snell Thermal Inspections
U.S. wide
Telephone: 1-800-636-9820
Web address: www.snellinspections.com

6.2.7.2 Infrared Internet Resource Sites

Academy of Infrared Thermography
(www.infraredtraining.net)

- Level I, II, and III certification information and training schedule
- Online store (books, software, videos)
- Online resources (links, image gallery, message board)
- Communication (classifieds, news, industry-related information
- Company profile and contact information

Snell Infrared (Snellinfrared.com)

- Training and course information
- Industry links
- IR library
- Newsletter
- Classifieds
- IR application information

6.3.1 Introduction

One of the oldest predictive maintenance technologies still in use today is that of oil analysis. Oil analysis is used to define three basic machine conditions related to the machine's lubrication or lubrication system. First is the condition of the oil, that is, will its current condition lubricate per design? Testing is performed to determine lubricant viscosity, acidity, etc., as well as other chemical analysis to quantify the condition of oil additives like corrosion inhibitors. Second is the lubrication system condition, that is, have any physical boundaries been violated causing lubricant contamination? By testing for water content, silicon, or other contaminants (depending on the system design), lubrication system integrity can be evaluated. Third is the machine condition itself. By analyzing wear particles existing in the lubricant, machine wear can be evaluated and quantified.

In addition to system degradation, oil analysis performed and trended over time can provide indication of improperly performed maintenance or operational practices. Introduction of contamination during lubricant change-out, improper system flush-out after repairs, addition of improper lubricant, and improper equipment operation are all conditions that have been found by the trending and evaluation of oil analysis data.

Several companies provide oil analysis services. These services are relatively inexpensive and some analysis laboratories can provide analysis results within 24 hours. Some services are currently using the Internet to provide quick and easy access to the analysis reports. Analysis equipment is also available should a facility wish to establish its own oil analysis laboratory. Regardless of whether the analysis is performed by an independent laboratory or by in-house forces, accurate results require proper sampling techniques. Samples should be taken from an active, low-pressure line, ahead of any filtration devices. For consistent results and accurate trending, samples should be taken from the same place in the system each time (using a permanently installed sample valve is highly recommended). Most independent laboratories supply sample containers, labels, and mailing cartons. If the oil analysis is to be done by a laboratory, all that is required is to take the sample, fill in information such as the machine number, machine type, and sample date, and send it to the laboratory. If the analysis is to be done on-site, analytical equipment must be purchased, installed, and standardized. Sample containers must be purchased, and a sample information form created and printed.

The most common oil analysis tests are used to determine the condition of the lubricant, excessive wearing of oil-wetted parts, and the presence of contamination. Oil condition is most easily determined by measuring viscosity, acid number, and base number. Additional tests can determine the presence and/or effectiveness of oil additives such as anti-wear additives, antioxidants, corrosion inhibitors, and anti-foam agents. Component wear can be determined by measuring the amount of wear metals such as iron, copper, chromium, aluminum, lead, tin, and nickel. Increases in specific wear metals can mean a particular part is wearing, or wear is taking place in a particular part of the machine. Contamination is determined by measuring water content, specific gravity, and the level of silicon. Often, changes in specific gravity mean that the fluid or lubricant has been contaminated with another type of oil or fuel. The presence of silicon (usually from sand) is an indication of contamination from dirt.

6.3.2 Test Types

- **Karl Fischer Water Test** – The Karl Fischer Test quantifies the amount of water in the lubricant.

  Significance: Water seriously damages the lubricating properties of oil and promotes component corrosion. Increased water concentrations indicate possible condensation, coolant leaks, or process leaks around the seals.

- **ICP Spectroscopy** – Measures the concentration of wear metals, contaminant metals, and additive metals in a lubricant.

  Significance: Measures and quantifies the elements associated with wear, contamination, and additives. This information assists in determining the oil and machine condition.

The following guide highlights the elements that may be identified by this test procedure. Also provided are brief descriptions explaining where the particles came from for engines, transmissions, gears, and hydraulic systems.

Spectrometer Metals Guide				
Metal	**Engines**	**Transmissions**	**Gears**	**Hydraulics**
Iron	Cylinder liners, rings, gears, crankshaft, camshaft, valve train, oil pump gear, wrist pins	Gears, disks, housing, bearings, brake bands, shaft	Gears, bearings, shaft, housing	Rods, cylinders, gears
Chrome	Rings, liners, exhaust valves, shaft plating, stainless steel alloy	Roller bearings	Roller bearings	Shaft
Aluminum	Pistons, thrust bearings, turbo bearings, main bearings (cat)	Pumps, thrust washers	Pumps, thrust washers	Bearings, thrust plates
Nickel	Valve plating, steel alloy from crankshaft, camshaft, gears from heavy bunker-type diesel fuels	Steel alloy from roller bearings and shaft	Steel alloy from roller bearings and shaft	
Copper	Lube coolers, main and rod bearings, bushings, turbo bearings, lube additive	Bushings, clutch plates (auto/ powershift), lube coolers	Bushings, thrust plates	Bushings, thrust plates, lube coolers
Lead	Main and rod bearings, bushings, lead solder	Bushings (bronze alloy), lube additive supplement	Bushings (bronze alloy), grease contamination	Bushing (bronze alloy)
Tin	Piston flashing, bearing over-lay, bronze alloy, babbit metal along with copper and lead	Bearing cage metal	Bearing cage metal, lube additive	
Cadmium	N/A	N/A	N/A	N/A
Silver	Wrist pin bushings (EMDs), silver solder (from lube coolers)	Torrington needle bearings (Allison transmission)	N/A	Silver solder (from lube coolers)
Titanium	Gas turbine bearings/hub/ blades, paint (white lead)	N/A	N/A	N/A
Vanadium	From heavy bunker-type diesel fuels	N/A	N/A	N/A

Spectrometer Metals Guide (contd)

