VOLVO

Volvo Group Trucks Operations Powertrain Production Köping

Condition Based Maintenance

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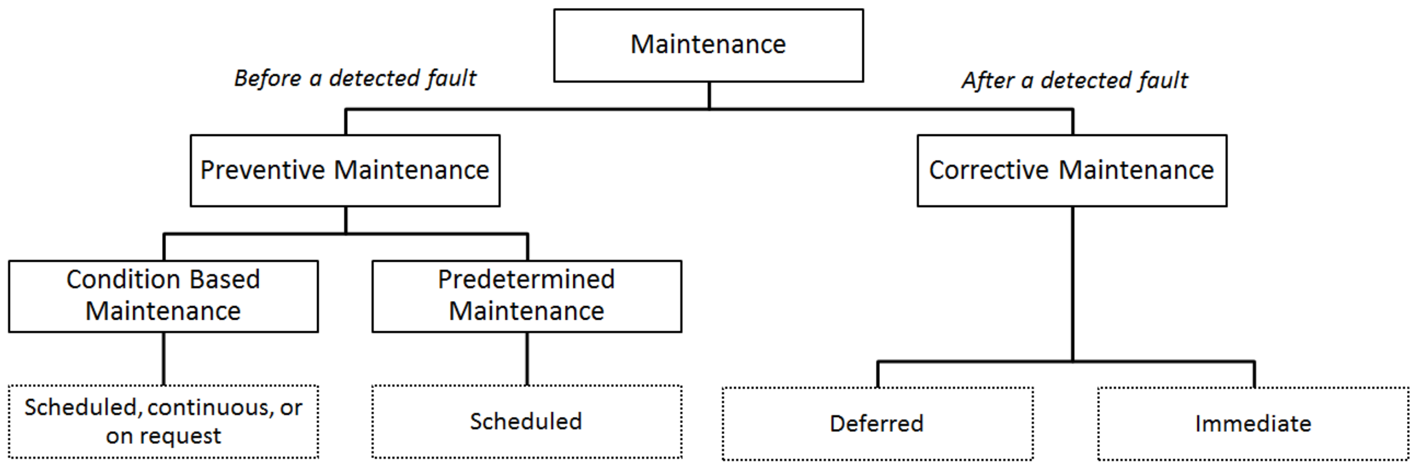
Maintenance types



Maintenance types

Corrective maintenance / breakdown maintenance (BM)

- It is sometimes used synonymously with breakdown maintenance (BM),failure-based maintenance (FBM), run-to-failure or reactive maintenance.
- “Maintenance carried out after fault recognition and intended to put an item into a state in which it can perform a required function” (SS-EN 13306, 2001, p.15).
- It is a strategy that is used to restore (repair or replace) equipment to its required function after it has failed (Blanchard et al., 1995).

Preventive maintenance (PM)

- “Maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item” (SS-EN 13306, 2001, p.14).
- The concept of preventive maintenance involves the performance of maintenance activities prior to the failure of equipment (Gertsbakh, 1977).

Preventive maintenance

Predetermined maintenance / time-based maintenance (TBM)

