ETME 3120
Maintenance of Mechatronic Systems

Lesson 4: Predictive Maintenance

Refer to Chapter 4 in the textbook

Reference: Productivity and Reliability-Based Maintenance Management, M. Stephens, 2010

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Predictive Maintenance (PDM)

- Definition:
- PDM measures and monitors various system and component operating characteristics and compares these data with established and known standards and specifications in order to predict failures.
- Also referred to it as: **Condition-based maintenance**
- On the average over **one-third** of all maintenance activities in an industrial organization need to be of the predictive nature.

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Predictive Maintenance (PDM)

- PDM evaluates the existing equipment condition and based on a projected trend of the deterioration, failures are predicted and appropriate steps are taken.
- PDM discovers potential problems before the eye can see, the ear can hear, or the nose can smell.
- PDM requires a great investment in time, advanced technology, and well trained maintenance professionals, and therefore demands a commitment from the management. .

Data Collection

- PDM is quantitative in nature. Data are collected, analyzed, charted, and interpreted.
- Data collection can be time-consuming and costly. Do not collect data that is not going to be used.
- The measurement instrument used itself can cause error, create bias and lead to faulty conclusions.
- Two general types of data collection approaches are possible: Fixed and Portable.

Data Collection

- Fixed-type devices are remote collection systems most appropriate for harsh environments.
- These devices may be permanently installed to monitor equipment conditions and are capable of collecting and transmitting the data.
- Portable-type devices can be taken from equipment to equipment for the purpose of data collection.

Data Analysis

- The data analysis may be chemical, engineering, statistical, or very likely a combination of these.
- The analysis outcome must be compared with established standards or a "baseline", generally provided by the equipment manufacturer.
- Trend lines and regression models then forecast the future equipment behavior.
- Be aware that the history of the data is as important as the data itself.

Vibration Analysis

- Most operating equipment experience some level of vibration.
- Most common causes of vibration: imbalance, misalignment, defective bearings or belts, loose bolts, harmonics.
- If vibration can be felt by human senses, it is probably too late, some damage has taken place.
- Factors affecting the vibration level: size, stiffness, and weight of the equipment, the rigidity of the base, and surrounding equipment.

Checking an aircraft engine for vibration. A pumpjack for an oil well.

Source : AZO Materials.https://www.azom.com/article.aspx?ArticleID=16246

Vibration Analysis

- Reciprocating equipment (i.e. pumps, compressors) normally exhibit higher levels of acceptable vibration than rotating equipment.
- The level of criticality determines monitoring frequency. In general, most machines should be monitored monthly.
- ISO standard 2372 (10816) sets general guidelines for vibration monitoring based on equipment classification and size, for machines operating at 600-12,000 RPM.
- Vibration velocity (inches or millimeters per second) of rotation equipment is a measure of forces on the bearings.

Vibration Standards

- **Class I**: Small machines (i.e. electrical motors up to 15kW).
- **Class II**: Medium size machines, such as electrical motors with 15 to 75 kW output without special foundation. Also, rigidly mounted machines up to 300 kW on special foundations.
- **Class III**: Large machines with rotating masses mounted on rigid and heavy foundations, which are relatively stiff in the direction of vibration measurement.
- **Class IV**: Large machines with rotating masses mounted on foundations, which are relatively soft in the direction of vibration measurement.

VIBRATION SEVERITY PER ISO 10816-1

Vibration Velocity Vrms

Machine in/s	Machine mm/s	Class I Small Machines	Class II Medium Machines	Class III Large Rigid Foundation	Class IV Large Soft Foundation	Severity
0.01	0.28					
0.02	0.45					
0.03	0.71		GOOD			A
0.04	1.12					
0.07	1.80					
0.11	2.80		SATISFACTORY			
0.18	4.50					
0.28	7.10		UNSATISFACTORY			B
0.44	11.20					
0.70	18.00					C
1.10	28.00		UNACCEPTABLE			
1.77	45.90					D