Contaminant Metals				
Silicon	Dirt, seals and sealants, coolant inhibitor, lube additive (15 ppm or less)	Dirt, seals and sealants, coolant inhibitor, lube additive (15 ppm or less)	Dirt, seals and sealants, coolant additive, lube additive (15 ppm or less)	Dirt, seals and sealant, coolant additive, lube additive (15 ppm or less)
Sodium	Lube additive, coolant inhibitor, salt water contamination, wash detergents	Lube additive, coolant inhibitor, salt water contamination, wash detergents	Lube additive, saltwater contamination, airborne contaminate	Lube additive, coolant inhibitor, saltwater contamination, airborne contaminate
Multi-Source Metals				
Molybdexznum	Ring plating, lube additive, coolant inhibitor	Lube additive, coolant inhibitor	Lube additive, coolant inhibitor, coolant inhibitor, grease additive	Lube additive, coolant inhibitor
Antimony	Lube additive	Lube additive	Lube additive	Lube additive
Manganese	Steel alloy	Steel alloy	Steel alloy	Steel alloy
Lithium	N/A	Lithium complex grease	Lithium complex grease	Lithium complex grease
Boron	Lube additive, coolant inhibitor	Lube additive, coolant inhibitor	Lube additive, coolant inhibitor	Lube additive, coolant inhibitor
Additive Metals				
Magnesium	Detergent dispersant additive, airborne contaminant at some sites	Detergent dispersant additive, airborne contaminant at some sites	Detergent dispersant additive, airborne contaminant at some sites	Detergent dispersant additive, airborne contaminant at some sites
Calcium	Detergent dispersant additive, airborne contaminant at some sites, contaminant from water	Detergent dispersant additive, airborne contaminant at some sites, contaminant from water	Detergent dispersant additive, airborne contaminant at some sites, contaminant from water	Detergent dispersant additive, airborne contaminant at some sites, contaminant from water
Barium	Usually an additive from synthetic lubricants	Usually an additive from synthetic lubricants	Usually an additive from synthetic lubricants	Usually an additive from synthetic lubricants
Phosphorus	Anti-wear additive (ZDP)	Anti-wear additive (ZDP)	Anti-wear additive (ZPD), EP additive (extreme pressure)	Anti-wear additive (ZDP)
Zinc	Anti-wear additive (ZDP)	Anti-wear additive (ZDP)	Anti-wear additive (ZPD)	Anti-wear additive (ZDP)

Test Types (contd)

- **Particle Count** – Measures the size and quantity of particles in a lubricant.

  Significance: Oil cleanliness and performance. An increase in particle size and gravity is an indication of a need for oil service.

- **Viscosity Test** – Measure of a lubricant's resistance to flow at a specific temperature.

  Significance: Viscosity is the most important physical property of oil. Viscosity determination provides a specific number to compare to the recommended oil in service. An abnormal viscosity (±15%) is usually indicative that lubricant replacement is required.

- **Fourier transform (FT)-IR Spectroscopy** – Measures the chemical composition of a lubricant.

  Significance: Molecular analysis of lubricants and hydraulic fluids by FT-IR spectroscopy produces direct information on molecular species of interest, including additives, fluid breakdown products, and external contamination.

- **Direct Read Ferrography** – Measures the relative amount of ferrous wear in a lubricant.

  Significance: The direct read gives a direct measure of the amount of ferrous wear metals of different size present in a sample. If trending of this information reveals changes in the wear mode of the system, then action is required.

- **Analytical Ferrography** – Allows analyst to visually examine wear particles present in a sample.

  Significance: A trained analyst visually determines the type and severity of wear deposited onto the substrate by using a high magnification microscope. The particles are readily identified and classified according to size, shape, and metallurgy.

- **Total Acid Number** – Measures the acidity of a lubricant.

  Description: Organic acids, a by-product of oil oxidation, degrade oil properties and lead to corrosion of the internal components. High acid levels are typically caused by oil oxidation.

6.3.3 Types of Equipment

Although independent laboratories generally perform oil analysis, some vendors do provide analysis equipment that can be used on-site to characterize oil condition, wear particles, and contamination. These devices are generally composed of several different types of test equipment and standards including viscometers, spectrometers, oil analyzers, particle counters, and microscopes. On-site testing can provide quick verification of a suspected oil problem associated with critical components such as water contamination. It can also provide a means to quickly define lubricant condition to determine when to change the lubricant medium. For the most part, detailed analysis will still require the services of an independent laboratory.

Typical oil analysis equipment available from several different vendors.

6.3.4 System Applications

All machines with motors 7.5 hp or larger, and critical or high-cost machines should be evaluated for routine lubricating oil analysis (NASA 2000) from monthly to quarterly. All hydraulic systems, except mobile systems, should be analyzed on a quarterly basis. Mobile systems should be considered for analysis based upon the machine size and the cost effectiveness of performing the analysis. Generally speaking, it is more cost effective in mobile equipment to maintain the hydraulic fluid based on the fluid condition. However, for small systems, the cost to flush and replace the hydraulic fluid on a time basis may be lower than the cost to analyze the fluid on a routine basis. Typical equipment applications include:

- Turbines
- Boiler feed pumps
- Electrohydraulic control (EHC) systems
- Hydraulics
- Servo valves
- Gearboxes
- Roller bearings
- Anti-friction bearings
- Any system where oil cleanliness is directly related to longer lubricant life, decreased equipment wear, or improved equipment performance

6.3.5 Equipment Cost/Payback

For facilities utilizing a large number of rotating machines that employ circulating lubricant, or for facilities with high dollar equipment using circulating lubricant, few predictive maintenance technologies can offer the opportunity of such a high return for dollars spent. Analysis for a single sample can run from $15 to $100 depending on the level of analysis requested – samples are typically sent through the mail to the testing center. Given the high equipment replacement cost, labor cost, and downtime cost involved with a bearing or gearbox failure, a single failure prevented by the performance of oil analysis can easily pay for a program for several years.

6.3.6 Training Availability

Training for lubricant and wear particle analysis typically takes place via vendors. Because the analysis is usually conducted by outside vendors at their location, training consists of proper sampling techniques (location and frequency) as well as requisite sample handling guidance.

6.3.7 Case Studies

Reduced Gear Box Failure

Through oil analysis, a company determined that each time oil was added to a gear reducer, contamination levels increased and this was accompanied by an increase in bearing and gear failures. Further examination determined that removing the cover plate to add oil allowed contamination from the process to fall into the sump. Based on this, the system was redesigned to prevent the introduction of contamination during oil addition. The result was a reduction in bearing/gearbox failure rates.

Oil Changes When Needed

A major northeast manufacturer switched from a preventive maintenance approach of changing oil in 400 machines using a time-based methodology to a condition-based method using in-house oil analysis. The oil is now being changed based on its actual condition and has resulted in a savings in excess of $54,000 per year.

Oil Changes and Equipment Scheduling

A northeast industrial facility gained an average of 0.5 years between oil changes when it changed oil change requirements from a preventive maintenance time-based approach to changing oil based on actual conditions. This resulted in greater than a $20,000 consumable cost in less than 9 months.

A large chemical manufacturing firm saved more than $55,000 in maintenance and lost production cost avoidance by scheduling repair of a centrifugal compressor when oil analysis indicated water contamination and the presence of high ferrous and non-ferrous particle counts.

6.3.8 References/Resources

The references and resources provided below are by no means all-inclusive. The listed organizations are not endorsed by the authors of this guide and are provided for your information only. To locate additional resources, the authors of this guide recommend contacting relevant trade groups, databases, and the world-wide web.

