Predictive Maintenance

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Introduction
To
Predictive
Maintenance

Introduction

- The purpose of this course is to introduce and provide individuals with an overview of predictive maintenance and a basic understanding of the methods and tools required..


objectives

Objectives

- **This course will present the following topics:**
- Define predictive maintenance programs.
- Define maintenance planning requirements and review Critical Path Method (CPM).
- Examine the principles of Vibration Theory and Analysis.
- Examine the basics of Lubrication and Analysis (Tribology).
- Examine the basics of Ultrasonic Analysis.
- Examine the basics of Thermographic Analysis.
- Examine the principles of Electrical Insulation Testing.
- Define inspection and performance measurement techniques.


Agenda!
1.
2.
3.
4.
5.

Agenda

- Predictive Maintenance
- Maintenance Planning
- Vibration Analysis
- Performance Monitoring
- Thermal Analysis

Agenda

- Lubrication and Tribology (Fluid Analysis)
- Non-destructive Testing and Inspection
- Ultrasonic Measurement
- Insulation Testing
- Balancing
- Review


Predictive
Maintenance

Objectives

- Define preventive maintenance.
- Define predictive maintenance.
- Define patterns of failure.
- Define condition monitoring.

Terms

- PM means: Preventive Maintenance
- PdM means: Predictive Maintenance
- PPM or P/PM means: Preventive and Predictive Maintenance.
- CMMS means Computerized Maintenance Management System.

How to View Maintenance

- Engineering
- Economic
- Management
- What else?

PM

- PM (Preventive Maintenance) is a series of tasks which are performed at sequence of time, quantity of production, equipment hours, mileage or condition for the purpose of:
  - Extending equipment life
  - Detect critical wear or impending breakdown

PdM

- PdM (Predictive Maintenance) is any inspection carried out with technological tools to detect when failures will occur.

Misconceptions about PM

- PM is the only way to determine when and what will break down.
- PM systems are the same
- PM is extra work/costs more.
- Unskilled people can do PM tasks.
- PM is obsolete due to new technology.
- PM will eliminate breakdowns.

Task Lists

- The task list is the heart of the PM system:
  - ✓ What to do?
  - ✓ What to use?
  - ✓ What to look for?
  - ✓ How to do it?
  - ✓ When to do it?

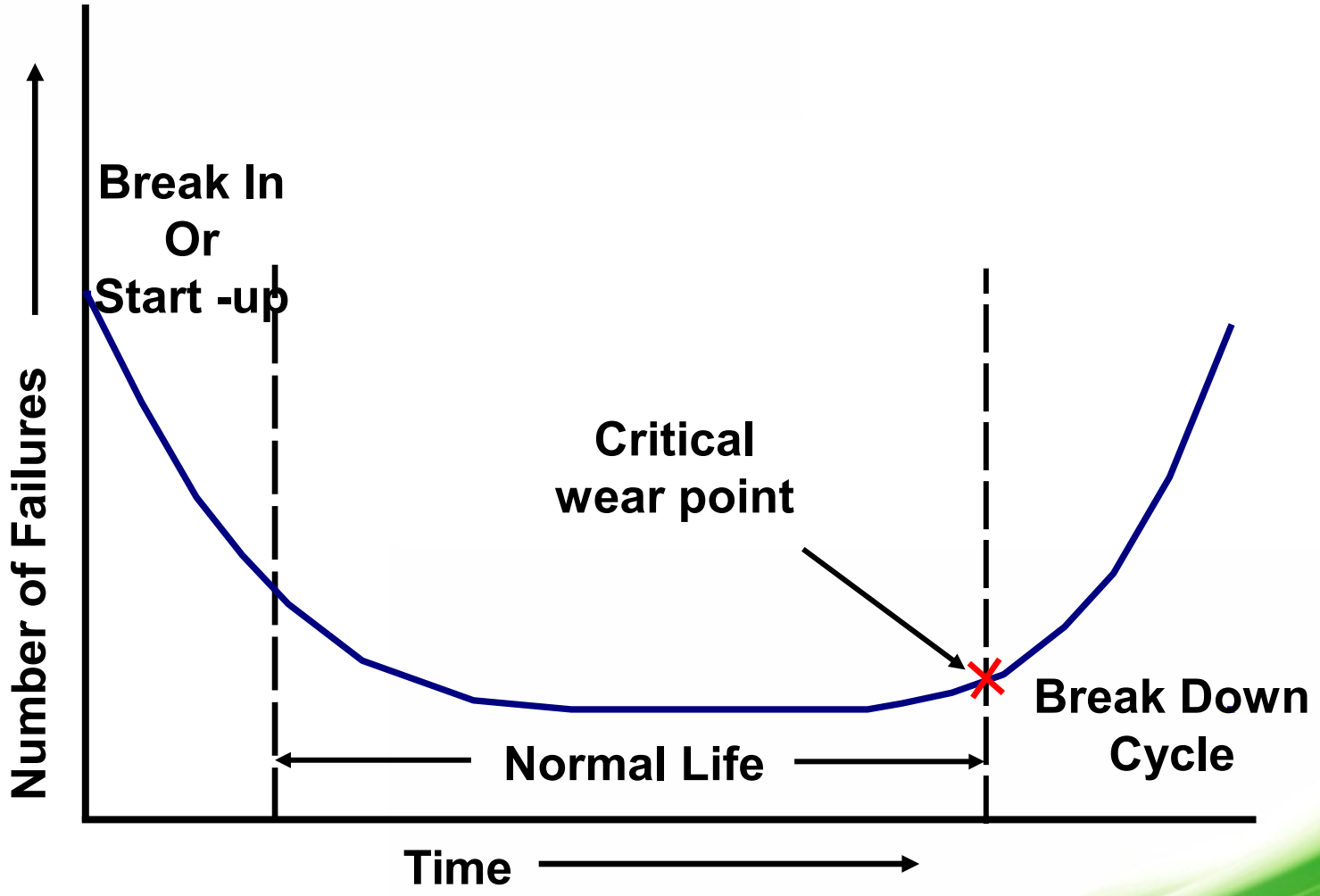
Common Tasks

1. Inspection
2. Predictive Maintenance
3. Cleaning
4. Tightening
5. Operate
6. Adjustments
7. Take Readings
8. Lubrication
9. Scheduled Replacement
10. Interview Operators
11. Analysis

Patterns of Failure

- Random
- Infant mortality
- Increasing
- Increasing then stable
- Ending mortality
- Bathtub

Bathtub Chart



Predictive Maintenance - PdM

- What do we mean by Predictive Maintenance?

“to declare or indicate in advance”

PdM Definitions

- Any inspection (condition based) activity on the PM task list is predictive condition
- Predictive Maintenance is a way to view data.

PdM Program

- A Predictive Maintenance programs is the active condition monitoring approach.
- This requires a program to:
  - Regularly monitor the mechanical condition of all critical production equipment.
  - Identify outstanding problems.

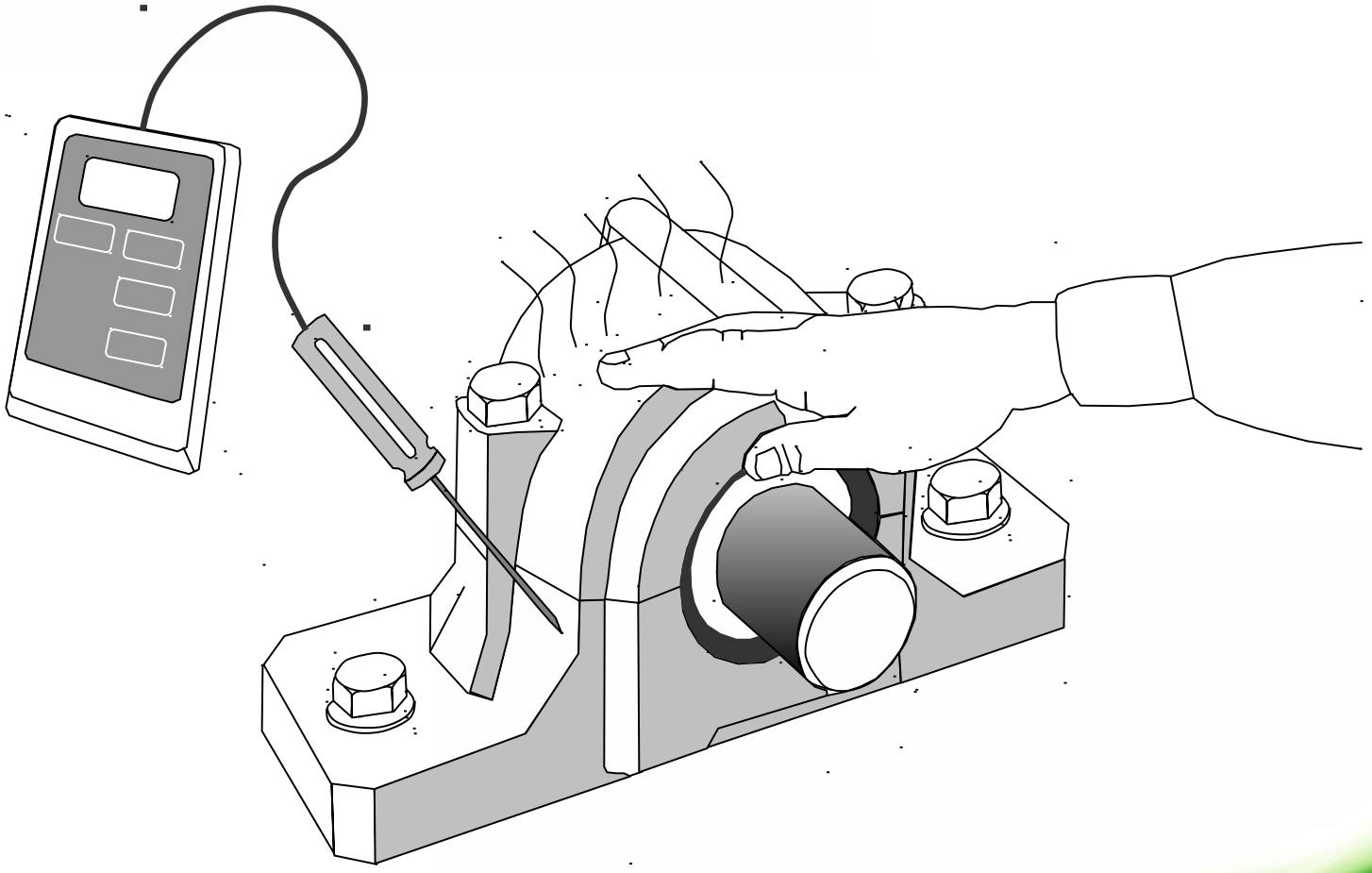
Equipment Condition Monitoring

- ✓ Vibration analysis.
- ✓ Thermography..
- ✓ Fluid analysis (tribology).
- ✓ Visual inspection.
- ✓ Operational-dynamics analysis.
- ✓ Electrical monitoring.
- ✓ Failure analysis.

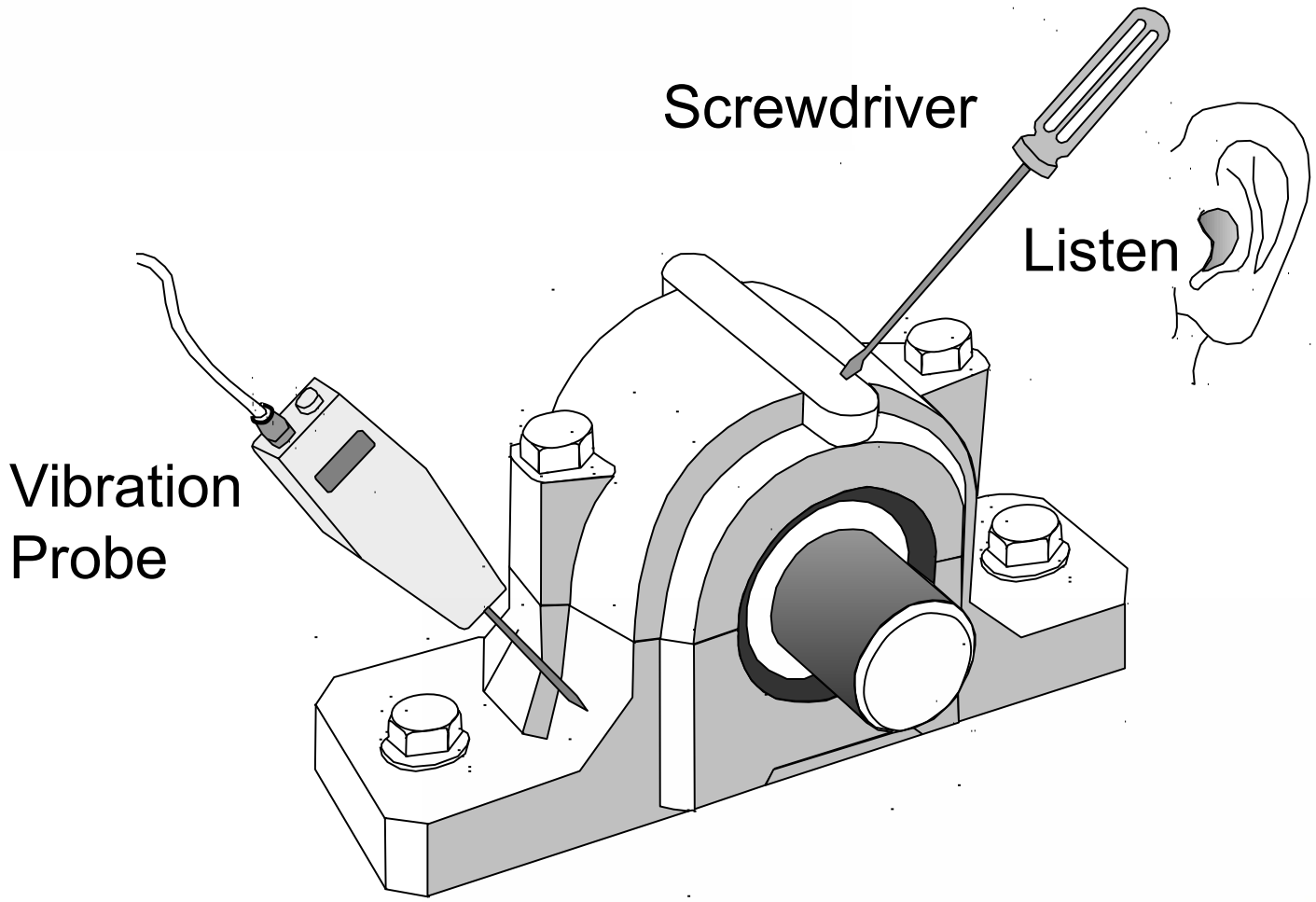
Condition Monitoring

- Temperature
- Vibration
- Changes in noise or sound
- Visually observed changes and problems