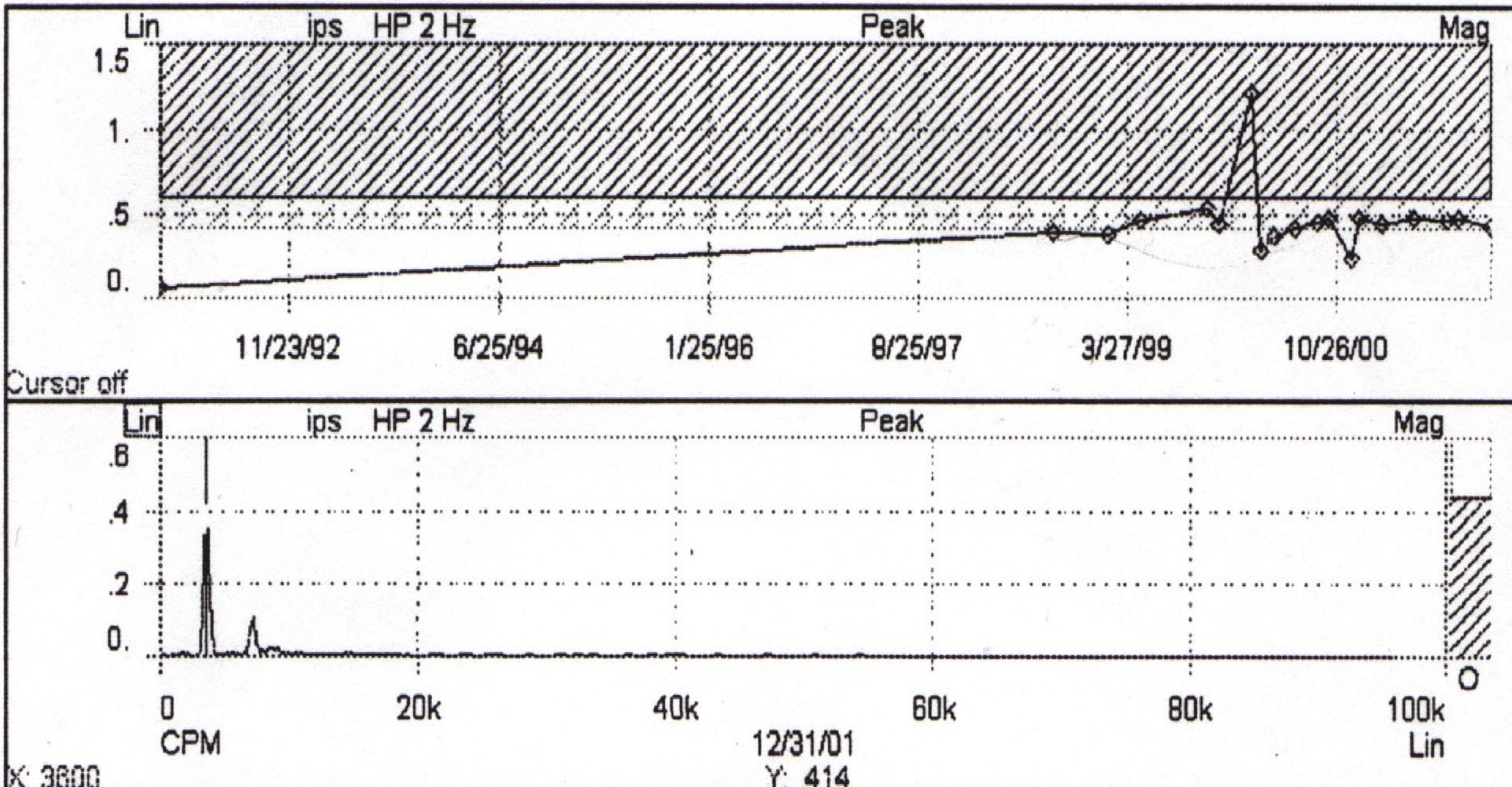
Effect of Level of Vibration on Equipment Condition

Vibration Velocity	Equipment Conditions
0.15 Inches/Second (or less)	Low Force Level. Bearing life should be a minimum of 10 to 16 years with proper lubrication.
0.30 Inches/Second	Double the Normal Force Level. Bearing life is decreased by a factor of 8. Bearing life will be 1.5 to 2 years with proper lubrication.
0.60 Inches/ Second	Very High Forces. Bearing life is now only 6 to 8 weeks. Force level is high enough to rupture the surface tension of an oil film and make lubrication ineffective.
0.90 Inches/Second	Extremely High Forces. Bearing is damaged with every revolution. Bearing life is from 3 days to a few weeks.