6.3.8.1 Analysis Equipment Resources

Computational Systems, Inc./
Emerson Process Management
Knoxville, TN
Telephone: (865) 675-2400
Fax: (865) 218-1401
Web address: **www.compsys.com**

Reliability Direct, Inc.
League City, TX
Telephone: 1-888-710-6786
Fax: (281) 334-4255
Web address: **www.reliabilitydirect.com**

Spectro, Inc.
Industrial Tribology Systems
Littleton, MA
Telephone: (978) 486-0123
Fax: (978) 486-0030
E-Mail: Info@SpectroInc.com
Web address: **www.spectroinc.com**

6.3.8.2 Oil Analysis Laboratories

Computational Systems, Inc./
Emerson Process Management
Knoxville, TN
Telephone: (865) 675-2400
Fax: (865) 218-1401
Web address: **www.comsys.com**

Polaris Laboratories
Indianapolis, IN
Telephone: (877) 808-3750
Fax: (317) 808-3751
Web address: **www.polarislabs1.com**

Analysts, Inc.
Locations throughout the U.S.
Telephone: (800) 336-3637
Fax: (310) 370-6637
Web address: **www.analystsinc.com**

LubeTrak
Sandy, UT
Telephone: 1-866-582-3872 (Toll Free)
Web address: **www.lubetrak.com**

6.3.8.3 Internet Resource Sites

www.testoil.com
- Sample report
- Free oil analysis
- Industry-related articles
- Test overview
- Laboratory services
- Training services

www.compsys.com
- Laboratory service
- Technical articles
- Application papers
- Sample report
- Training services
- Technical notes

www.natrib.com
- Technical articles
- Case studies
- Newsletters
- Application notes

6.4 Ultrasonic Analysis

6.4.1 Introduction

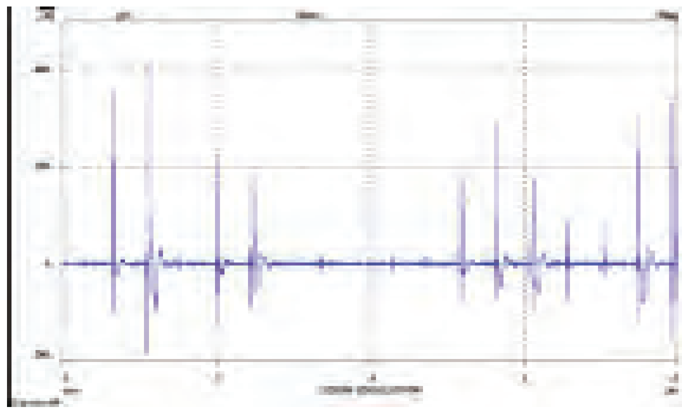
Ultrasonic, or ultrasounds, are defined as sound waves that have a frequency level above 20 kHz. Sound waves in this frequency spectrum are higher than what can normally be heard by humans. Non-contact ultrasonic detectors used in predictive maintenance detect airborne ultrasound. The frequency spectrums of these ultrasounds fall within a range of 20 to 100 kHz. In contrast to IR emissions, ultrasounds travel a relatively short distance from their source. Like IR emissions, ultrasounds travel in a straight line and will not penetrate solid surfaces. Most rotating equipment and many fluid system conditions will emit sound patterns in the ultrasonic frequency spectrum. Changes in these ultrasonic wave emissions are reflective of equipment condition. Ultrasonic detectors can be used to identify problems related to component wear as well as fluid leaks, vacuum leaks, and steam trap failures. A compressed gas or fluid forced through a small opening creates turbulence with strong ultrasonic components on the downstream side of the opening. Even though such a leak may not be audible to the human ear, the ultrasound will still be detectable with a scanning ultrasound device.

Ultrasounds generated in vacuum systems are generated within the system. A small percentage of these ultrasonic waves escape from the vacuum leak and are detectable, provided the monitoring is performed close to the source or the detector gain is properly adjusted to increase detection performance. In addition to system vacuum or fluid leaks, ultrasonic wave detection is also useful in defining abnormal conditions generated within a system or component. Poorly seated valves (as in the case of a failed steam trap) emit ultrasounds within the system boundaries as the fluid leaks past the valve seat (similar to the sonic signature generated if the fluid was leaking through the pipe or fitting walls). These ultrasounds can be detected using a contact-type ultrasonic probe.

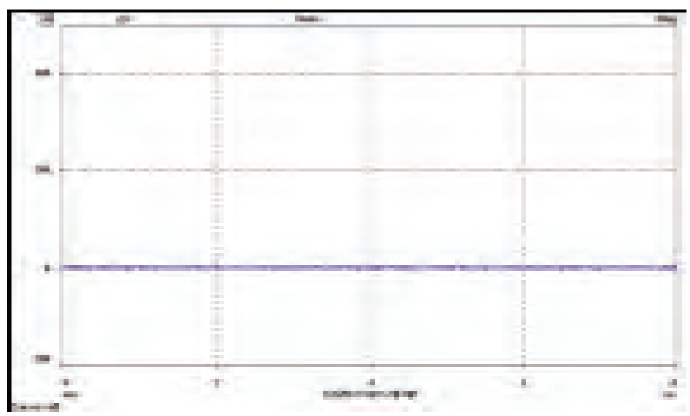
Ultrasonic detection devices can also be used for bearing condition monitoring. According to National Aeronautics and Space Administration (NASA) research, a 12-50x increase in the amplitude of a monitored ultrasonic frequency (28 to 32 kHz) can provide an early indication of bearing deterioration.

Ultrasonic detection devices are becoming more widely used in detection of certain electrical system anomalies. Arcing/tracking or corona all produce some form of ionization that disturbs the air molecules around the equipment being diagnosed and produces some level of ultrasonic signature. An ultrasonic device can detect the high-frequency noise produced by this effect and translate it, via heterodyning, down into the audible ranges. The specific sound quality of each type of emission is heard in headphones while the intensity of the signal can be observed on a meter to allow quantification of the signal.

In addition to translating ultrasonic sound waves into frequencies heard by the human ear or seen on a meter face, many ultrasonic sound wave detectors provide the capability to capture and store the detectors output. Utilizing display and analysis software, a time waveform of the ultrasonic signature can then be visually displayed. This functionality increases the technology's capability to capture and store quantifiable data related to a components operating condition. Ultrasonic signature information can then be used to baseline, analyze, and trend a component's condition. In contrast to a technician's subjective analysis of a component's condition using an audio signal, many ultrasonic anomalies indicative of component problems are more easily defined using a signature profile. The following images of ultrasonic time waveforms from two identical gearboxes illustrate how ultrasonic signature data storage and analysis can be used to quantify machine condition. Gearbox "1" waveform shows an ultrasonic signature anomaly that may be attributable to missing or worn gear teeth, while Gearbox "2" signature shows a flat profile.