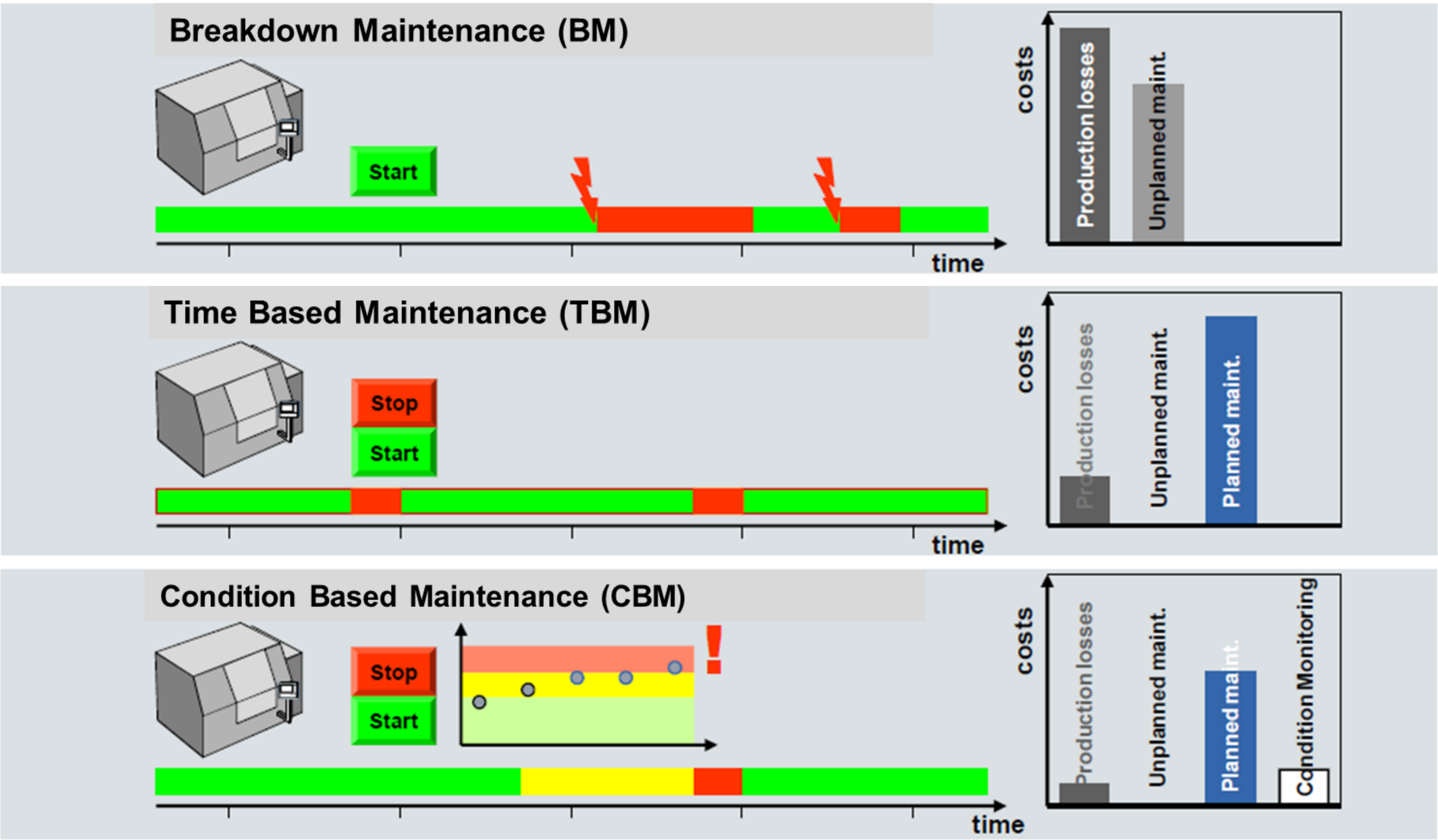
- “Preventive maintenance carried out in accordance with established intervals of time or number of units of use such as scheduled maintenance but without previous item condition investigation” (SS-EN 13306 2001,p.15).
- In the industry, application of the TBM strategy can be generally performed following either experience or original equipment manufacturer (OEM) recommendations and is based on a scientific approach (Rosmaini and Kamaruddin, 2012).

Condition Based Maintenance (CBM)

- “preventive maintenance based on performance and/or parameter monitoring and the subsequent actions” (SS-EN 13306 2001,p.15).

Maintenance decision making

assessing and selecting the most efficient maintenance approach



Why the maintenance plans provided by machine manufacturers are not completely reliable?