Vibration

- The amplitude of variation by frequency over time is referred to as the vibration signature.
- Changes to the vibration signature signal a change in the characteristics of one of the rotating elements (i.e., bearing, shaft, etc.)
- The vibration signature, or vibration baseline, of a piece of equipment shows the overall vibration velocity of all the components of that equipment.
- It is against this baseline or signature that any abnormality can be assessed or detected.
- Each peak in the vibration signature can be attributed to a specific component in the equipment.

Vibration Trend and Signature



PURDUE NEW PLANT
5A COND TRANSFER 5A COND TRANS. 3 Speed:1.775k
Position:0 Direction:Horizontal Latest

Chemical Analysis

- Chemical analysis allows to study the internal conditions of the equipment.
- Analytical data show the level of deterioration and the type of contaminants in the lubricants, which point to various causes and abnormalities.
- Some common chemical analysis techniques are:
  - Spectrographic Analysis
  - Tribology

Spectrographic Analysis

- This method determines the presence and quantity of various elements in a sample.
- The method is based on the fact that when light energy is passed through matter, the matter absorbs certain amount of this energy and a certain portion is emitted.   .
- The amount of absorption and emission is characteristically unique for each substance   .
- The presence of wear metals signals abnormal equipment conditions such as improper alignment, out-of-balance inadequate clearances and tolerances, which contribute to excessive wear.

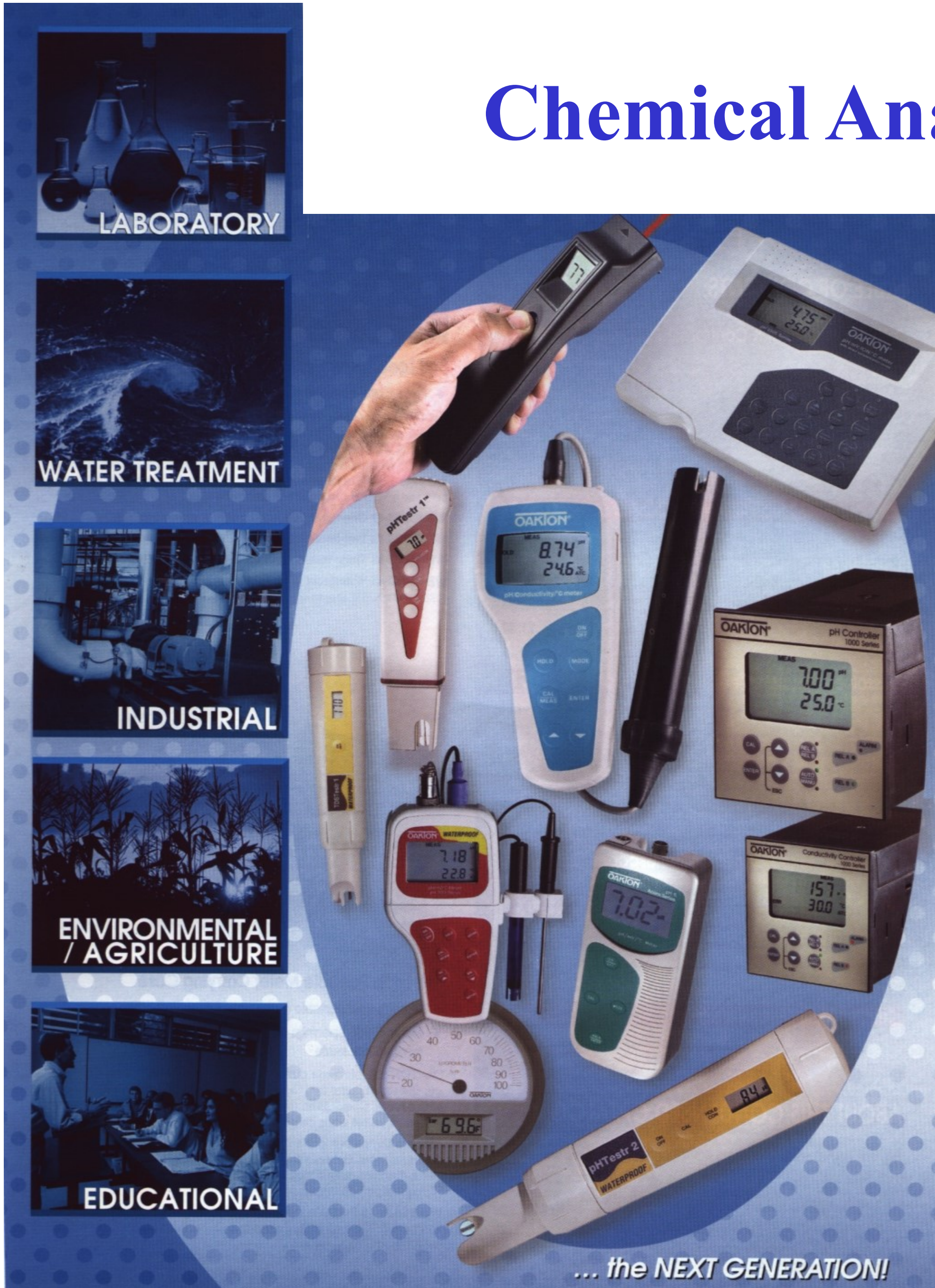
Partial List of Elements Found in Lubricant and Possible Sources