Gearbox 1



Gearbox 2

Generally, this type of diagnosis can be performed on a standard personal computer (PC). The programs not only provide the spectral and time series views of the ultrasonic signature but enable users to hear the translated sound samples simultaneously as they are viewing them on the PC monitor.

6.4.2 Types of Equipment

Ultrasonic analysis is one of the less complex and less expensive predictive maintenance technologies. The equipment is relatively small, light, and easy to use. Measurement data are presented in a straightforward manner using meters or digital readouts. The cost of the equipment is moderate and the amount of training is minimal when compared to other predictive maintenance technologies. The picture to the right shows a typical ultrasonic detection device.

Typical hand-held ultrasonic detector

Since ultrasounds travel only a short distance, some scanning applications could present a safety hazard to the technician or the area of interest may not be easily accessible. In these applications, the scanning device is generally designed with a gain adjust to increase its sensitivity, thereby allowing scanning from a greater distance than normal. Some ultrasonic detectors are designed to allow connection of a special parabolic dish-type sensing device (shown at right) that greatly extends the normal scanning distance.

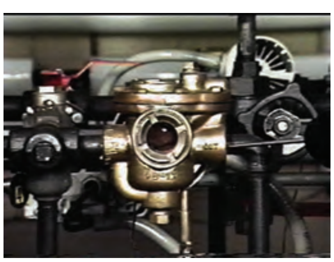
Parabolic dish used with ultrasonic detector greatly extends detection range abilities.

6.4.3 System Applications

6.4.3.1 Pressure/Vacuum Leaks

- Compressed air
- Oxygen
- Hydrogen
- Heat exchangers
- Boilers
- Condensers
- Tanks
- Pipes
- Valves
- Steam traps.

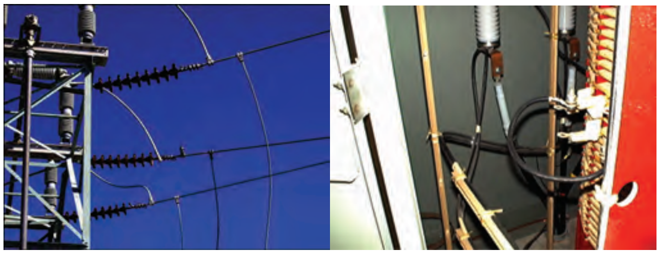
Ultrasonic detection can be used to locate underground system leaks and detect heat exchanger tube leakage.



From steam trap faults and valve leakage to compressor problems, ultrasonic detection can be used to find a variety of problems that generate ultrasonic signatures.

6.4.3.2 Mechanical Applications

- Mechanical inspection
- Bearings
- Lack of lubrication
- Pumps
- Motors
- Gears/Gearboxes
- Fans
- Compressors
- Conveyers.



Mechanical devices are not the only sources of ultrasonic emission. Electrical equipment will also generate ultrasonic waves if arcing/tracking or corona are present.

6.4.3.3 Electrical Applications

- Arcing/tracking/corona
- Switchgear
- Transformers
- Insulators
- Seals/Potheads
- Junction boxes
- Circuit breakers.

6.4.4 Equipment Cost/Payback

As indicated earlier, ultrasonic analysis equipment cost is minimal when compared to other predictive maintenance technologies. A typical handheld scanner, software, probes, will cost from $750 to $10,000 – depending on the type, accuracy and features. The minimal expense combined with the large savings opportunities will most often result in an equipment payback period of 6 months or less.

6.4.5 Training Availability

Training for ultrasonic analysis is available through a variety of system manufacturers and vendors. Depending on your needs, consider training that will qualify you for the American Society of Non-destructive Testing (ASNT) various levels of certification. Generically, these levels take the following form:
Level I – the student is competent with equipment function and use; Level II – the student is fully capable and experienced and can complete diagnostics and recommendations; Level III – the student is fully experienced to supervise and teach Level I and II student.

Steam Trap Applications
(NASA 2000):

Steam traps should be monitored on the down-stream side of the trap using the test equipment's contact mode. Each type of steam trap produces a distinct sound as briefly described below. It is recommended that users receive training and then gain experience in a controlled environment before diagnosing operating systems.

Typical ultrasonic signatures will include and opening and closing sound characterized by steam rushing sound followed by a period of relative quiet. Many types of traps fail in the open position, producing a continuous, rushing sound. Common trap types and their diagnostic signatures include:

Inverted Bucket: A normal trap sounds as if it is floating; a failed trap sinks, producing a continuous flow noise.

Float and Thermostatic (Continuous Load): Flow and noise associated with these traps are usually modulated as the trap opens and closes. Failed traps are normally cold and silent.

Thermostatic: Ultrasonic testing results of this type of trap vary. The signatures produced by these traps can be continuous or intermittent depending on the type. It is best to reference a properly functioning trap for a baseline signature for comparison.

6.4.6 Case Studies

Ultrasound Detects Compressed Air Leaks

A northeast industrial plant was experiencing some air problems. The facility's two compressors were in the on mode for an inordinate amount of time, and plant management assumed a third compressor was needed, at a cost of $50,000. Instead, the foundry invested less than $1,000 in contracting an outside firm to perform an ultrasound inspection of its air system. In a single day, the ultrasound technician detected 64 air leaks accounting for an estimated total air loss of 295.8 cfm (26% of total system capacity). Considering it cost approximately $50,014 per year (calculated at $.04/kilowatt/hour) to operate the two air compressors, at a total of 1,120 cfm, correcting this air loss saved the plant $13,000 per year. In addition, the plant avoided having to spend another $50,000 on another air compressor, because after the leaks were found and repaired, the existing compressors were adequate to supply demand.

A Midwest manufacturer saved an estimated $75,900 in annual energy costs as a result of an ultrasound survey of its air system. A total of 107 air leaks were detected and tagged for repair. These leaks accounted for an air loss of 1,031 cfm, equal to 16% of the total 6,400 cfm produced by the air compressors that supply the facility.

Steam Trap Monitoring (NASA 2000)

Implementation of a steam trap monitoring program often has significant financial benefit. Initial steam trap surveys in the petrochemical industry revealed that 34% of the steam traps inspected had failed, mostly in the open position. For facilities with a periodic steam trap monitoring program, the following distribution of degradations were discovered during each survey:

- Five steam leaks (other than traps) per 150 traps
- Two leaking valves per 150 traps
- Twenty of the 150 traps leak

Building off these findings – one trap (failed open) with a ¼ inch orifice will lose roughly 500 MBtu/year (at 25 psi) if undiscovered. With a cost of steam at $7.50 per MBtu, a boiler efficiency of 75% and a system energized for 50% of the year, the annual cost savings of detecting this leak is $2,500. This one leak could justify the purchase of an ultrasonic detector – and this is likely one of many leaks to be found.