Temperature



Vibration



Vibration Problems

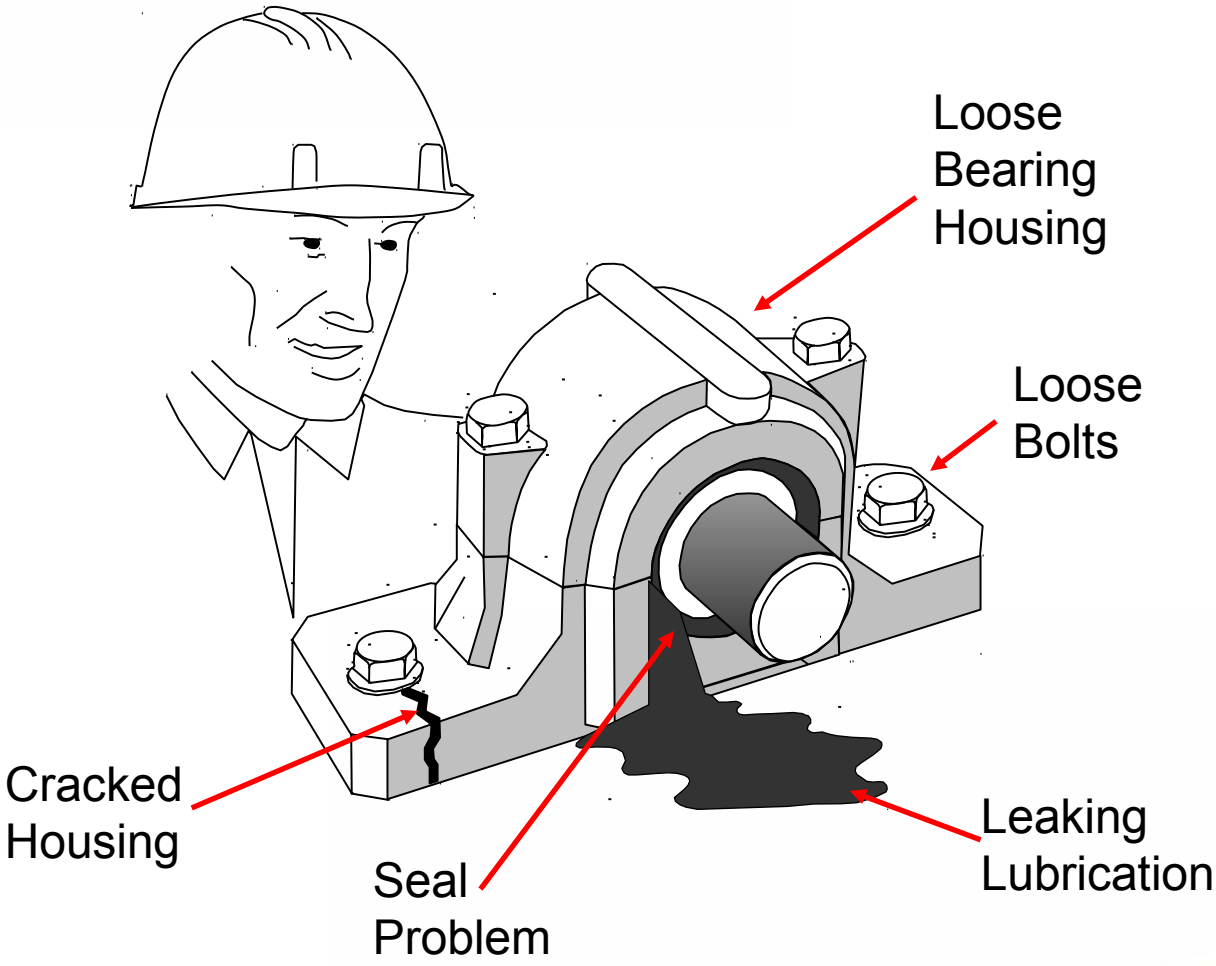
- Many vibration problems can be solved by studying the history of the machine:
  - operational changes.
  - maintenance changes.
- Talk to the operators and maintenance people, and review the maintenance records.
- Knowledge of the machine and its internal components will be of value in this diagnosis

Sound/Noise

- Listening
- Sound Measurements

Sound Intensity and the Human Ear	
Change in Sound Density	**Human Ear Response**
1 dB	Detect change under controlled conditions
3 dB – 5 dB	Noticeable difference in loudness
6 dB	Significant increase in loudness
10 dB	Appears almost twice as loud to the human ear
10 dB – 20 dB	Unbelievably louder
Example: a 6 dB change in sound intensity will be a significant increase in loudness or a 10 dB change in sound intensity is 3.162 x sound pressure, or almost twice as loud as the original sound heard.	

Sight


Loose
Bearing
Housing
Loose
Bolts
Cracked
Housing
Seal
Problem
Leaking
Lubrication

Summary

- Review Objectives.
- Question and Answer session.


Maintenance
Planning

Maintenance Program Objectives

- The primary objectives of any maintenance program's activities include:
- To ensure that the equipment operates safely and relatively trouble-free for long periods of time.
- To maximize the availability of machinery and equipment necessary to meet the planned production and operational objectives.

Maintenance Program Objectives

- To consistently maintain the plant equipment in order to minimize wear and premature deterioration.
- To make the equipment reliable so it can be counted on to perform to set standards and conditions.

Maintenance Plans

- Long range planning.
- Short or Mid-range planning.
- Immediate planning.

Maintenance Improvement and Reliability Programs

- The following ten steps outline a plan when a company is considering developing an effective Maintenance Improvement and Reliability Program (MIRP).

1- Initialization

- **Step 1**: Begin by initiating a “total maintenance” approach. Production and maintenance must collectively work together.
- The maintenance department has to be viewed as being an integral part of the organization.

2 - Clear Vision

- **Step 2**: Establish a clear vision by having the employees and management identify the problems.
- Then specify the goals and objectives that must be set in order to achieve success.

3 - Analyze

- **Step 3**: Analyze the organization.

✓ Will the organization, as a whole, support the type of improvements required?

✓ If not, consider changing the organizational structure and/or redesign the system to meet the identified needs.

✓ Review the production and operational policies and procedures, as they may not be suited to the maintenance improvement and reliability program

4 - Develop

- **Step 4**: Begin to develop an ‘action plan.”

✓ Identify what is going to be attempted, who is to be involved, what are the resources required, etc.

✓ Action plans take on many different forms, but it is important that the plan contain inputs drawn from the reviews and analysis rather than from complaints.

5 - Assess

- **Step 5**: Assess the condition of the equipment and facilities.

✓ Be objective in the assessment.

✓ Determine which equipment requires immediate attention.

6 - Select

- **Step 6**: Select the appropriate maintenance program. is a computerized maintenance system needed?
- What technique will be employed, reactive, preventive or predictive maintenance?
- Determine the order maintenance activities will be carried out, first, then second, etc.?
- What type of reporting system will be used to track and record the data collected when measuring the performance of each piece of equipment?

7 - Measure

- **Step 7**: Measure equipment condition.
- When measuring for equipment condition which method(s) will be considered:

✓ vibration analysis?

✓ fluid analysis?

✓ non-destructive testing?

✓ performance monitoring methods?

8 - Prepare

- **Step 8**: Prepare the maintenance personnel.

✓ As the maintenance program activities and methods are implemented ensure that the maintenance personnel are:

  ✓ trained to understand the program

  ✓ why the activities and methods are performed.

✓ Without this step no type of maintenance improvement and reliability program will succeed.

9 - Monitor

- **Step 9**: Monitor equipment and machinery effectiveness to the detail the maintenance program requires.
- Monitor for:
  - ✓ performance
  - ✓ reliability
  - ✓ quality
- Over time, the recorded information can be used to evaluate the machinery and equipment condition and situation.
- This is an on-going activity of any quality maintenance program.

10 - Review

- **Step 10**: Initiate periodic reviews
- Equipment and machinery effectiveness is based on scheduled predictive and preventive maintenance activities.
  - ✓ The review of these activities may indicate common problems and trends which identify any design or operational changes required.
  - ✓ Include engineering, maintenance and production personnel in these periodic reviews.
  - ✓ Ensure that action plans develop from these review sessions, not just complaints.


Vibration
Analysis

Benefits from Vibration Analysis

- Identifies early stages of machine defects such as:
  - ✓ Unbalance of Rotating Parts
  - ✓ Misalignment of Couplings & Bearings
  - ✓ Bent Shafts
  - ✓ Bad Bearings – Anti Friction Type
  - ✓ Bad Drive Belts and Drive Chains
  - ✓ Resonance
  - ✓ Loose or broken parts
  - ✓ Torque Variations
  - ✓ Improper Lubricant
  - ✓ Hydraulic or Aerodynamic Forces
  - ✓ Rubbing
  - ✓ Electrical problems
  - ✓ Worn, Eccentric, or Damaged Gears
- Provides for time to plan maintenance activities
- Saves Cost of Unnecessary Repairs
- Evaluates work done

Vibration CbM Philosophy

- Based on three principles:

✓ All rotating equipment vibrates

✓ Vibration increases/changes as equipment condition deteriorates

✓ Vibration can be accurately measured and interpreted

Causes of Vibration:

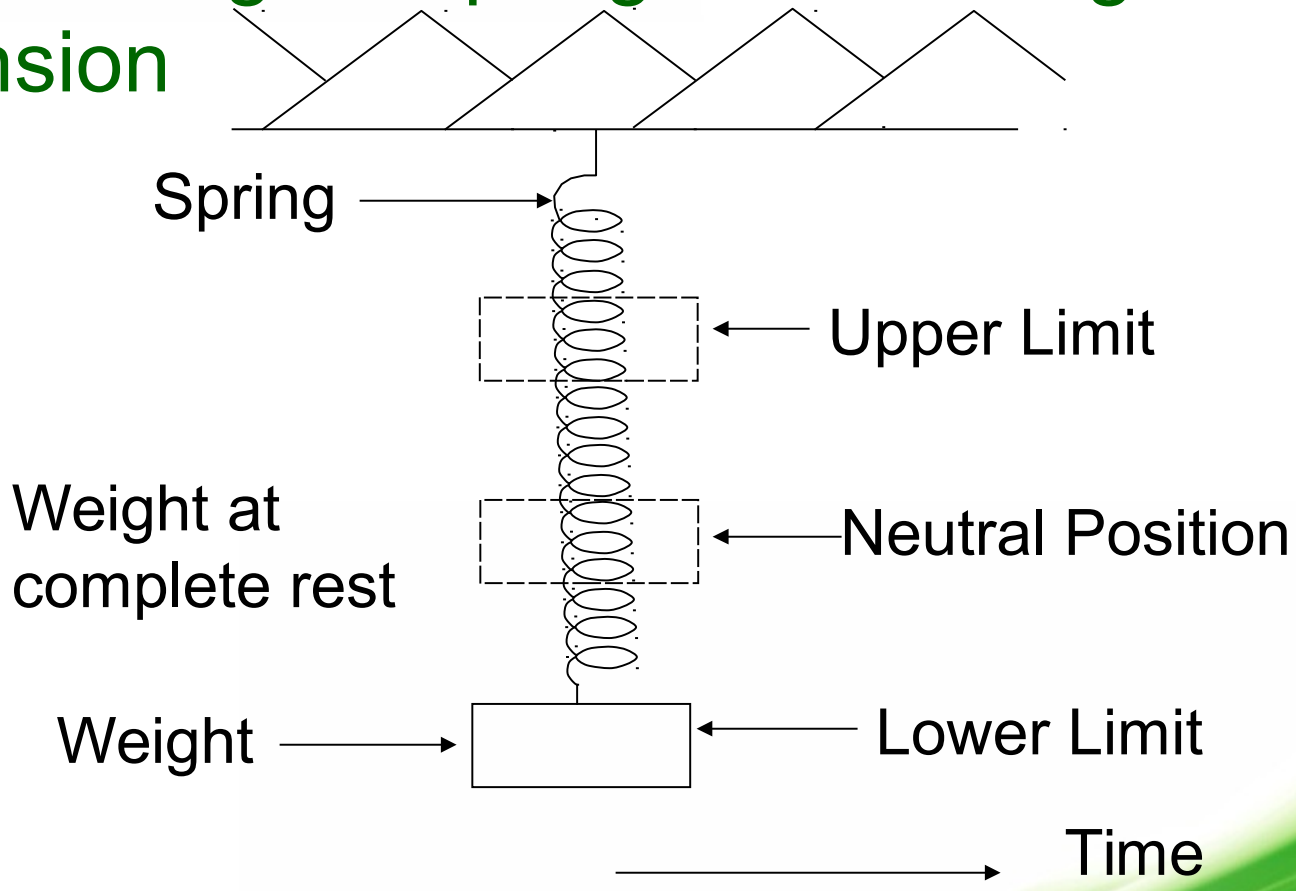
- Forces that change in direction with time (e.g., Rotating Unbalance)
- Forces that change in amplitude or intensity with time (e.g., Motor Problems)
- Frictional Forces (e.g., Rotor Rub)
- Forces that cause impacts (e.g., Bearing Defects)
- Randomly generated forces (e.g., Turbulence)

When Condition of Machinery Deteriorates

- Dynamic forces increase, cause increase in vibration.
  - ✓ Wear, corrosion, or buildup of deposits increases unbalance
  - ✓ Settling of foundation may increase misalignment forces
- The stiffness of the machine reduces, thus increasing vibration.
  - ✓ Loosening or stretching of mounting bolts
  - ✓ Broken weld
  - ✓ Crack in the foundation
  - ✓ Deterioration of grouting