Element	Source
Iron (Fe)	Cylinders, gears, pistons, crankshafts, bearings, housings, rust
Chromium (Cr)	Rings, bearings, plating
Copper (Cu)	Bushings, bearings, washers, friction plates
Tin (Sn)	Bearings, bushings, pistons
Aluminum (Al)	Pistons, pumps, bearings, rotors, blowers
Nickel (Ni)	Valves
Silver (Ag)	Plating, bearings, bushings
Manganese (Mn)	Liners, rings
Silicon (Si)	Airborne dirt
Sodium (Na) Magnesium (Mg) Calcium (Ca) Phosphorus (P) Zinc (Zn)	Anti-freeze and other additives

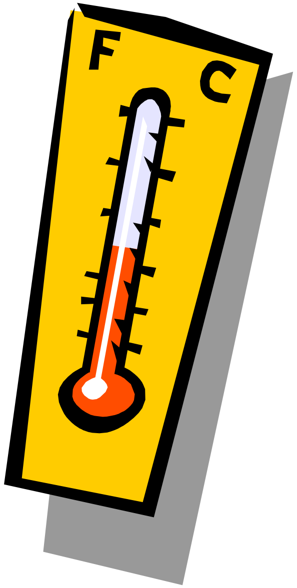
Tribology

- Tribology is the science and technology of friction, lubrication, and wear.
- The effect of frictional forces is to a great degree, a function of the physical properties of the two surfaces that are in relative motion to each other.
- In the most favorable conditions some surface damage will occur even with lightly loaded well lubricated surfaces.

Chemical Analysis Equipment



Thermography



- Thermography uses tools such as pyrometers, thermocouples, and heat sensitive tapes.
- Infrared imagining (IR) is one of the most versatile and widely used methods for detecting surface temperature variances.
- Heat due to physical, chemical, or electrical abnormalities can be detected by infrared imaging.