They are not aware of:

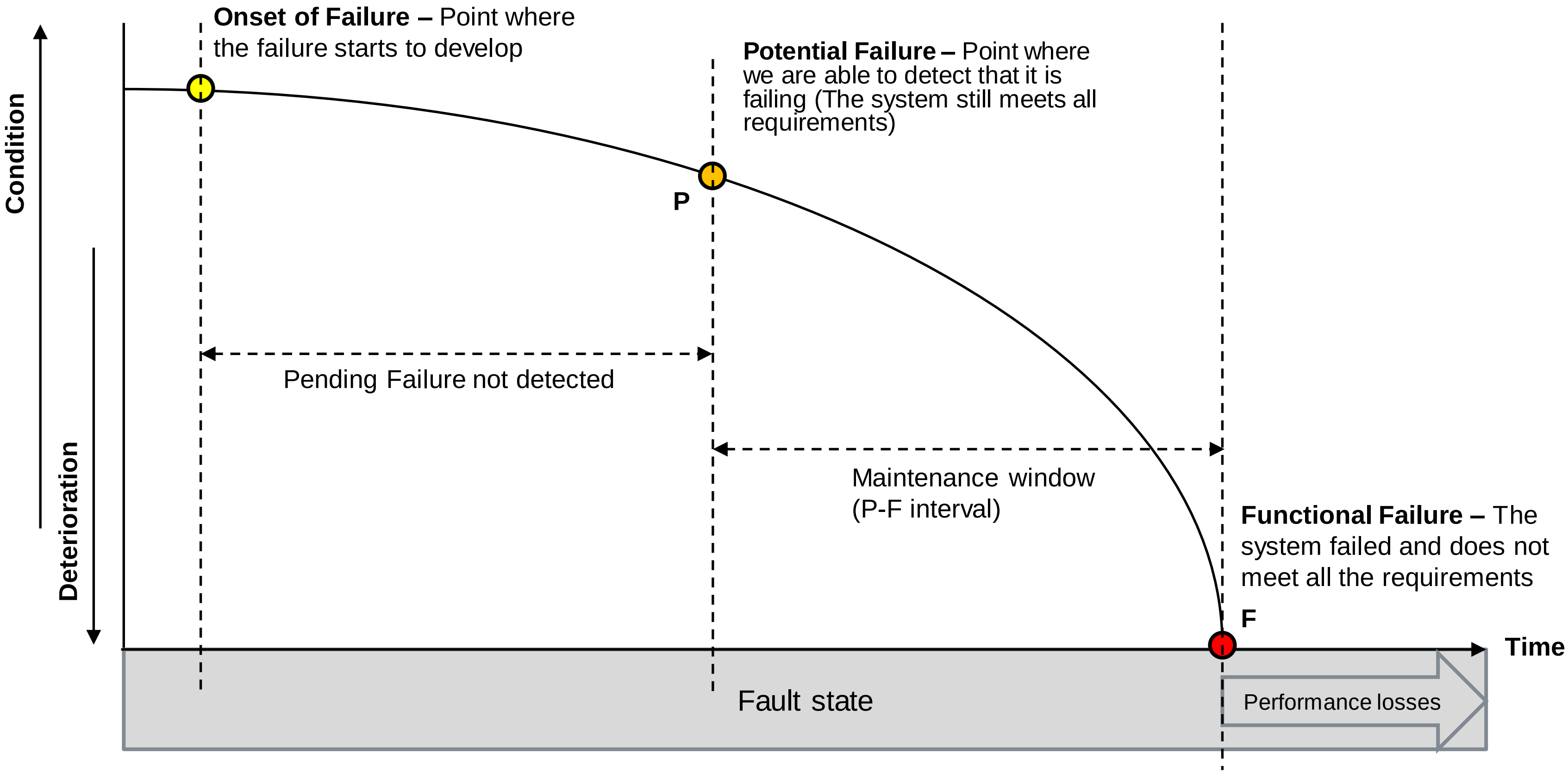
- Business-related consequences of failure
- Safety considerations
- The use of condition monitoring techniques
- Availability of resources
- Unique environmental conditions

Preventive maintenance challenges and risks

- Challenge:
  - To estimate the life of a machine, and then perform the overhaul before it fails.