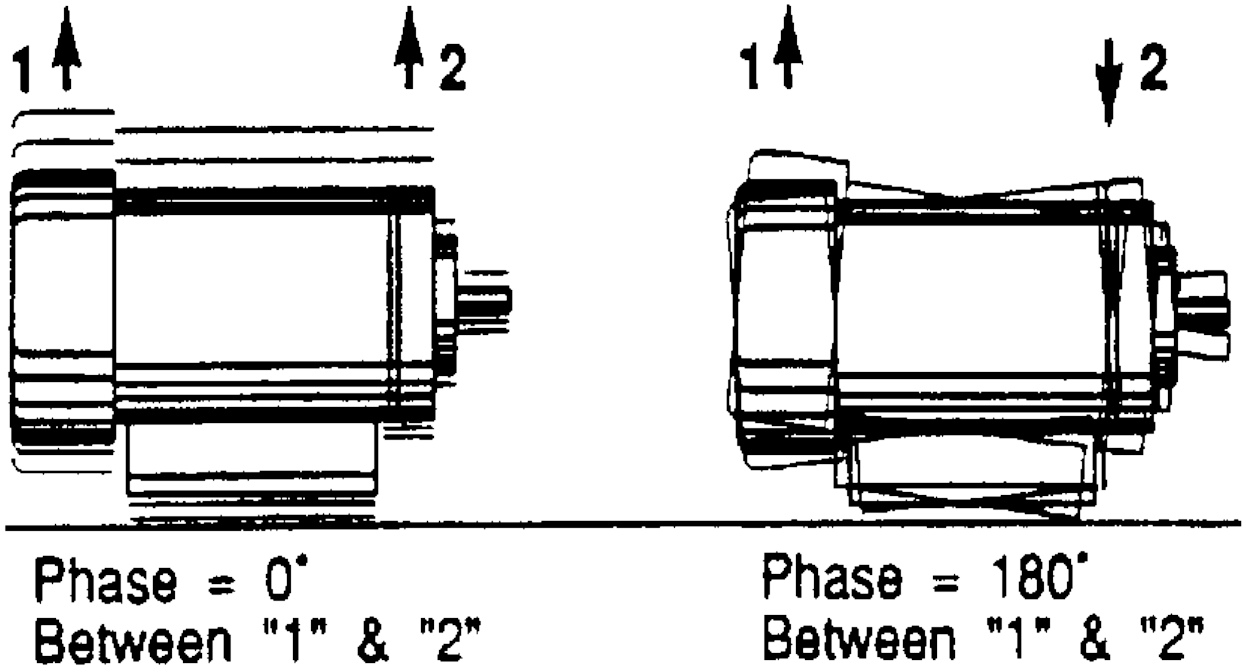
Vibration Demonstration

- Vibration-Single spring and weight in suspension



RELATIVE PHASE

- Comparative phase readings show “how” the machine is vibrating
- Note how relative phase causes significant changes in vibration seen at the coupling with little to no change in the amplitudes measured at points 1 and 2



Vibration Quality

Vibration Quality	Vibration Velocity	
	IPS	mm/sec
Extremely Smooth	< 0.005	<0.125
Very Smooth	0.005	0.125
Smooth	0.009	0.250
Very Good	0.019	0.500
Good	0.036	1.000
Fair	0.075	2.000
Slightly Rough	0.150	4.000
Rough	0.300	8.000
Very Rough	0.600	16.00
Extremely Rough	1.200	32.00

Frequency Characteristics

- Synchronous Vibration
- Asynchronous Vibration
- Natural Frequency
- Resonance

Critical Speed

- Critical Speed is defined as being a type of resonance which occurs when a shaft or rotating machine component revolves at a speed close to its natural frequency .

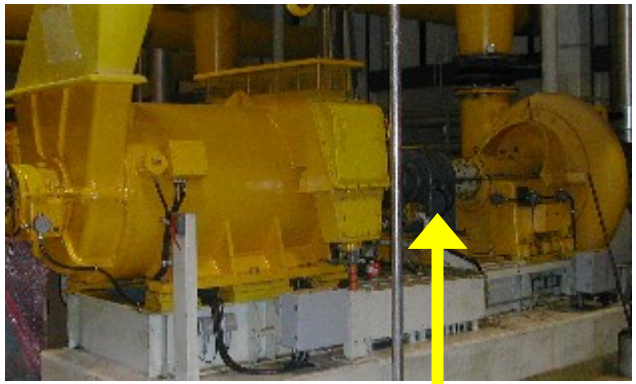
Overall Velocity Guidelines

OVERALL VELOCITY GUIDELINES FOR VIBRATION SEVERITY

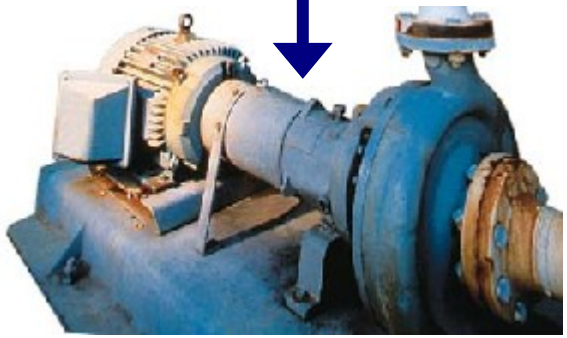
Overall Vibration Velocity Pk	Classification	Description
.6 in/s & up (15 mm/s & up)	VERY ROUGH	***Severe vibration. Potentially unsafe.*** Make immediate detailed vibration analysis to identify trouble. Excessive vibrations may cause oil-film breakdown. Consider shutdown to avoid in-service failure.
.3 to .6 in/sec (8 to 15 mm/s)	ROUGH	***Potentially damaging vibration.*** Make detailed vibration analysis to identify trouble. Rapid wear expected. Make more frequent periodic checks. Schedule for repair.
.2 to .3 in/sec (5 to 8 mm/s)	SLIGHTLY ROUGH	***Faults likely.*** Make detailed vibration analysis. Continue periodic checks. Schedule repair as necessary.
.1 to .2 in/s (3 to 5 mm/s)	AVERAGE	***Minor faults.*** Continue routine periodic checks. Watch for increase.
.05 to .1 in/s (1 to 3 mm/s)	SMOOTH	***Well Balanced.*** Typical of well balanced, well aligned equipment. Make routine periodic checks.
0 to .05 in/s (0 to 1 mm/s)	VERY SMOOTH	***Exceptional.*** Extremely well balanced, well aligned equipment. Make routine periodic checks.

A Coupling / Alignment Example

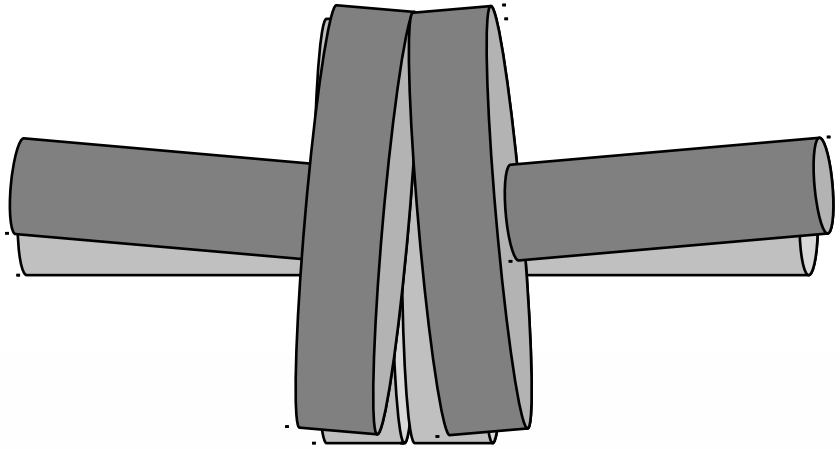
There will be a coupling joining every component on a machine



coupling

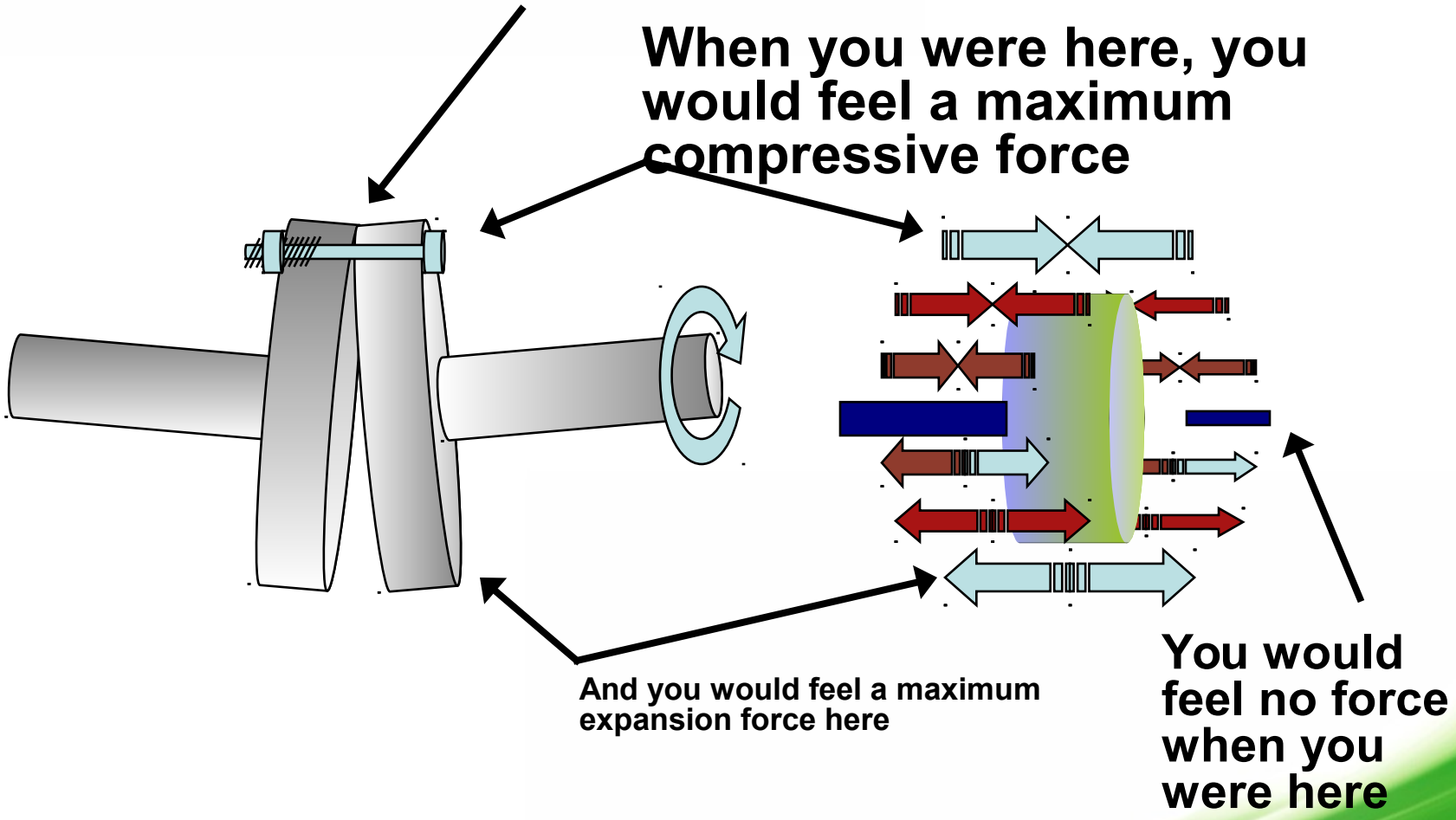


This is called "angular" misalignment (you don't really need to know that though)



Two Maximum Forces per Revolution

Imagine that you are this bolt…




Performance
Monitoring

Monitoring Methods

- Measuring Electrical Performance
- Measuring Fluid Performance
- Measuring Temperature
- Measuring RPM

Establishing Standards

- Standards which represent absolute values.
- Qualitative type of comparative criteria such as manufacturer's design limits.

Judging Performance

- What seems to be out of its limit or has changed?
- By how much have the limits changed?
- Are the changes occurring slowly or rapidly?
- Are there any other changes which either confirm or contradict the initial observations?

Measuring Electrical Performance

- First – follow proper safety rules
- Common Electrical instruments
  - Voltmeters
  - Ammeters
  - Ohmmeters
  - Megohmmeters
  - wattmeters

Basic Instruments- Multimeters

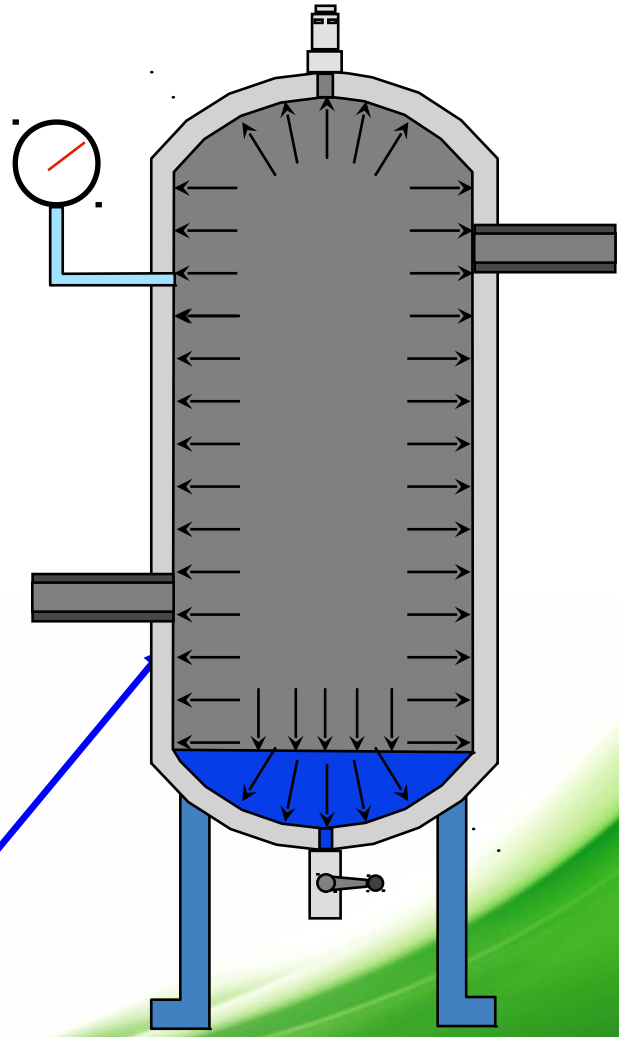
- Combines reading of:
  - Voltages
  - Resistance
  - Current

Digital Multimeter

Analog Multimeter

Measuring Fluid Performance

- Pascal's Law simply stated says: "Pressure applied on a confined fluid is transmitted undiminished in all directions, and acts with equal force on equal areas, and at right angles to the surface."



Pressure Measurement

- Bourdon Style Gage

Tube tends to straighten under pressure causing pointer to rotate.