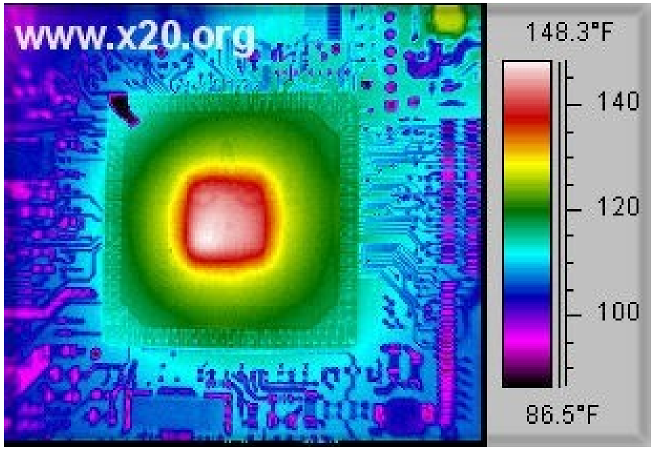
Infrared Imaging

- IR is based on the fact that all objects at temperatures above absolute zero (-273.15 ^{o}C or –459.67 ^{o}F) radiate infrared energy.
- The intensity of this radiation increases with the surface temperature of the object.
- IR detects this radiation converting it into an image.

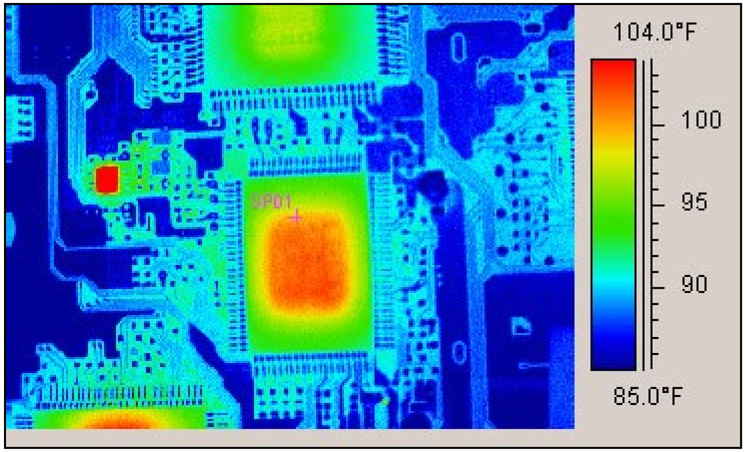
Infrared Imaging

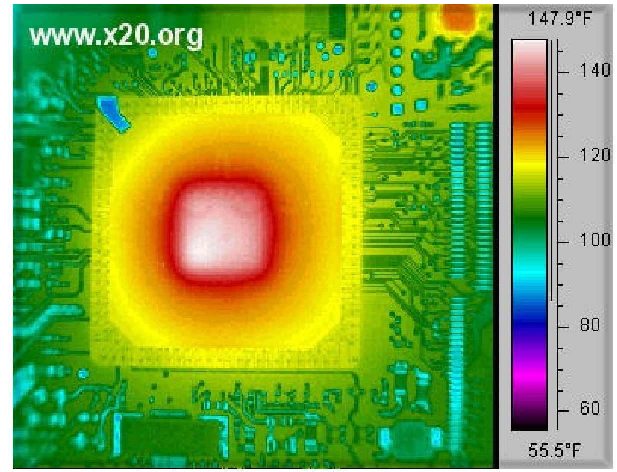
- Color thermographs are usually coded so that increases in surface temperature progress from blue to green to yellow to orange to red, and finally to white.
- Each color represents a specific range of temperature.