- Risk:
  - Balanced against cost.
  - If maintenance is put off too long, the machine may fail.
  - If the overhaul is performed too early, it becomes too expensive, in labor, production losses and spare parts. And it increases the risk of infant mortality.

Degradation process, P-F curve

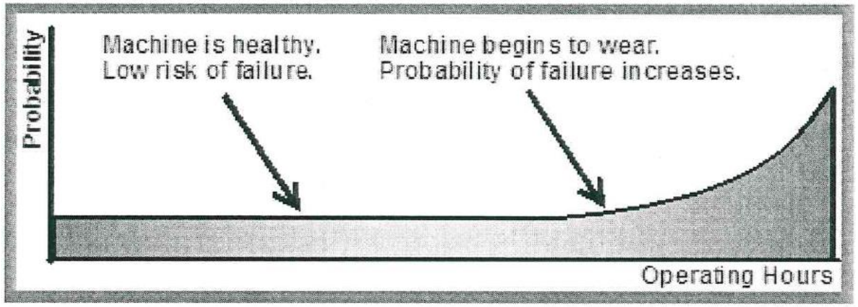


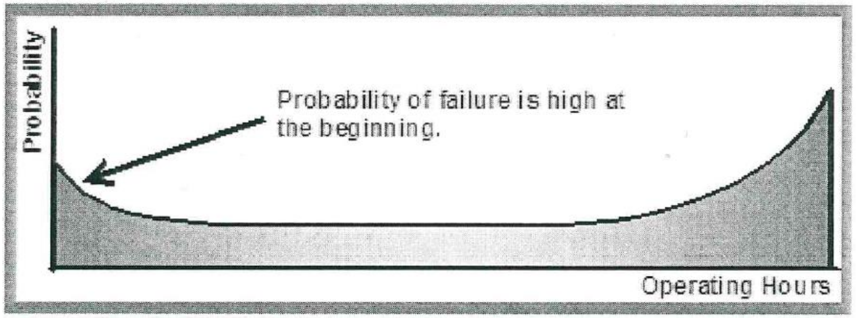
- By detecting a potential failure in time, we are able to better plan and provide spare parts and other needed items to solve the problem.

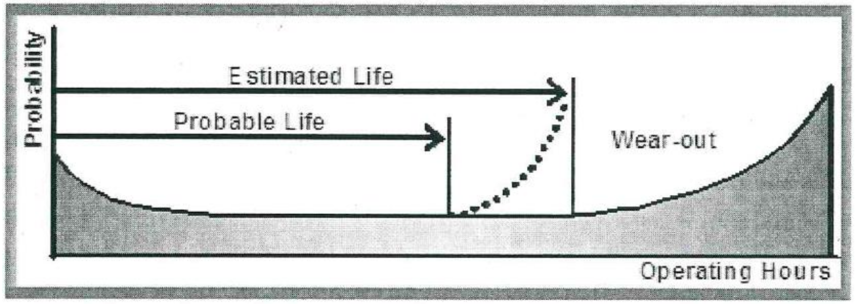
Failures

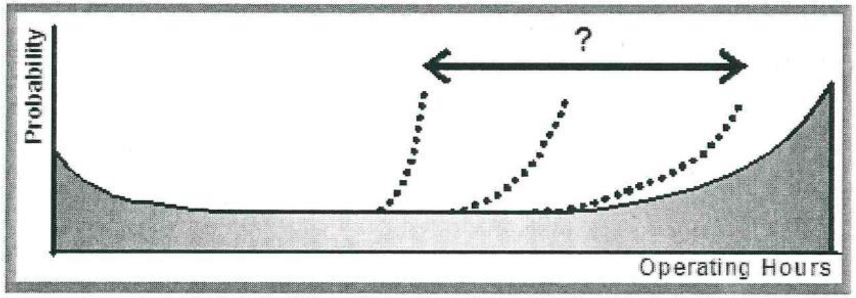
- Everything that the asset has to do should be defined as a function
- Functions may fail in many ways
- Each failure must be defined in terms of loss of specific function (function not delivered to an acceptable performance)