Bourdon tube

Pressure Inlet

Flow Measurement

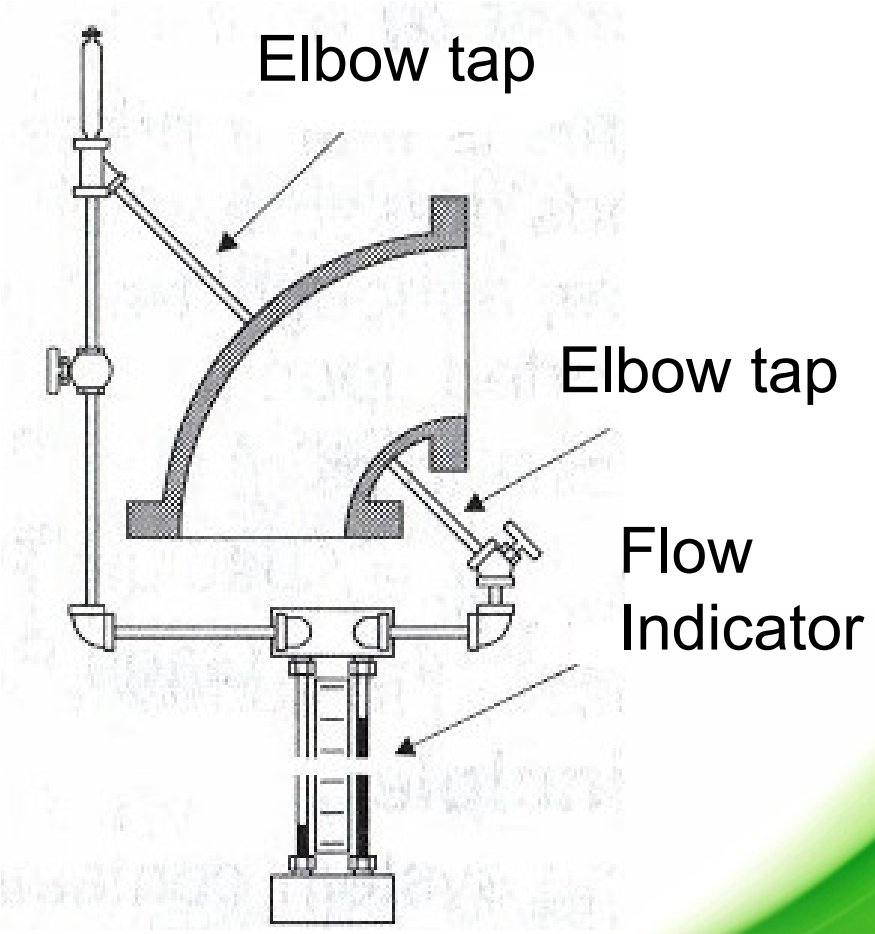
- By determining the rate of flow to what the recommended flow rate is supposed to be is essential for determining pumping capabilities and efficiencies.

Flow Measurement Cont'd

- Types of flow measurement devices are the list following are but a few of the most common types
  - Elbow tap switches
  - Flow switches
  - Turbine Flow meters
  - Rotameter Flow meters
  - Orfice Flow meters
  - Venturi tube flow measurement
  - Doppler Flow meters
  - Volumetric Flow meters

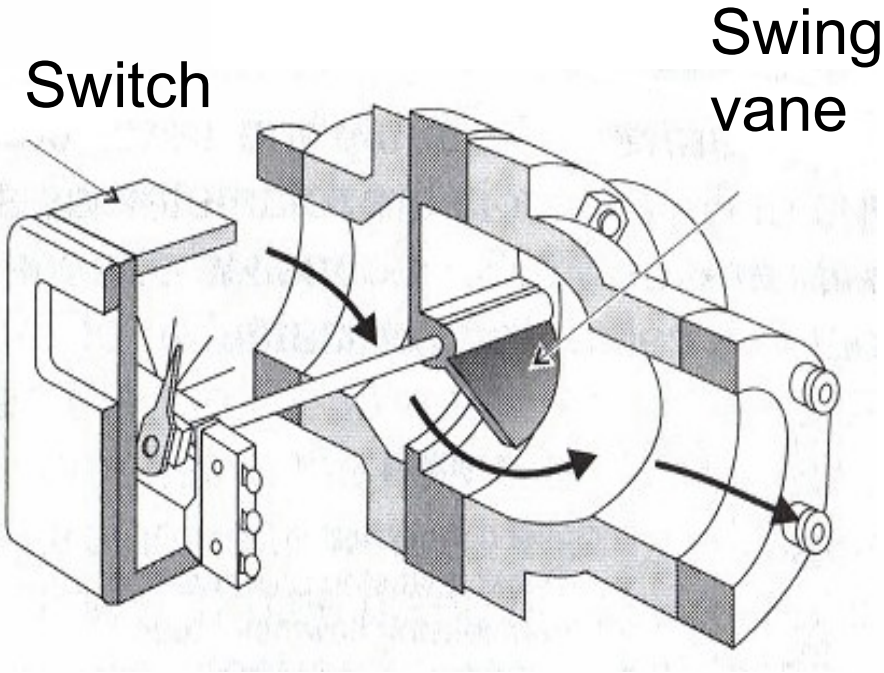
Elbow Taps

- Elbow Taps: A flow measurement using elbow taps depends on the detection of the differential pressure developed by centrifugal force as the direction of fluid flow is changed in a pipe elbow

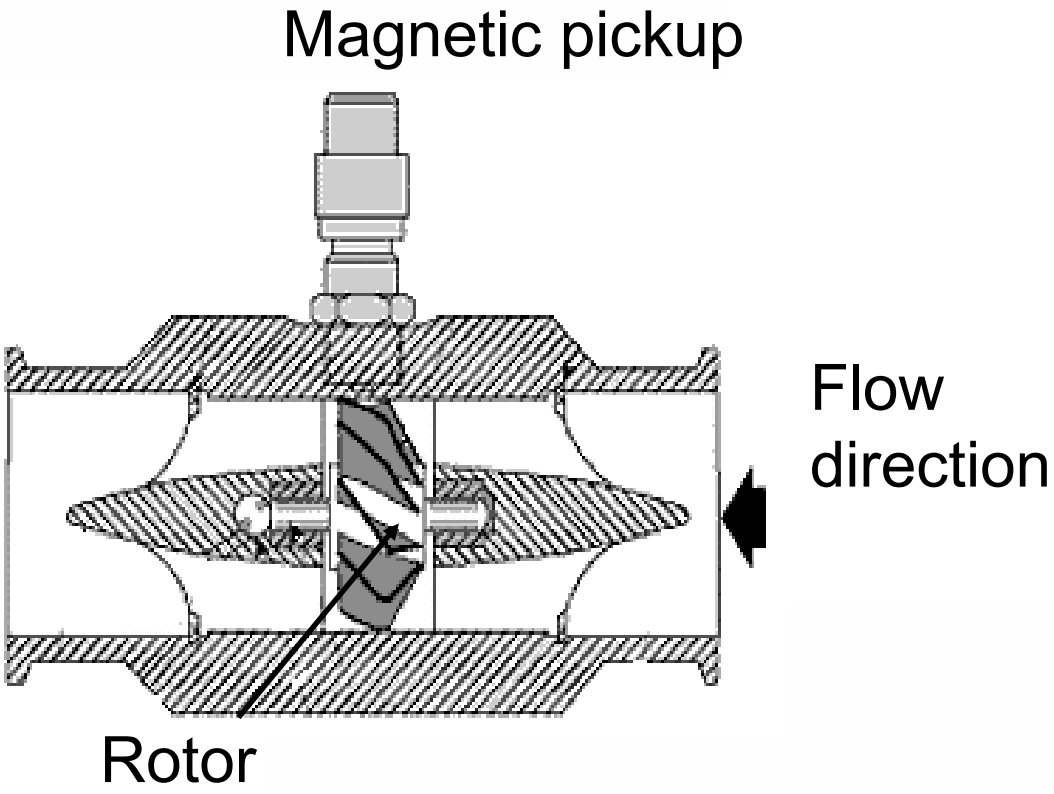


Flow switches

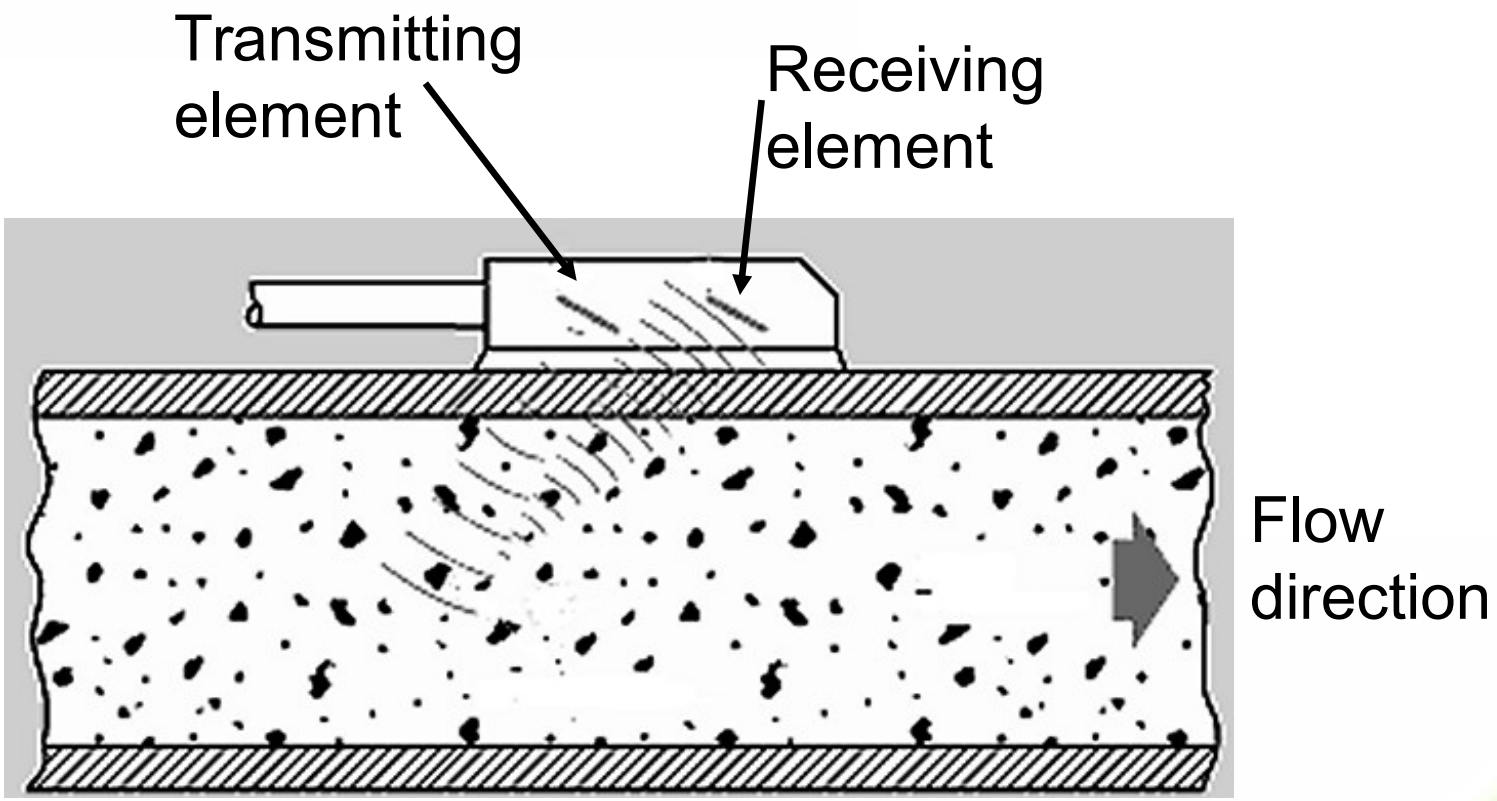
- Flow switches are used to determine if the flow rate is above or below a certain value. One type of flow switch is the swinging vane flow switch.