6.4.7 References/Resources

The references and resources provided below are by no means all-inclusive. The listed organizations are not endorsed by the authors of this guide and are provided for your information only. To locate additional resources, the authors of this guide recommend contacting relevant trade groups, databases, and the world-wide web.

6.4.7.1 Equipment Resources

UE Systems
Elmsford, NY
Telephone: (914) 592-1220 or
1-800-223-1325
Fax: (914) 347-2181
Web address: **www.uesystems.com**

CTRL Systems, Inc.
Westminster, MD
Telephone: (877) 287-5797
Web address: **www.ctrlsys.com**

Specialized Diagnostic Technologies, Inc.
SDT North America
Cobourg, Ontario
Canada
Telephone: 1-800-667-5325
Web address: **www.sdtnorthamerica.com**

Superior Signal Company
Spotswood, NJ
Telephone: 1-800-945-TEST(8378) or
(732) 251-0800
Fax: (732) 251-9442
Web address: **www.superiorsignal.com**

6.4.7.2 Service Companies

Mid-Atlantic Infrared Services, Inc.
Bethesda, MD
Telephone: (301) 320-2870
Web address: **www.midatlanticinfrared.com**

UE Systems, Inc.
Telephone: (914) 592-1220 or
1-800-223-1325 (Toll Free)
Fax: (914) 347-2181
Web address: **www.uesystems.com**

Leek Seek
Telephone: TX: (512) 246-2071
CA: (909) 786-0795
FL: (727) 866-8118
Web address: **www.leekseek.com**

6.4.7.3 Internet Resource Sites

www.uesystems.com
- Technology overview
- Training
- Links
- Sound demos

www.superiorsignal.com
- Technology overview
- Ultrasonic sound bites (examples)
- Ultrasonic spectral graphs

6.5 Vibration Analysis

6.5.1 Introduction

As all of us who ride or drive an automobile with some regularity know, certain mechanical faults or problems produce symptoms that can be detected by our sense of feel. Vibrations felt in the steering wheel can be an indicator of an out-of-balance wheel or looseness in the steering linkage. Transmission gear problems can be felt on the shift linkage. Looseness in exhaust system components can sometimes be felt as vibrations in the floorboard. The common thread with all these problems is that degeneration of some mechanical device beyond permissible operational design limitations has manifested itself by the generation of abnormal levels of vibration. What is vibration and what do we mean by levels of vibration? The dictionary defines vibration as "a periodic motion of the particles of an elastic body or medium in alternately opposite directions from the position of equilibrium when that equilibrium has been disturbed or the state of being vibrated or in vibratory motion as in (1) oscillation or (2) a quivering or trembling motion."

The key elements to take away from this definition are vibration is motion, and this motion is cyclic around a position of equilibrium. How many times have you touched a machine to see if it was running? You are able to tell by touch if the motor is running because of vibration generated by motion of rotational machine components and the transmittal of these forces to the machine housing. Many parts of the machine are rotating and each one of these parts is generating its own distinctive pattern and level of vibration. The level and frequency of these vibrations are different and the human touch is not sensitive enough to discern these differences. This is where vibration detection instrumentation and signature analysis software can provide us the necessary sensitivity. Sensors are used to quantify the magnitude of vibration or how rough or smooth the machine is running. This is expressed as vibration amplitude. This magnitude of vibration is expressed as:

- **Displacement** – The total distance traveled by the vibrating part from one extreme limit of travel to the other extreme limit of travel. This distance is also called the "peak-to-peak displacement."
- **Velocity** – A measurement of the speed at which a machine or machine component is moving as it undergoes oscillating motion.
- **Acceleration** – The rate of change of velocity. Recognizing that vibrational forces are cyclic, both the magnitude of displacement and velocity change from a neutral or minimum value to some maximum. Acceleration is a value representing the maximum rate that velocity (speed of the displacement) is increasing.

Various transducers are available that will sense and provide an electrical output reflective of the vibrational displacement, velocity, or acceleration. The specific unit of measure to best evaluate the machine condition will be

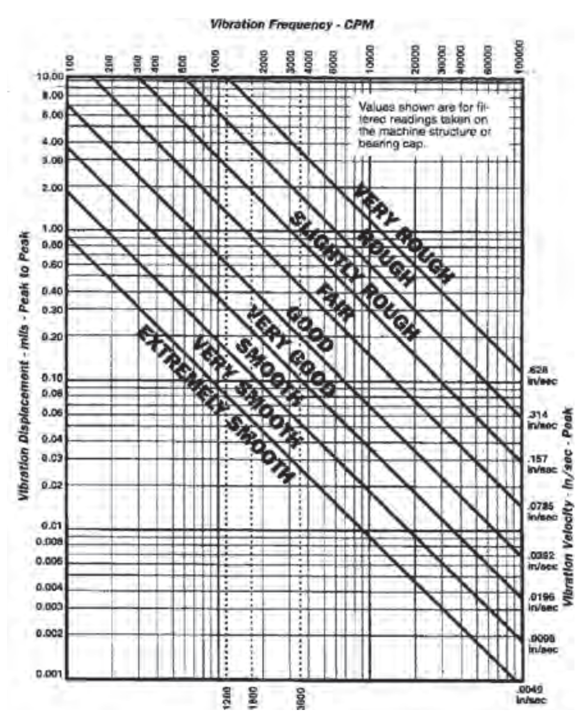


Figure 6.5.1. Vibration severity chart

dependent on the machine speed and design. Several guidelines have been published to provide assistance in determination of the relative running condition of a machine. An example is seen in Figure 6.5.1. It should be said that the values defined in this guideline, or similar guidelines, are not absolute vibration limits above which the machine will fail and below which the machine will run indefinitely. It is impossible to establish absolute vibration limits. However, in setting up a predictive maintenance program, it is necessary to establish some severity criteria or limits above which action will be taken. Such charts are not intended to be used for establishing vibration acceptance criteria for rebuilt or newly installed machines. They are to be used to evaluate the general or overall condition of machines that are already installed and operating in service. For those, setting up a predictive maintenance program, lacking experience or historical data, similar charts can serve as an excellent guide to get started.

As indicated earlier, many vibration signals are generated at one time. Once a magnitude of vibration exceeds some predetermined value, vibration signature analysis can be used in defining the machine location that is the source of the vibration and in need of repair or replacement. By using analysis equipment and software, the individual vibration signals are separated and displayed in a manner that defines the magnitude of vibration and frequency (Figure 6.5.2). With the understanding of machine design and operation, an individual schooled in vibration signature analysis can interpret this information to define the machine problem to a component level.