PC Board



Infrared Imaging

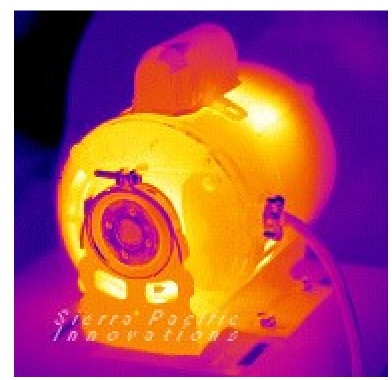




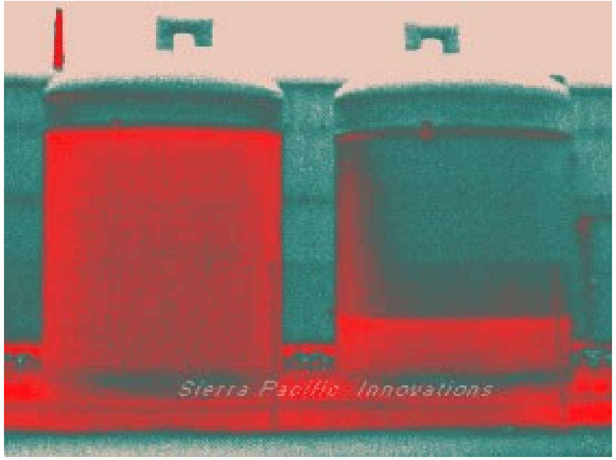
PC Boards

Electrical Contacts

Motor

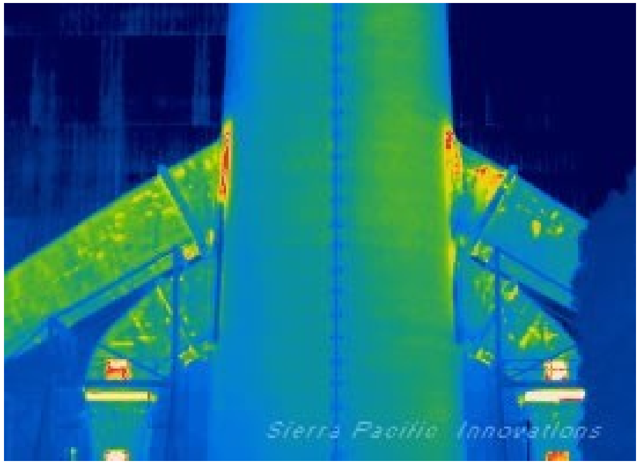


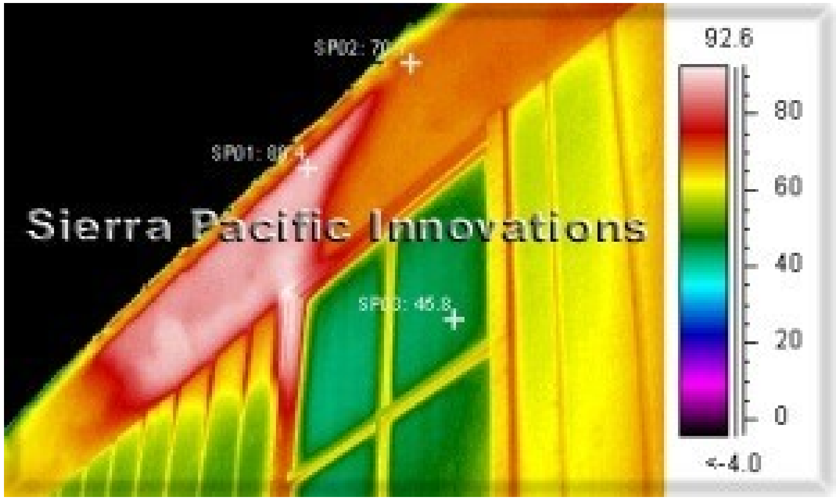
Infrared Imaging



Storage Tanks

Power Plant Steam Tunnel

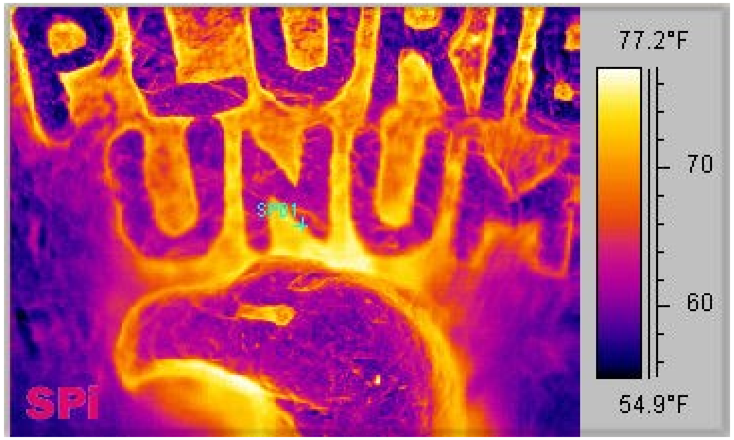




Electrical Predictive Maintenance Reference

Problem Classification	*Phase to Phase Temperature Rise*	*Comments*
Minor	$1^{o} – 10^{o}$ C	Repair in regular maintenance schedule; little probability of physical damage
Intermediate	$10^{o} – 30^{o}$ C	Repair in the near future (2-4 weeks). Watch load and change accordingly. Inspect for physical damage. There is probability of damage in the component, but not in the surrounding components.
Serious	$30^{o} – 70^{o}$ C	Repair in immediate future (1-2 days). Replace component and inspect the surrounding components for probable damage.
Critical	above 70^{o} C	Repair immediately (overtime). Replace component, inspect

IR Equipment



Quarter

Ultrasound Techniques

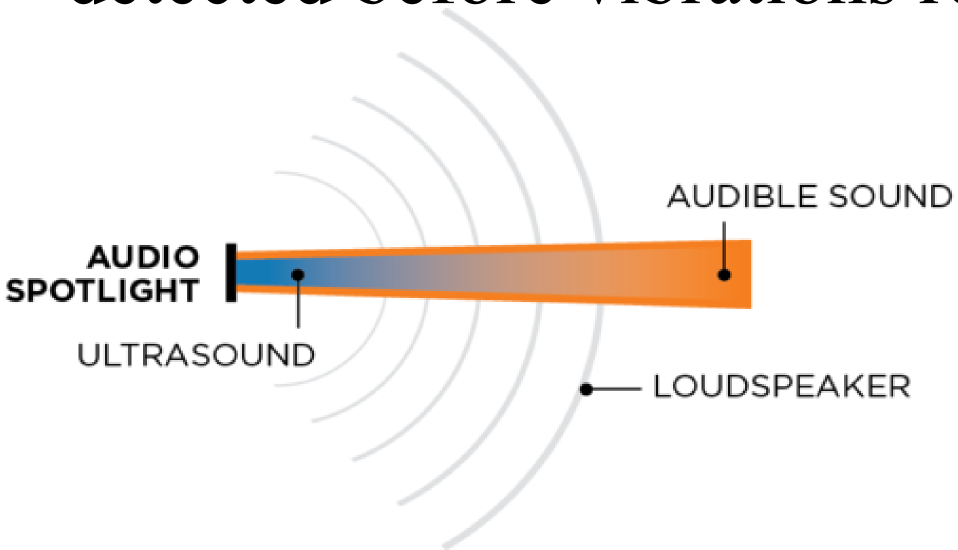
- Ultrasonic frequencies are short wave directional signals beyond the normal hearing range (frequency above 20 kHz) but detected by various instruments.
- Working equipment produce characteristic ultrasound frequencies or "sonic signatures"
- Changes in sonic signatures signal changes in the equipment and predict potential failures.
- Ultrasound frequencies are also emitted by leaks from hydraulic and pneumatic pipes, steam traps, valves, and heat exchangers, as well as from electrical arcing and coronas caused by worn and frayed conductors, or shorts.
- Potential bearing failures can be detected by ultrasonic means long before vibration or heat detection techniques can be effectively used.

Ultrasound Categories

- One technique involves a transducer emitting high frequency ultrasonic waves towards an object.
- This technique can reveal changes in material properties such as thickness, pits, cracks, voids, and corrosion.
- This technique can also reveal leaks in pipes or other containers.

Ultrasound Categories

- The second technique requires the detection of the ultrasound frequencies generated by a source.
- Ultrasounds are considered **directional**, allowing their sources to be easily located.
- Ultrasound frequencies generated by damaged or worn pumps, gears, gearboxes, and bearings can be detected before vibrations reach detectable levels.



An application of ultrasound directionality in audio spotlights.
https://www.holosonics.com/what-makes-a-sound-source-directional