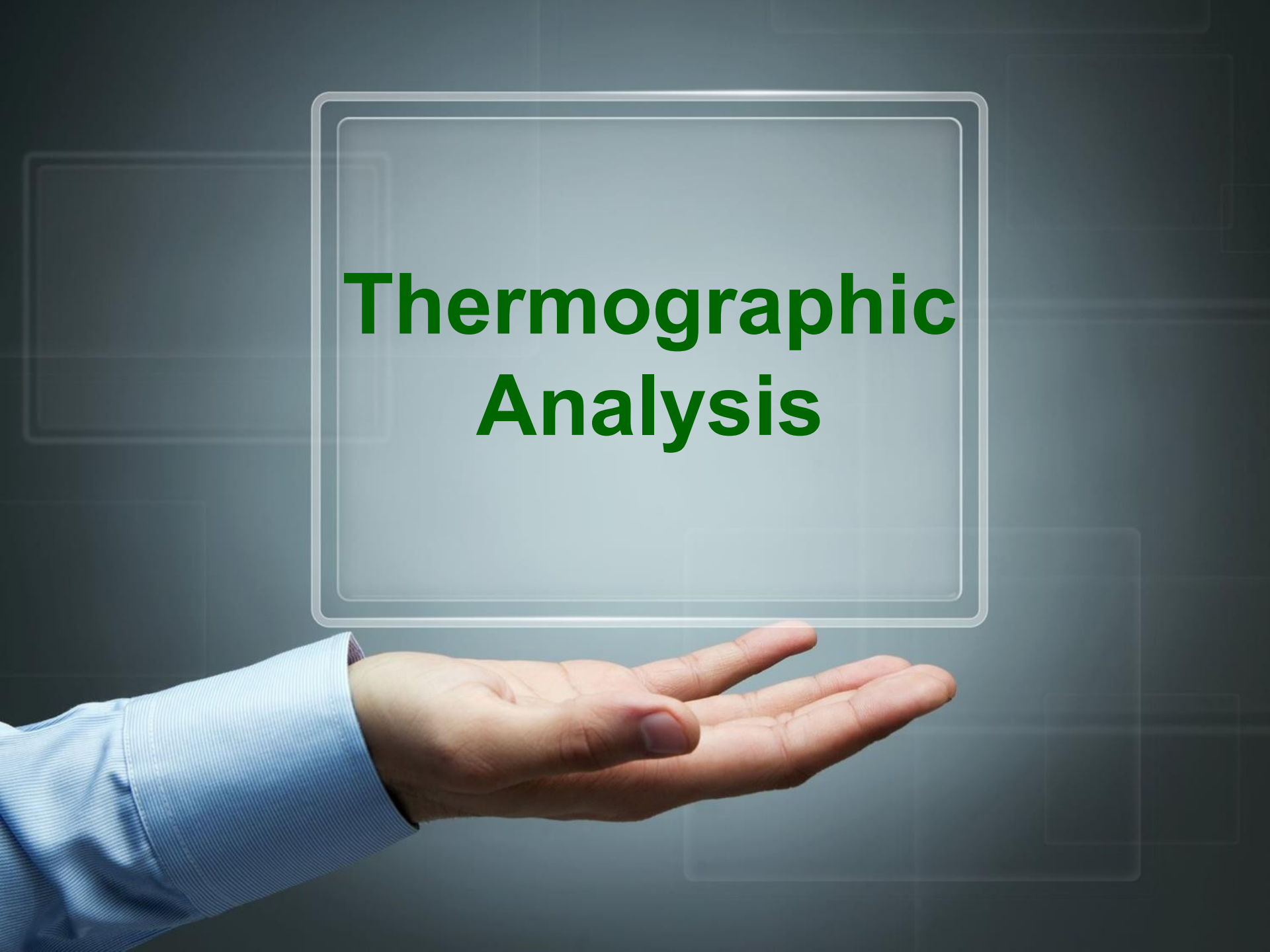
Turbine Flowmeter



Doppler Flowmeters



Thermographic Analysis



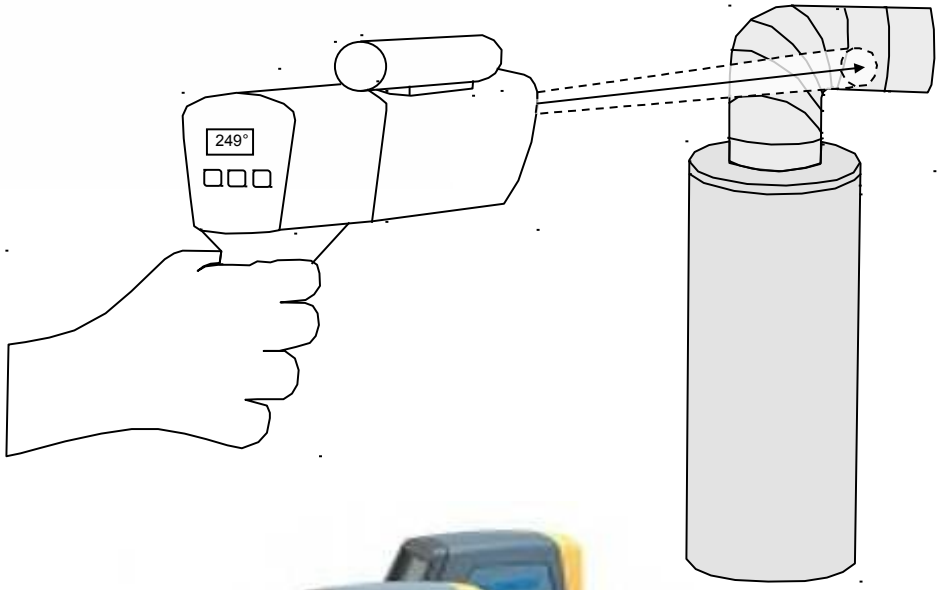
Introduction

- Thermography is a predictive maintenance technique that can be used to monitor the condition of plant machinery, structures, and systems.
- Involves the measurement or mapping surface temperatures as heat flows to, from and/or through an object.

Infrared Basics

- Objects with a temperature above absolute zero emit energy or radiation
- Infrared radiation is one form of this emitted energy.
- Three sources of energy
  - Emitted energy
  - Reflected energy
  - Transmitted energy
- Only emitted energy is important in a predictive maintenance program.

Infrared Thermometers

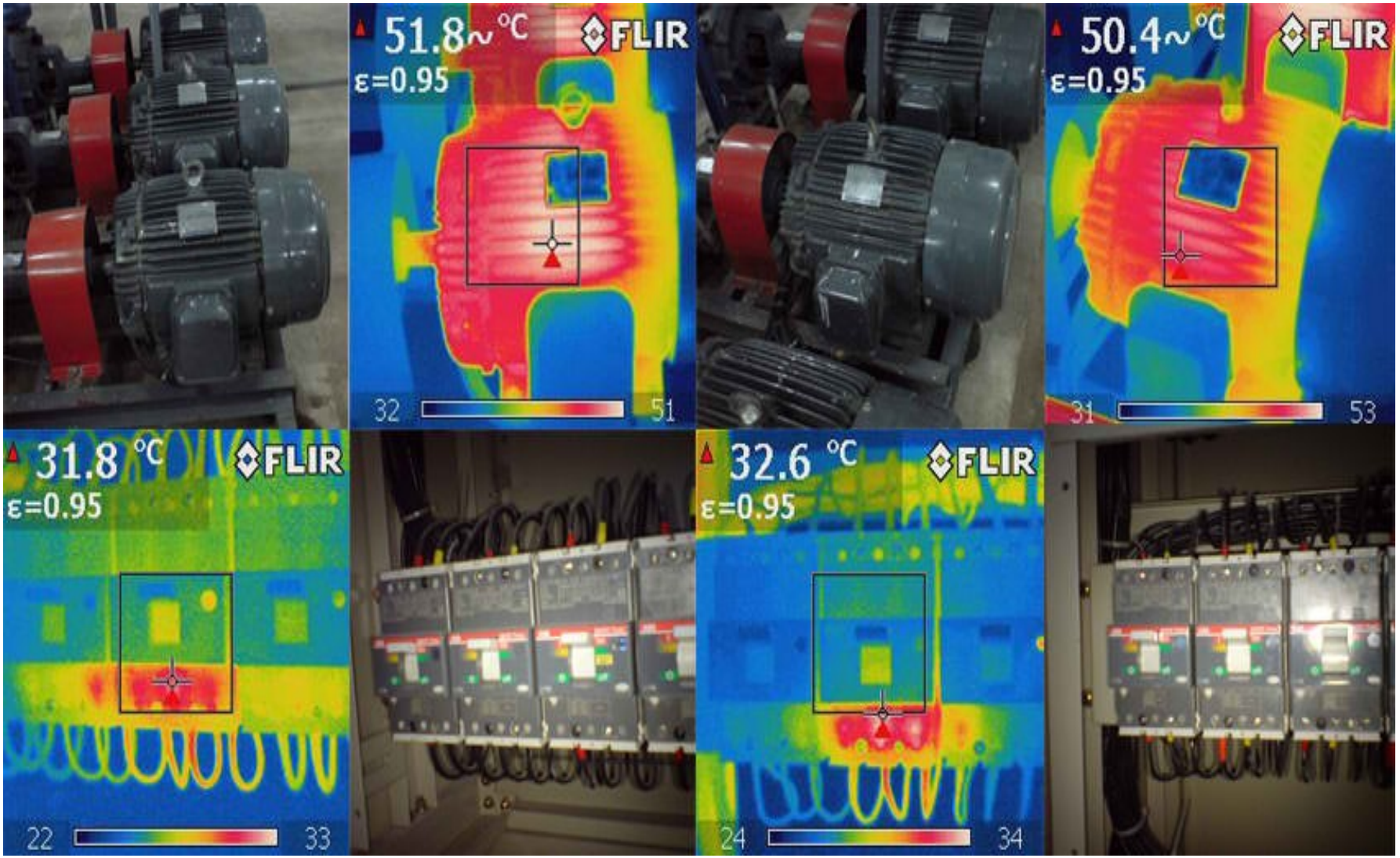


Line Scanners

- This type of infrared instrument provides a single-dimensional scan or line of comparative radiation.

Infrared Imaging

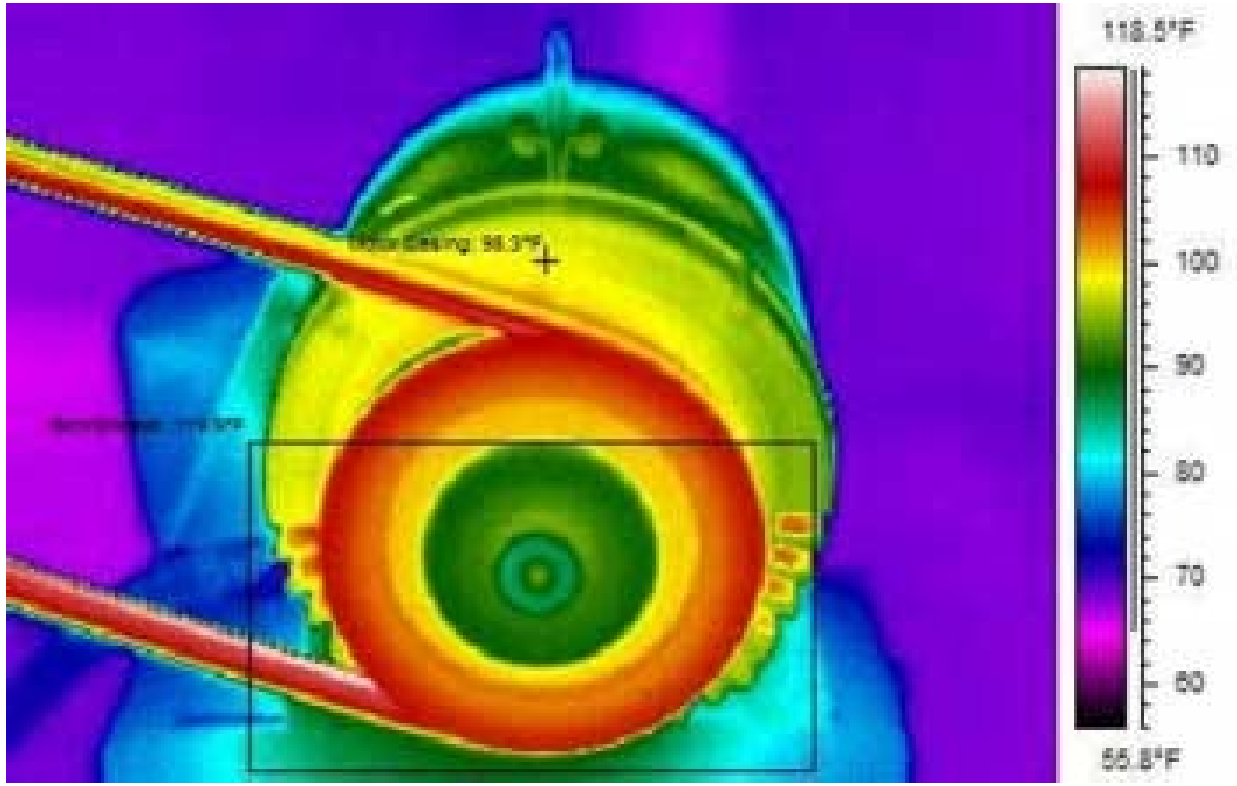
Infrared Imaging



Implementing a Maintenance Program

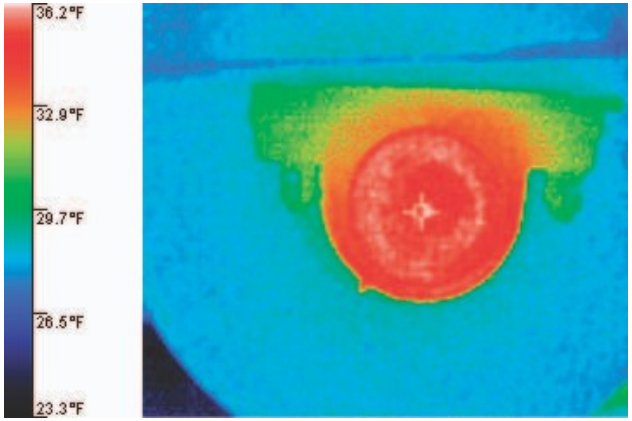
- Gain support from management .
- Practice reading thermographic images
- Meet regularly with managers, line supervisors and other co-workers
- Integrate with other predictive maintenance efforts
- Establish written inspection procedures
- Create inspection routes
- Reporting results

Overheating Belt/Sheave



Inspect Bearings

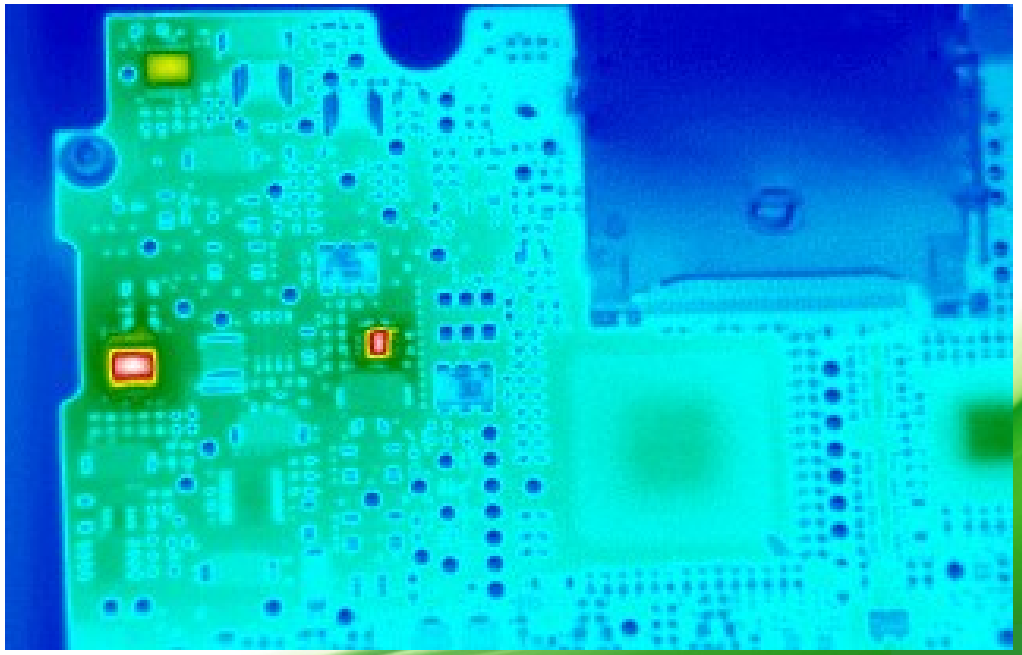
- When a motor bearing fails, the motor heats up and lubrication begins to break down. The windings overheat and then the temperature sensor cuts out and stops the motor. Worst case, the shaft binds up, the rotor locks up and the motor fails completely.



- overheating shaft and bearing may be an indicator of bearing failure, lack of proper lubrication, or misalignment.