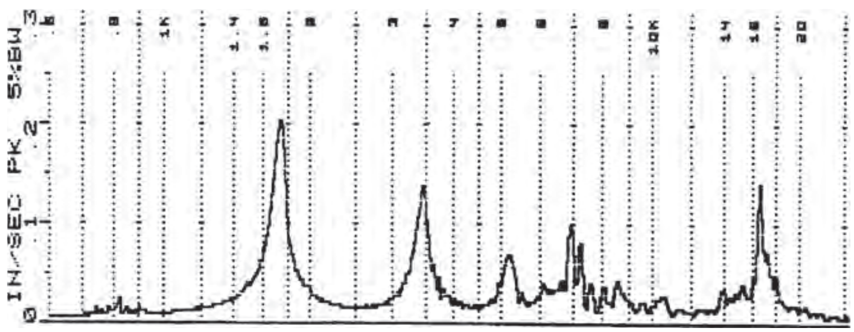


Figure 6.5.2. FFT – Example of graph breaking down vibration level at different frequencies

6.5.2 Types of Equipment

Depending on the application, a wide variety of hardware options exist in the world of vibration. Although not complicated, actual hardware requirements depend on several factors. The speed of the machine, on-line monitoring versus off-line data collection, analysis needs, signal output requirements, etc., will affect the type of equipment options available. Regardless of the approach, any vibration program will require a sensing device (transducer) to measure the existing vibration and translate this information into some electronic signal. Transducers are relatively small in size (see Figure 6.5.3) and can be permanently mounted or affixed to the monitoring location periodically during data collection.

Figure 6.5.3. Typical vibration transducers

In some cases, the actual translation of the vibration to an electrical signal occurs in a handheld monitoring device. A metal probe attached to a handheld instrument is held against a point of interest and the instrument translates the motions felt on the probe to some sort of electrical signal. Other portable devices use a transducer and handheld data-collection device. Both styles will provide

Examples of typical hand-held vibration sensing meters. Note readout providing immediate level indication.

Typical Vibration Analyzer – Note liquid crystal display providing actual vibration waveform information in addition to machine condition analytical capabilities.

some sort of display where the vibration magnitude is defined. Styles and equipment size vary greatly, but equipment is designed to be portable.

Some signal acquisition and analysis equipment interface a PC directly with the sensors.

In addition to instruments designed to measure vibration magnitude, many manufacturers provide instrumentation that will perform signal analysis as well. Some equipment is a stand-alone design and performs analysis in the field independent of computer interface while other equipment designs interface tranducers directly with a PC where analysis software is utilized to interpret the signal data.

6.5.3 System Applications

Vibration monitoring and analysis can be used to discover and diagnose a wide variety of problems related to rotating equipment. The following list provides some generally accepted abnormal equipment conditions/faults where this predictive maintenance technology can be of use in defining existing problems:

- Unbalance
- Eccentric rotors
- Misalignment
- Resonance problems
- Mechanical looseness/weakness
- Rotor rub
- Sleeve-bearing problems
- Rolling element bearing problems

- Flow-induced vibration problems
- Gear problems
- Electrical problems
- Belt drive problems.

Analyzing equipment to determine the presence of these problems is not a simple and easily performed procedure. Properly performed and evaluated vibration signature analysis requires highly trained and skilled individuals, knowledgeable in both the technology and the equipment being tested. Determination of some of the problems listed is less straightforward than other problems and may require many hours of experience by the technician to properly diagnosis the condition.

6.5.4 Equipment Cost/Payback

As indicated earlier, the styles, types, and capabilities of vibration monitoring equipment vary greatly. Naturally, equipment cost follows this variance. Transducers can cost under $100. The expected cost for vibration metering devices capable of defining magnitude with no analysis capability is approximately $1,000. The cost goes up from there. A high-end vibration analyzer with software and all the accessories can exceed $30,000. A typical industrial site can expect to recover the cost of the high-end equipment investment within 2 years. Sites with a minimal number of rotating equipment, low-cost equipment installations, and/or no production-related concerns may find it uneconomically advantageous to purchase a $30,000 vibration analysis system. These facilities may be wise to establish an internal program of vibration monitoring using a low-cost vibration-metering device and then employ the services of an outside contractor to conduct periodic surveys. These services generally range in cost from $600 to $1,200 per day.

6.5.5 Training Availability

Training for vibration analysis is available through a variety of system manufacturers and vendors. Additional training and certification is available through the Vibration Institute (see Resources section for contact information) from where certification for Levels I – IV is available.

6.5.6 Case Studies

Vibration Analysis on Pump

Vibration analysis on a 200-hp motor/pump combination resulted in determination of improperly sized shaft bearings on both the pump end and the motor end. Repair costs were less than $2,700. Continued operation would have led to failure and a replacement cost exceeding $10,000.

6.5.7 References/Resources

The references and resources provided below are by no means all-inclusive. The listed organizations are not endorsed by the authors of this guide and are provided for your information only. To locate additional resources, the authors of this guide recommend contacting relevant trade groups, databases, and the world-wide web.

6.5.7.1 Training Equipment Resources

Wilcoxon Research, Inc.
Gaithersburg, MD
Telephone: (301) 330-8811 or 1-800-945-2696
Web site: www.wilcoxon.com

Computational Systems, Inc./
Emerson Process Management
Web address: www.compsys.com

DLI Engineering Corporation
U.S. wide
Telephone: 1-800-654-2844 or (206) 842-7656
Web address: www.dliengineering.com

Commtest, Inc.
Knoxville, TN
Telephone: 1-877-582-2946
Web address: www.commtest.com

6.5.7.2 Service Companies

Industrial Research Technology
Bethlehem, PA - Pittsburgh, PA -
Cleveland, OH - Detroit, MI - Chicago, IL -
Charleston, SC
Telephone: (610) 867-0101 or
1-800-360-3594
Fax: (610) 867-2341

Computational Systems, Inc./
Emerson Process Management
835 Innovation Drive
Knoxville, TN 37932
Telephone: (865) 675-2110
Fax: (865) 218-1401

6.5.7.3 Training/Internet Resource Sites

Vibration Institute
www.vibinst.org
6262 S. Kingery Highway
Suite 212, Willowbrook, IL 60527
Telephone: (630)654-2254
Fax: (630)654-2271

www.plant-maintenance.com
- Training material
- Industry links
- Free software
  - FFT/CMMS/Inventory control
- Technical articles
- Maintenance-related articles

www.reliabilityweb.com
- Training material
- Industry links
- Free software
  - FFT/CMMS/Inventory control
- Technical articles
- Maintenance-related articles

www.maintenance-news.com
- Industry links
- Technical articles
- Maintenance-related articles

6.6 Motor Analysis

6.6.1 Introduction

When it comes to motor condition analysis, infrared (IR) and vibration will not provide all the answers required to properly characterize motor condition. Over the past several years, motor condition analysis techniques have evolved from simple testing into testing techniques that more accurately define a motor's condition. Motor faults or conditions like winding short-circuits, open coils, improper torque settings, as well as many mechanically-related problems can be diagnosed using motor analysis techniques. Use of these predictive maintenance techniques and technologies to evaluate winding insulation and motor condition has not grown as rapidly as other predictive techniques. Motor analysis equipment remains fairly expensive and proper analysis requires a high degree of skill and knowledge. Recent advances in equipment portability and an increase in the number of vendors providing contracted testing services continue to advance predictive motor analysis techniques. Currently, more than 20 different types of motor tests exist, depending on how the individual tests are defined and grouped. The section below provides an overview of two commonly used tests.