Printed Circuit Boards

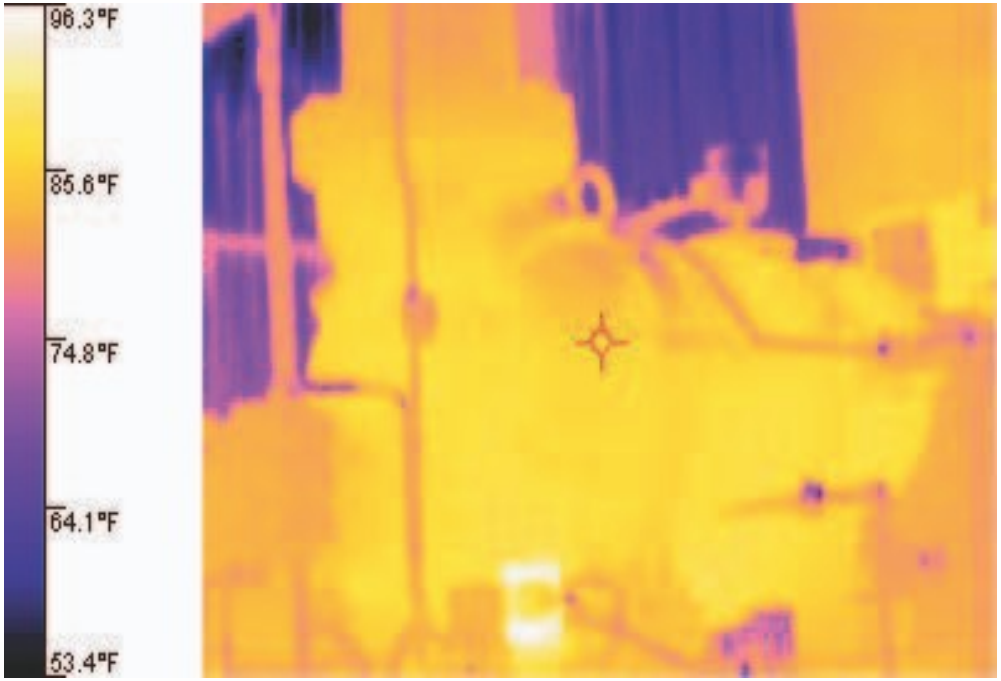
- Thermal imagers capture two-dimensional representations of the surface temperatures of electronics, electrical components and other objects. Since over- heating may signal that a trace, a solder joint, or a component (chip, capacitor, resistor, etc.) is malfunctioning.



Building Inspection

- Thermal imaging or thermography can capture two-dimensional representations of the surface temperatures of parts of buildings, including roofs, walls, doors, windows and construction joints.

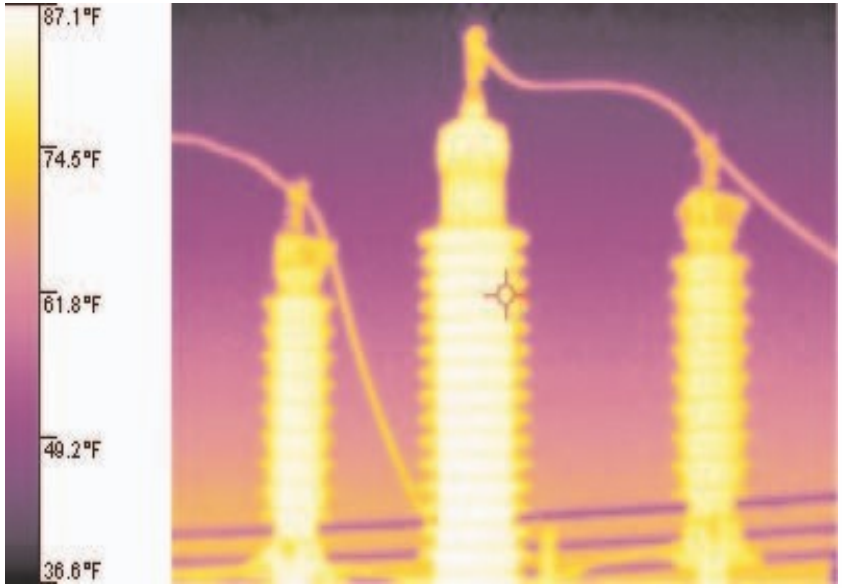
Petroleumand petrochemical processing



- This nitrogen pump had a persistently leaky seal and had to be changed out regularly. Thermal imaging revealed a restriction preventing the seal from receiving enough cool airflow. As a result, the seal was overheating and melting.

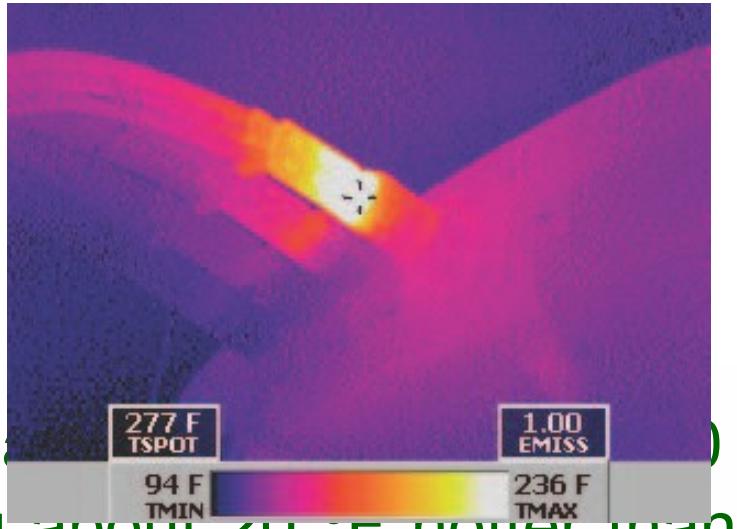
Substations and Switchgear

- Since overheating as well as abnormally cool operating temperatures may signal the degradation of an electrical component, thermal imagers provide the predictive capabilities required for substation and switchgear maintenance.



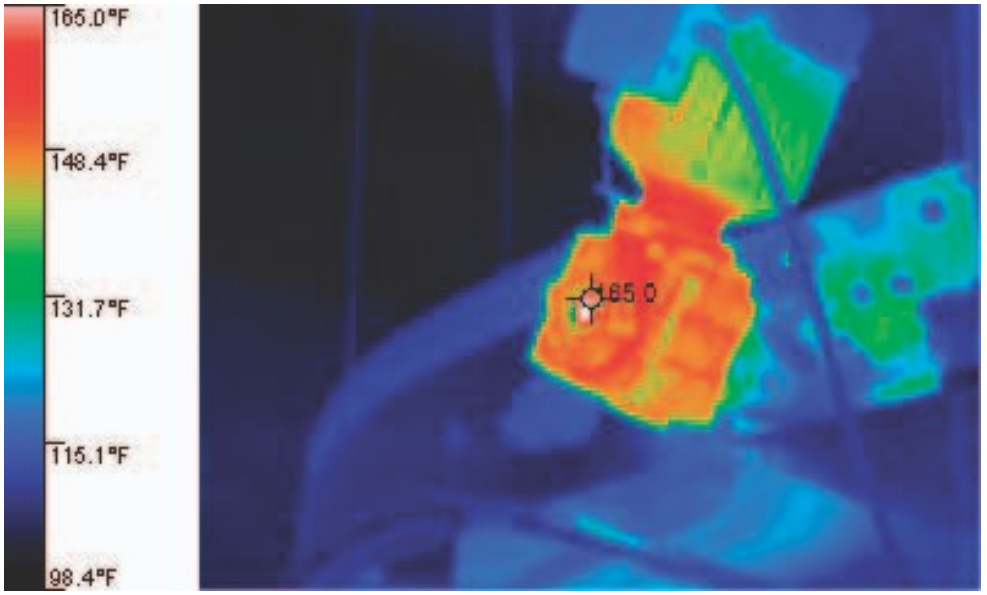
Monitoring transformers

- Most transformers are cooled by either oil or air while operating at temperatures much higher than ambient.



- A termin V main transformer is running about 20 °F hotter than it should.

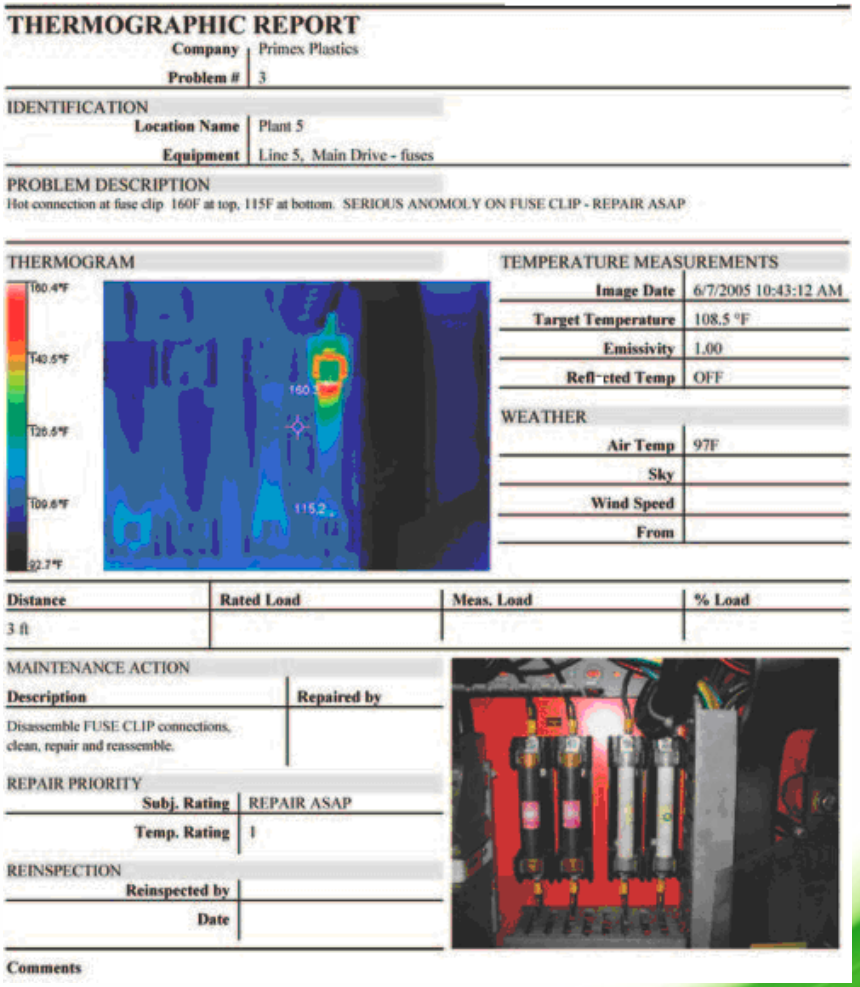
Industrial gearboxes



- The gearbox on this conveyor belt motor assembly is abnormally warm. The clue is the white-hot shaft at the center.

Reports

- When an image reveals a situation that may require repairs, a report should be created describing what the image shows and possibly suggesting a remedy. The report can then be circulated to personnel responsible for equipment reliability, who can investigate the problem further.



THERMOGRAPHIC REPORT

Company	Primex Plastics
Problem #	3

IDENTIFICATION

Location Name	Plant 5
Equipment	Line 5, Main Drive - fuses

PROBLEM DESCRIPTION

Hot connection at fuse clip 160F at top, 115F at bottom. SERIOUS ANOMOLY ON FUSE CLIP - REPAIR ASAP

THERMOGRAM

T80.4°F
T40.5°F
T26.5°F
T09.6°F
92.7°F
160.3
115.2

TEMPERATURE MEASUREMENTS

Image Date	6/7/2005 10:43:12 AM
Target Temperature	108.5 °F
Emissivity	1.00
Reflected Temp	OFF

WEATHER

Air Temp	97F
Sky	
Wind Speed	
From	

Distance	Rated Load	Meas. Load	% Load
3 ft			

MAINTENANCE ACTION

Description	Repaired by
Disassemble FUSE CLIP connections, clean, repair and reassemble.	

REPAIR PRIORITY

Subj. Rating	REPAIR ASAP
Temp. Rating	1

REINSPECTION

Reinspected by	
Date	

Comments


Lubrication

Introduction to Lubrication

- Why use lubricants?

✓ Reduce Friction.

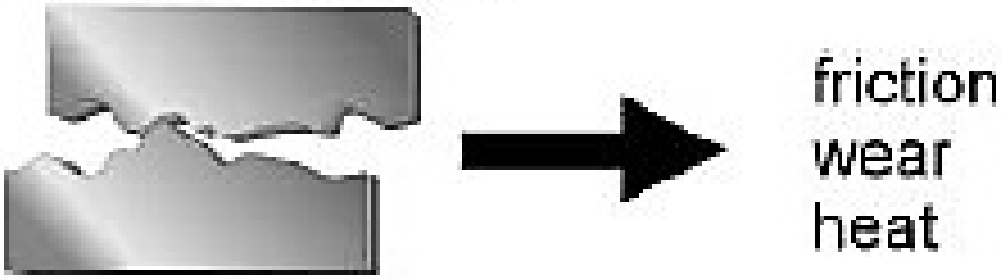
✓ Increase Cooling.

Lubrication Functions

- Form a lubricant film between components.
- Reduce the effect of friction
- Protect against corrosion
- Seal against contaminants
- Cool moving parts