6.6.2 Motor Analysis Test

6.6.2.1 Electrical Surge Comparison

In addition to ground wall insulation resistance, one of the primary concerns related to motor condition is winding insulation. Surge comparison testing can be used to identify turn-to-turn and phase-to-phase insulation deterioration, as well as a reversal or open circuit in the connection of one or more coils or coil groups. Recent advances in the portability of test devices now allow this test technique to be used in troubleshooting and predictive maintenance. Because of differences in insulation thickness, motor winding insulation tends to be more susceptible to failure from the inherent stresses existing within the motor environment than ground wall insulation. Surge comparison testing identifies insulation deterioration by applying a high frequency transient surge to equal parts of a winding and comparing the resulting voltage waveforms. Differences seen in the resulting waveforms are indicative insulation or coil deterioration. A properly trained test technician can use these differences to properly diagnose the type and severity of the fault. In addition to utilization of this motor analysis technique in a predictive maintenance program, it can also be used to identify improper motor repair practices or improper operating conditions (speeds, temperature, load).

Surge comparison testing is a moderately complex and expensive predictive maintenance technique. As with most predictive maintenance techniques, the greatest saving opportunities do not come directly from preventing a catastrophic failure of a component (i.e., motor) but rather the less tangible cost saving benefits. Reduced downtimes, ability to schedule maintenance, increased production, decreased overtime, and decreased inventory cost are just a few of the advantages of being able to predict an upcoming motor failure.

6.6.2.2 Motor Current Signature Analysis

Another useful tool in the motor predictive maintenance arsenal is motor current signature analysis (MCSA). MCSA provides a non-intrusive method for detecting mechanical and electrical problems in motor-driven rotating equipment. The technology is based on the principle that a conventional electric motor driving a mechanical load acts as a transducer. The motor (acting as a transducer) senses mechanical load variations and converts them into electric current variations that are transmitted along the motor power cables. These current signatures are reflective of a machine's condition and closely resemble signatures produced using vibration monitoring. These current signals are recorded and processed by software to produce a visual representation of the existing frequencies against current amplitude. Analysis of these variations can provide an indication of machine condition, which may be trended over time to provide an early warning of machine deterioration or process alteration.

Motor current signature analysis is one of the moderately complex and expensive predictive techniques. The complexity stems in large part from the relatively subjective nature of interpreting the spectra, and the limited number of industry-wide historical or comparative spectra available for specific applications. This type of analysis is typically limited to mission critical applications and/or those with life/health/safety implications.

6.6.3 System Applications

- Stem packing degradation
- Incorrect torque switch settings
- Degraded stem or gear case lubrication
- Worn gear tooth wear
- Restricted valve stem travel
- Obstructions in the valve seat area
- Disengagement of the motor pinion gear
- Improper seal/packing installation
- Improper bearing or gear installation
- Inaccurate shaft alignment or rotor balancing
- Insulation deterioration
- Turn-to-turn shorting
- Phase-to-phase shorting
- Short circuits
- Reversed or open coils.

6.6.4 Equipment Cost/Payback

As indicated earlier, motor analysis equipment is still costly and generally requires a high degree of training and experience to properly diagnosis equipment problems. A facility with a large number of motors critical to process throughput may find that ownership of this technology and adequately trained personnel more than pays for itself in reduced downtime, overtime cost, and motor inventory needs. Smaller facilities may find utilization of one of the many contracted service providers valuable in defining and maintaining the health of the motors within their facility. As with most predictive maintenance contract services, cost will range from $600 to $1,200 per day for on-site support. Finding a single motor problem whose failure would result in facility downtime can quickly offset the cost of these services.

6.6.5 Training Availability

Training for motor analysis is usually highly specialized and typically available through a variety of system manufacturers and vendors.

6.6.6 References/Resources

The references and resources provided below are by no means all-inclusive. The listed organizations are not endorsed by the authors of this guide and are provided for your information only. To locate additional resources, the authors of this guide recommend contacting relevant trade groups, databases, and the world-wide web.

6.6.6.1 Equipment Resources

Computational Systems, Inc./
Emerson ProcessManagement
835 Innovation Drive
Knoxville, TN 37932
Telephone: (865) 675-2110
Fax: (865) 218-1401

Chauvin Arnoux®, Inc.
d.b.a. AEMC® Instruments
200 Foxborough Boulevard
Foxborough, MA 02035
Telephone: (508) 698-2115
or (800) 343-1391
Fax: (508) 698-2118
Email: sales@aemc.com

AVO International
4651 S. Westmoreland Road
Dallas, TX 75237-1017
Telephone: (800) 723-2861
Fax: (214) 333-3533

Baker Instrument Company
4812 McMurry Avenue
Fort Collins, CO 80525
Telephone: (970) 282-1200 or (800) 752-8272
Fax: (970) 282-1010

6.6.6.2 Service Companies

Industrial Technology Research
Bethlehem, PA - Pittsburgh, PA -
Cleveland, OH - Detroit, MI - Chicago, IL -
Charleston, SC - Hamilton, ONT
Telephone: (610) 867-0101 or (800) 360-3594
Fax: (610) 867-2341

6.6.6.3 Internet Site Resources

www.mt-online.com
- Technology overview
- Technology vendors
- Industry articles

www.reliabilityweb.com
- Service companies
- Training services
- Software links (including Motor Master)

6.7 Performance Trending

6.7.1 Introduction

In addition to the general preventive maintenance we perform, or have performed on our vehicles, many of us log and trend important parametric information related to the health of our vehicles and use this information to determine maintenance needs. We calculate and trend our cars mileage per gallon of gas. We track engine temperature and oil pressure. We track oil usage. This information is then used to define when vehicle maintenance is required. Maintenance activities such as tune-ups, thermostat replacement, cooling system flushes, belt replacements, oil seal replacements, etc., may all be originally stimulated by vehicle parametric information we trend.