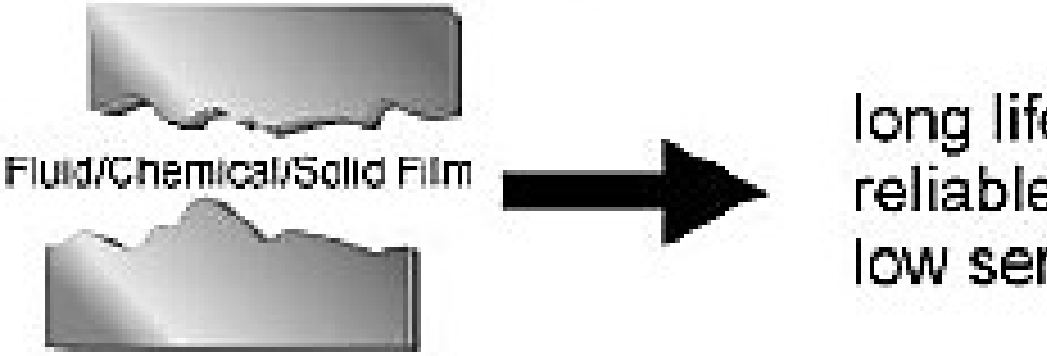
Lubrication

Poor Lubrication



friction
wear
heat

Good Lubrication

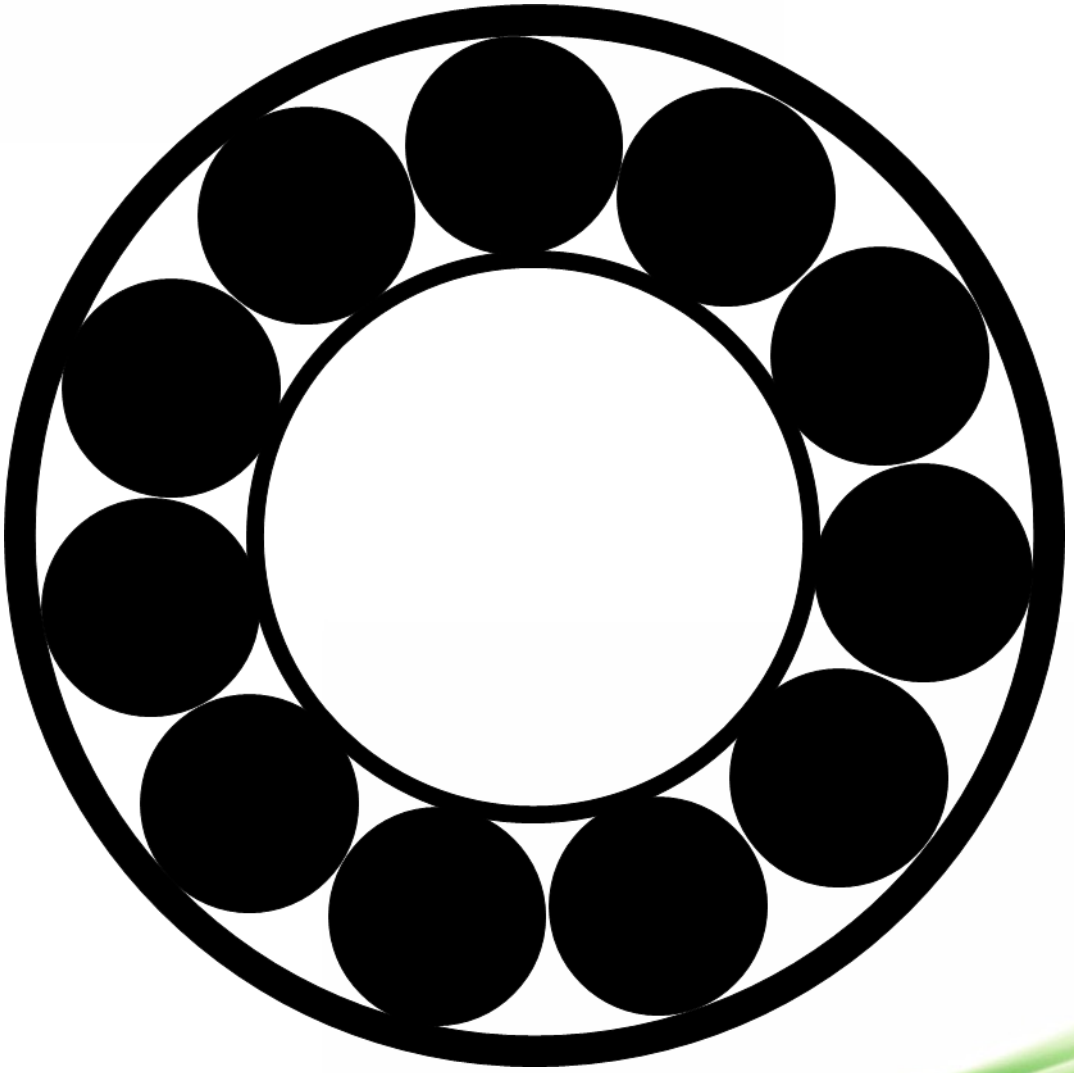


long life
reliable operation
low service cost

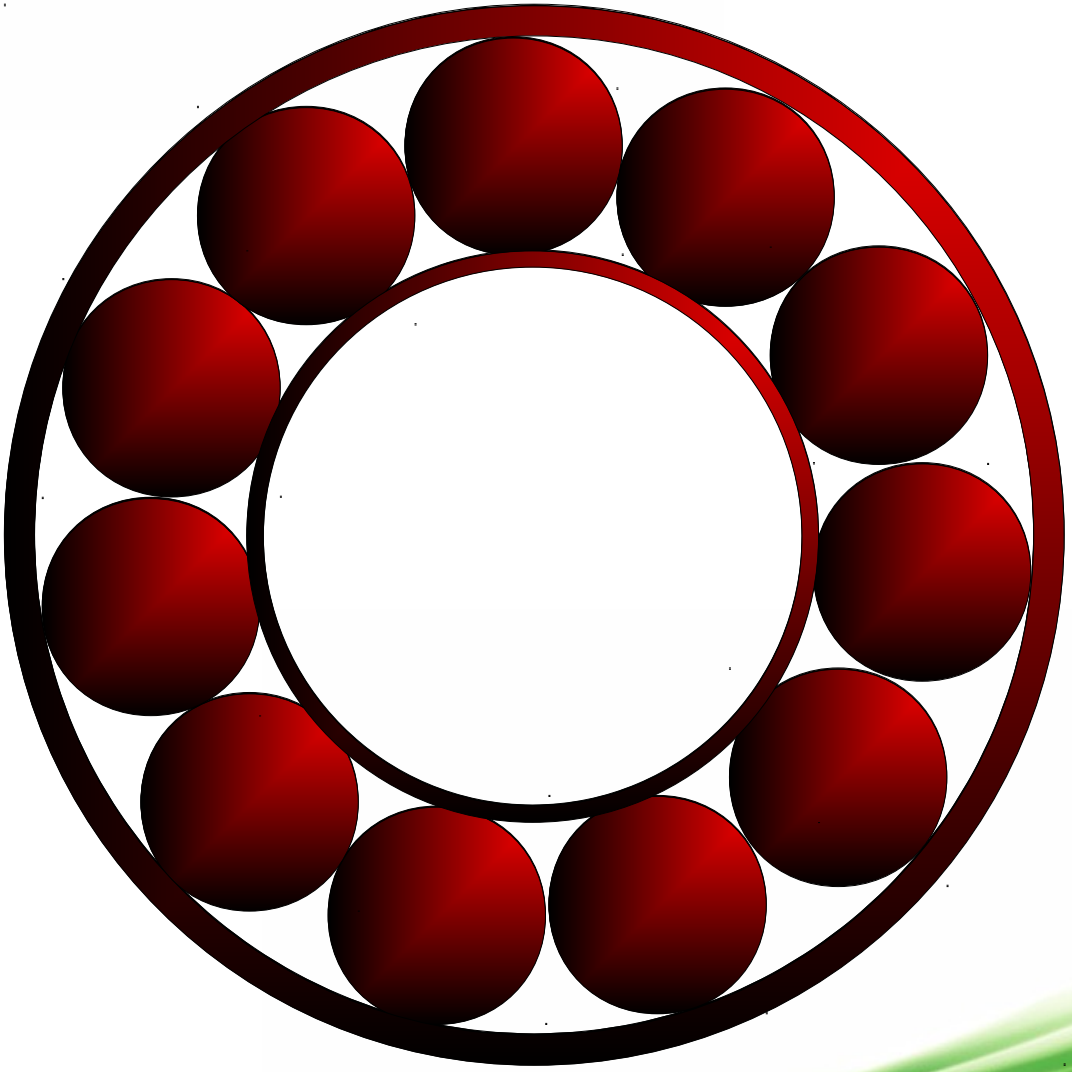
Friction

- Grease and oil lubricate the moving parts of a machine
- Grease and oil reduce friction, heat, and wear of moving machine parts

Oil = Low Friction and Heat



No Oil = High Friction and Heat



Lubrication Prevents Failure of:

- Bearings
- Gears
- Couplings
- Chains
- Engine components
- Hydraulic pumps
- Gas and Steam Turbines
- Any moving parts

Lubricants prevent failure by:

- Inhibiting rust and corrosion
- Absorbing contaminates
- Displacing moisture
- Flushing away particles

Lubricant Selection

- Operating temperature
- Load
- Speed
- Environment
- Grease Lubrication
- Oil Lubrication

Grease

- Grease is a heavy, non-liquid lubricant
- Grease can have a mineral, lithium or soap base
- Grease is pasty, thick and sticky
- Some greases remain a paste from below 0°C to above 200°C.
- The flashpoint of most greases is above 200°C
- Grease does not become a mist under pressure

Oil

- Oil can be a heavy or thin liquid lubricant
- Oil can have a natural base (mineral)
- Oil can have a synthetic base (engineered)
- Oil remains liquid from below 0°C to above 200°C.
- The flashpoint of many oils is above 200°C
- The flashpoint is very low for pressurized oil mist. Why?

How are grease and oil different?

- How oil is used:

- Oil used in closed systems with pumps. An oil sump on a diesel engine pumps liquid oil.
- Oil is used in gas and steam turbines
- Oil is used in most machines that need liquid lubricant

How grease is used?

- In areas where a continuous supply of oil cannot be retained, (open bearings, gears chains, hinged joints)
- Factors to be considered when selecting greases are:
  - ✓ Type. Depends on operating temperatures, water resistance, oxidation stability etc.
  - ✓ Characteristics. Viscosity and consistency

Grease or Oil?

- What determines whether a machine needs grease or oil?
- The manufacturer specifies what lubricant is used in their machines, based on the properties of the lubricant. One important property is VISCOSITY.

Viscosity

- Liquid oil has lower viscosity than grease paste
- Grease paste has higher viscosity than liquid oil

What is Viscosity?

Viscosity

- Viscosity is a liquid's resistance to flow
- Viscosity affects the thickness of a liquid
- **High viscosity** liquids are hard to pour
- **Low viscosity** liquids are easy to pour

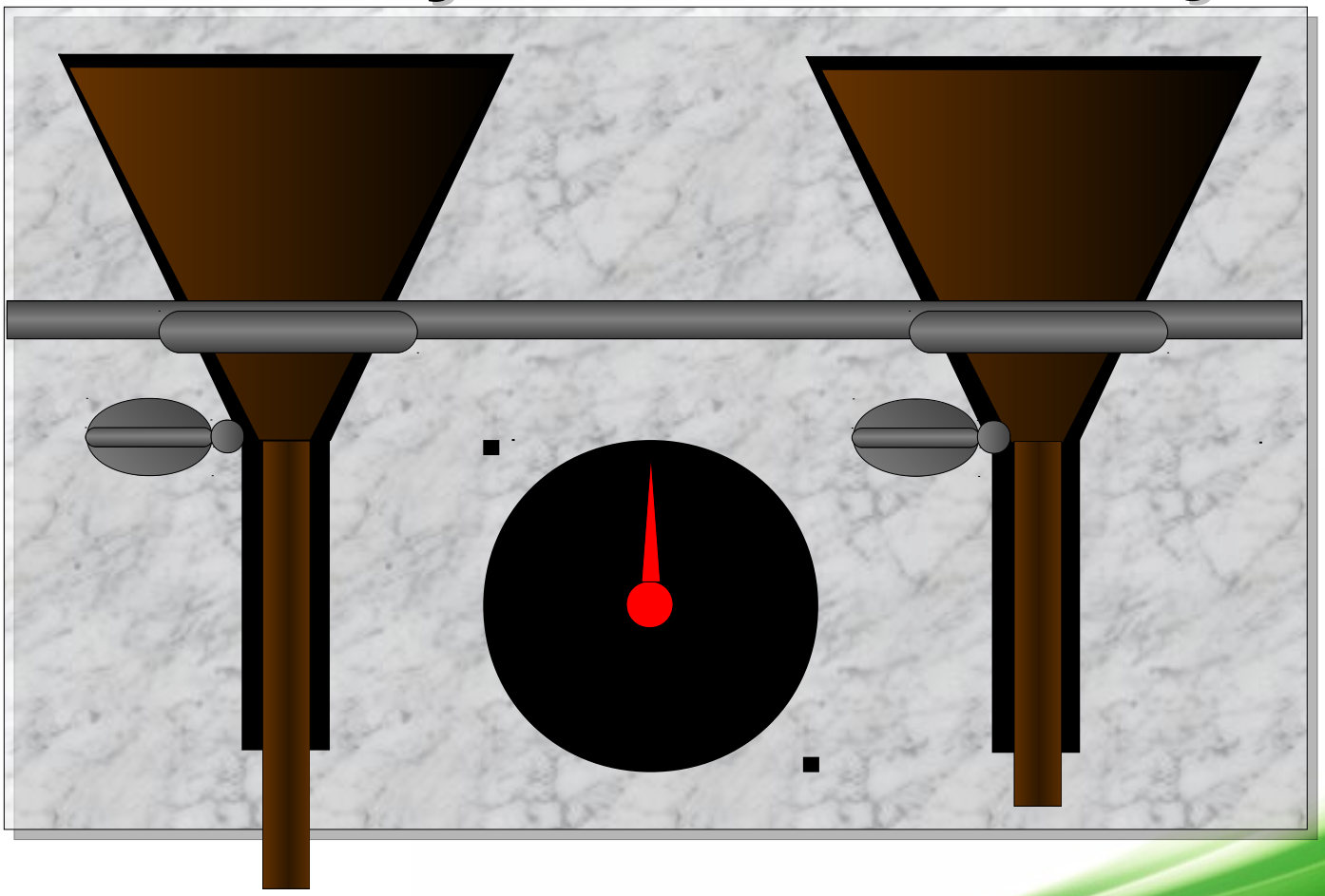
Viscosity Rules of Thumb

- The lower the temperature, the lighter the oil
- The higher the temperature, the heavier the oil
- The heavier the load, the heavier the oil
- The lighter the load, the lighter the oil
- The faster the speed, the lighter the oil
- The slower the speed, the heavier the oil

Viscosity

Low Viscosity

High Viscosity



Viscosity

- Temperature affects viscosity.
- Heat decreases viscosity
- Cold increases viscosity
- Viscosity is measured in centistokes (cSt)

Consistency

- Fundamental principle
- Thickener
- Operating temperature
- Mechanical conditions
- Low temperature effect
- High temperature effect

Advantages of Grease Lubrication

- Reduction of dripping and splattering
- Hard to get points
- Reduction of frequency of lubrication
- Helps seal out contaminants and corrosives.
- Ability to cling to part
- Used to suspend other solids

Grease Selection Factors

- Load condition
- Speed range
- Operating conditions
- Temperature conditions
- Sealing efficiency
- External environment

Oil Types

- Two types of lubrication oil are:
  - Mineral-based
  - Synthetic

Lubricant Specifications

- **ISO** = International Standards Organization
- **SAE** = Society of Automotive Engineers

ISO Lubricant Specifications

- ISO Grade lubricants are for industrial use. ISO specifications exist for lubricants in extreme industrial environments.

Using Different Lubricants

- Why do we use different lubricants?
- What happens if oils are mixed?

Mixing Lubricants

- Consequences of mixing different lubricants are:
  - Change of viscosity
  - Stripping of machine's internal coatings, damage to seals
  - Reduced flash point, risk of fire
  - Loss of corrosion protection
  - Poor water separation
  - Foaming
  - Thermal instability

Fundamentals of Lubrication

- Equipment lubrication
  - Bearings
  - Gears
  - Couplings
  - Chains

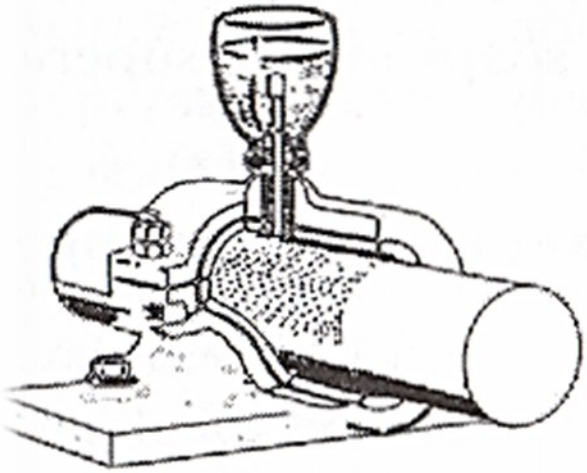
Lubricant Delivery Methods

- Force Feed Lubricant
- Oil Mist
- Constant Circulation
- Oil Slinger
- Zerk Fittings
- Surface Application (brush or spray)

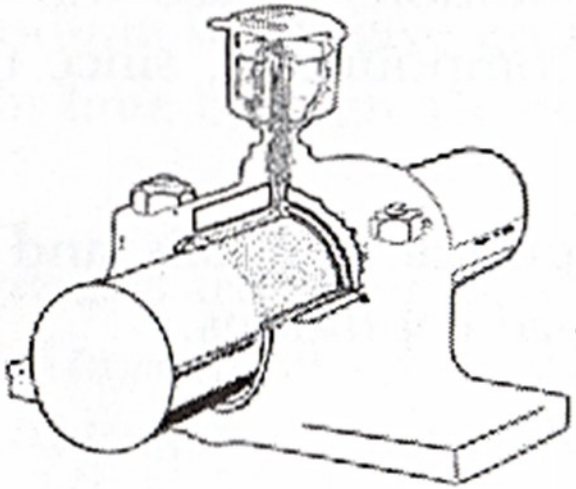
Force Feed Lubrication

- A force feed lubricant system is like an automated version of the hand held oil can. An automatic plunger applies pressure to deliver a few drops at predetermined time intervals.

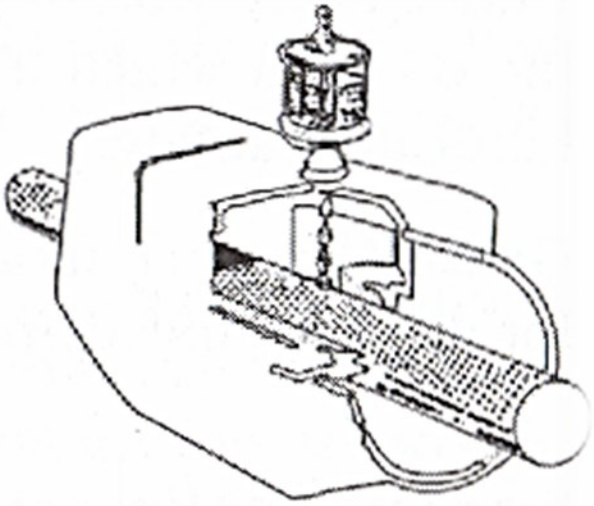
Oil Applicators



Bottle oiler

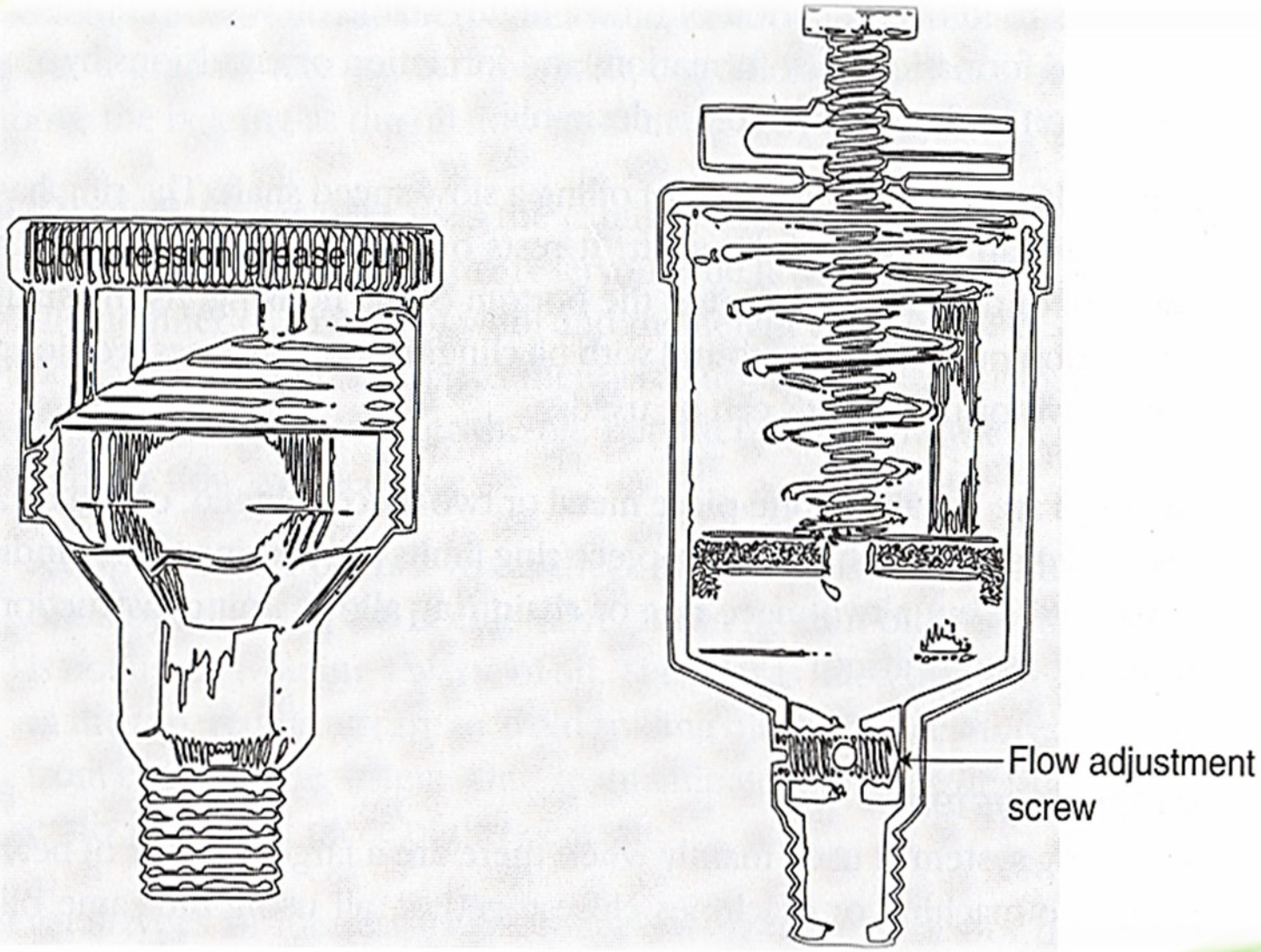


Wick feed oiler



Drop feed oiler

Grease Lubrication



Lubrication Practices

- Using grease gun
- Oil samples
- Removing contamination
- Leaks
- Follow lubrication instructions


Rotor
Balancing

Rotor Balancing

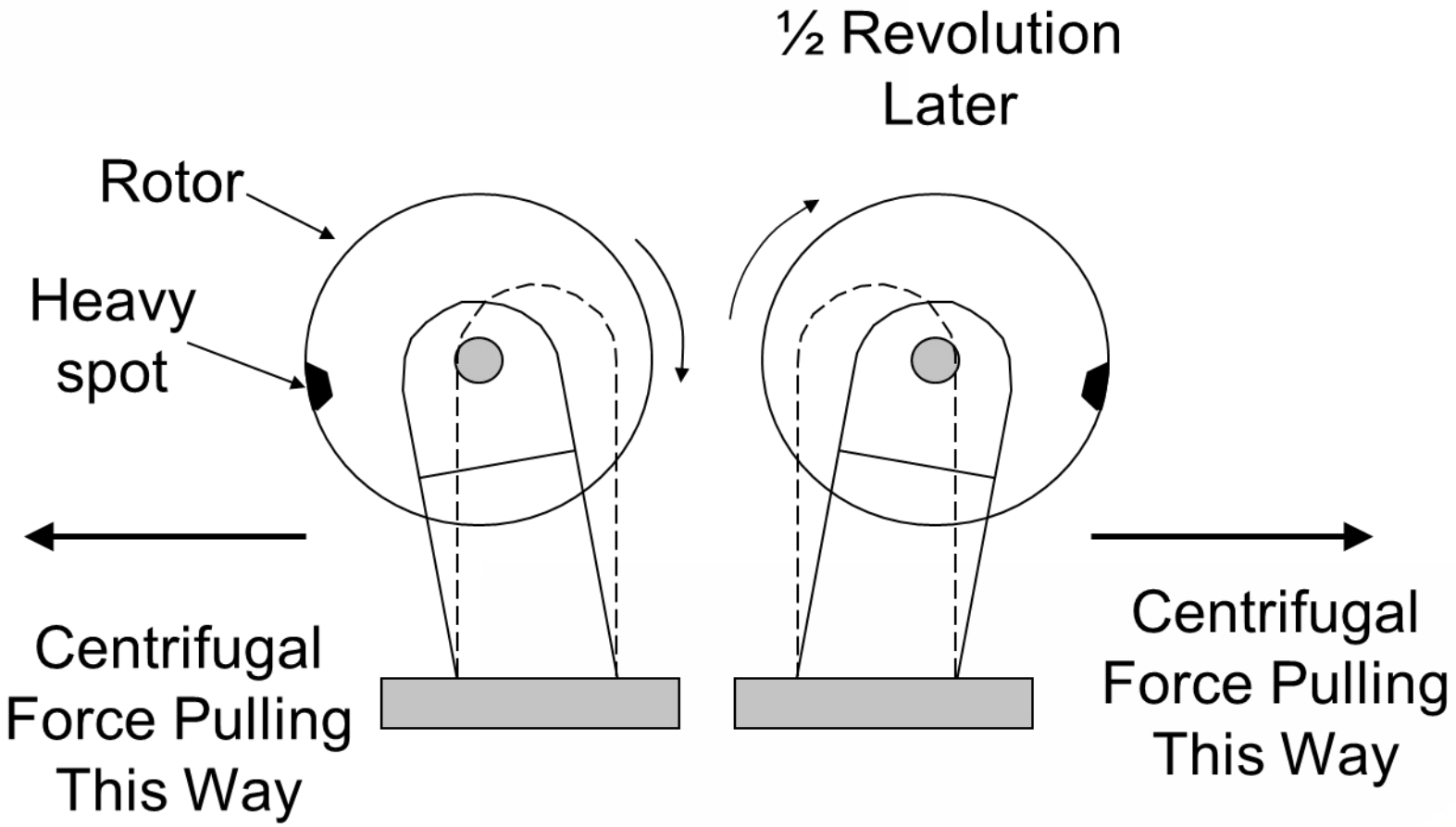
- Introduction
- Imbalance = unbalance
- Unbalance is one of the most common causes of machinery vibration.

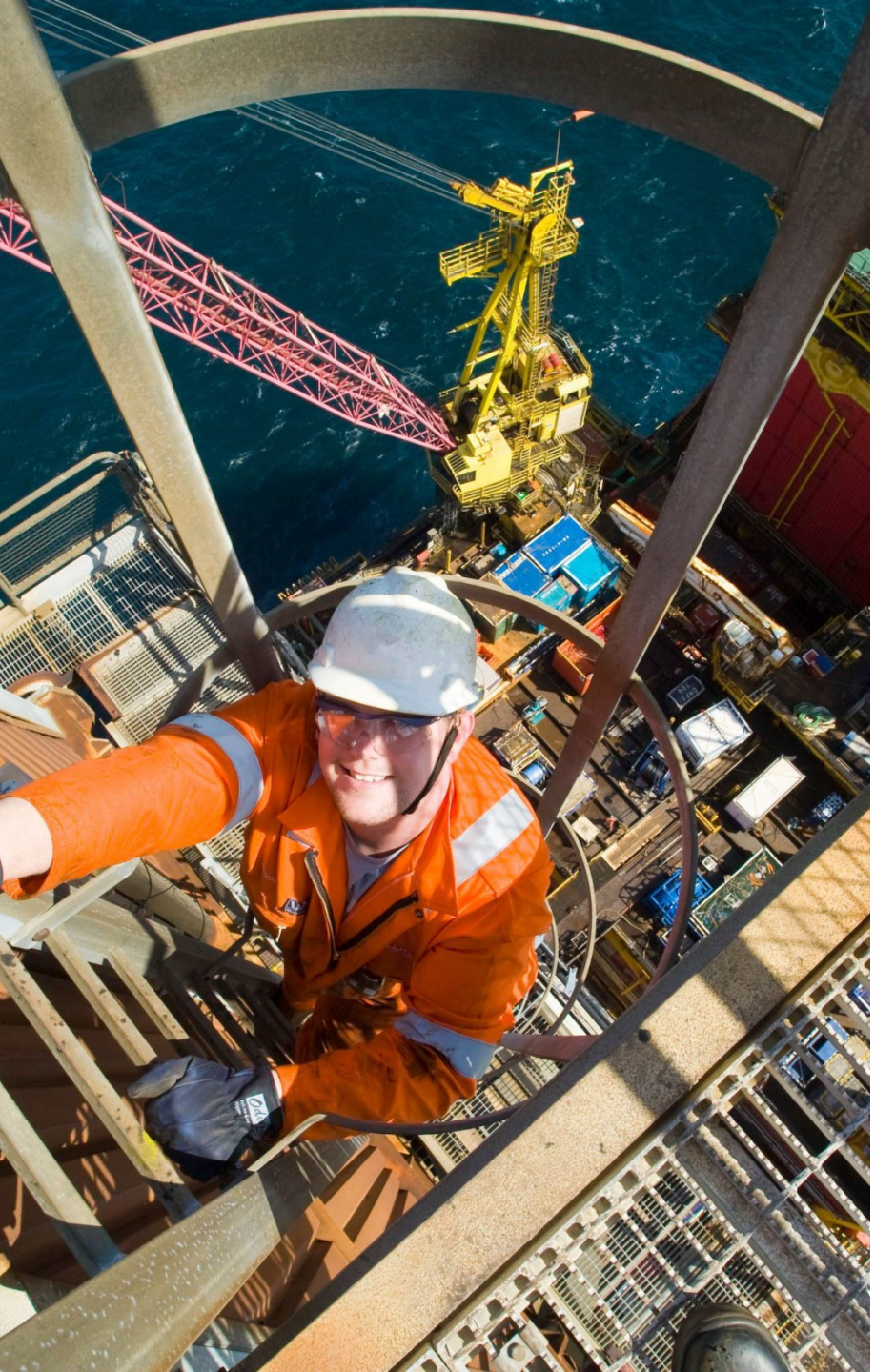
Balancing Machine

Sources of Vibration

- Assembly errors
  - Center of rotation
  - Method of locating
  - Cocked rotor
- Incorrect key lengths

Unbalance Example





Than k You