Using this performance trending approach can also be a valuable tool in maintaining the health and operational performance of the components in our facilities/plants. By logging and trending the differential pressure across a supply or discharge filter in the HVAC system, we can determine when filter replacement is required, rather than changing the filter out at some pre-defined interval (preventive maintenance). Logging and trending temperature data can monitor the performance of many heat exchangers. This information can be used to assist in the scheduling of tube cleaning. It may also serve as an indication that flow control valves are not working properly or chemical control measures are inadequate. Perhaps a decrease in heat exchanger performance, as seen by a change in delta-temperature, is due to biological fouling at our cooling loop pump suction. An increase in boiler stack temperature might be an indication of tube scaling. We may need to perform tube cleaning and adjust our chemistry control measures. Changes in combustion efficiency may be indicative of improperly operating oxygen trim control, fuel flow control, air box leakage, or tube scaling.

The key idea of performance trending is that much of the equipment installed in our facilities is already provided with instrumentation that can be used to assist in determination of the health/condition of the related component. Where the instruments are not present, installation of a pressure, temperature, or current sensing data loggers can be relatively straight forward and rather inexpensive. A particular good resource to better understand portable meters or data loggers and their vendors is the report titled *Portable Data Loggers Diagnostic Tools for Energy-Efficient Building Operations* (PECI 1999).

6.7.2 How to Establish a Performance Trending Program

One of the first steps of any predictive maintenance program is to know what equipment exists in your facility. First, generate a master equipment list, then prioritize the equipment on the list to define which pieces of equipment are critical to your facility's operation, important to personnel safety, or can have a significant budget impact (either through failure or inefficient operation).

Evaluate what parametric data should/could be easily collected from installed or portable instrumentation to provide information related to the condition/performance of the equipment on the master list based on your equipment prioritization.

Determine what, if any, of the defined data are already collected. Evaluate if any related parametric information is currently being tracked and if that information provides information regarding the condition or efficiency of a component or system. Terminate the collection of information not useful in the evaluation of a component's condition/efficiency unless required by other administrative requirements.

Define and install instrumentation not currently available to monitor a critical component's condition/efficiency.

Log the information at some frequency defined by plant engineering or operational staff. For example, the frequency may be every 4 hours while operating or may simply be a single reading after reaching steady-state conditions, depending on the data evaluation needs.

Provide collected data to individual with knowledge and background necessary to properly trend and evaluate it.

6.7.3 System Applications

Generally, any plant component with installed, or easily installed, instrumentation useful in evaluating the components condition, operation, or efficiency can be trended. Information can also be obtained using portable instrumentation, (e.g., an infrared thermometer or a variety of stand-alone data logging devices). Some general applications might be:

- Heat exchangers
- Filters
- Pumps
- HVAC equipment
- Compressors
- Diesel/gasoline engines
- Boilers.

6.7.4 Equipment Cost/Payback

The cost to establish an effective trending program is minimal and can provide one of the largest returns on dollars expended. Most plants have much of the instrumentation needed to gain the parametric information already installed. Today's instrumentation offers many cost-effective opportunities to gather information without having to incur the expense of running conduit with power and signal cabling. The information gatherers are generally already on the payroll and in many cases, already gathering the needed information to be trended. For the most part, establishing a trending program would require little more than using the information already gathered and currently collecting dust. When portable data-logging systems are purchased, the payback for the little extra money spent is quickly recovered in increased machine efficiency and decreased energy cost.

6.7.5 Training Availability

Training for performance trending is very application-specific. Most trending is done via pre-installed system sensors, an existing building automation system and/or the use of portable data loggers. All of these systems will function differently with education and training typically available through equipment vendors or distributors.

6.7.6 Case Studies

Operational Efficiency Opportunity Using Data Logger Data to Validate Boiler Operation (FEMP 2007)

Objective: Use data logger (5-minute run-time, time-series data) to validate proper boiler operation.

Situation: Federal facility with boiler heating/process loads. End-use run-time data logger installed. Data reported are from peak-season loading conditions.

Findings: Reviewing the 5-minute run-time data (data collected with stand-alone magnetic field enabled logger placed near boiler combustion-air blower motor) reveals excessive cycling of boiler; Figure 6.7.1 presents these data. A bar in the figure rising from 0 to 1 indicates the boiler cycling "on," the bar returning from 1 to 0 indicates the boiler cycling "off." Therefore, each bar in the graph represents one on/off cycle.

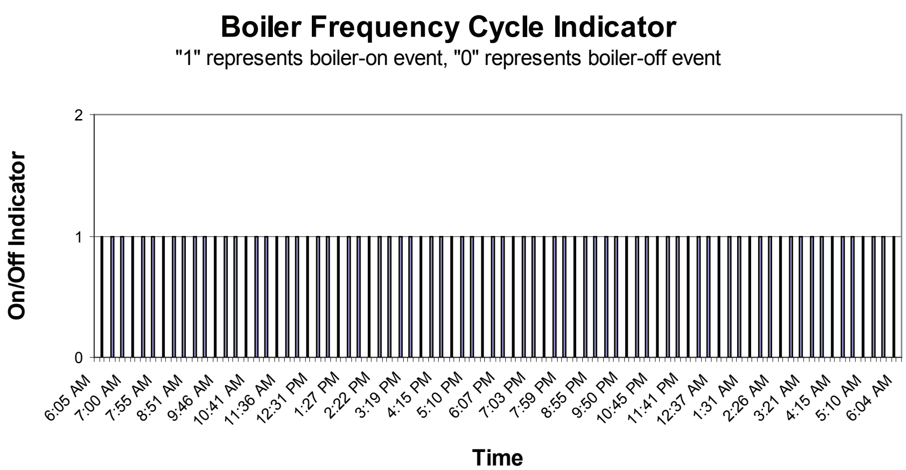


Figure 6.7.1. Boiler Cycling Frequency Data

Outcome: Processing these data reveals an average of 6.5 on/off cycles per hour – far in excess of the recommended 1-2, depending on load conditions. Further exploration uncovered gross boiler over-sizing due to partial decommissioning of building/process loads. The outcome recommendation includes installation of smaller, properly sized, and more efficient boiler to carry load.

6.8 References

FEMP. 2007. *Metering Best Practices Guide: A Guide to Achieving Utility Resource Efficiency*. DOE/EE-0323. U.S. Department of Energy, Federal Energy Management Program, Washington, D.C.

NASA. 2000. Reliability Centered Maintenance Guide for Facilities and Collateral Equipment. National Aeronautics and Space Administration, Washington, D.C.

PECI. 1999. *Portable Data Loggers Diagnostic Tools for Energy-Efficient Building Operations*. Prepared for the U.S. EPA and U.S. DOE by Portland Energy Conservation, Incorporated, Portland, Oregon.