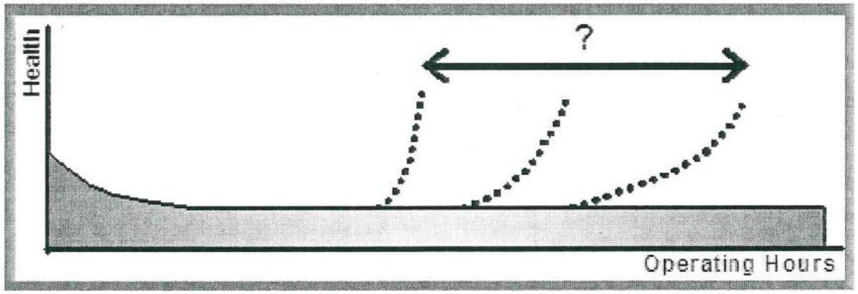
Failure models



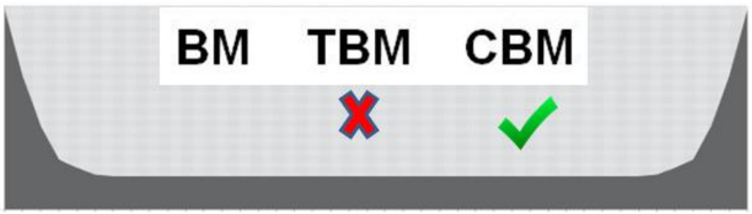






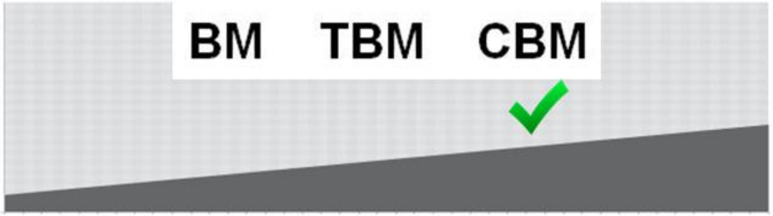


Maintenance decision making based on the failure models

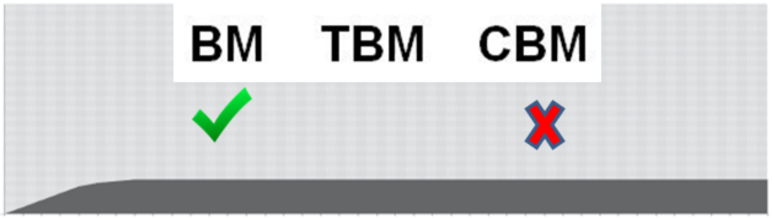


A • *Bathtub curve: Infant mortality – useful life –rapid wear out.*

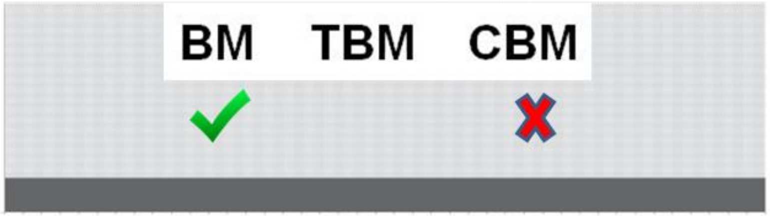
B • *Rapid wear out after long useful life.*



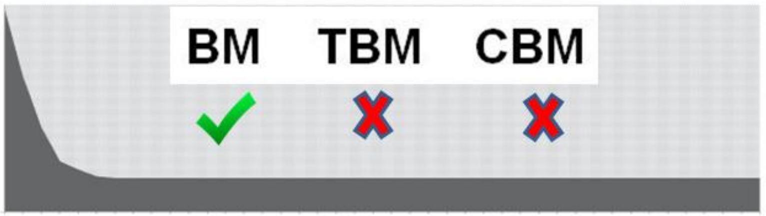
C • *Gradual wear out.*



D • *No infant mortality followed by indefinite useful life.*



E • *Indefinite useful life.*



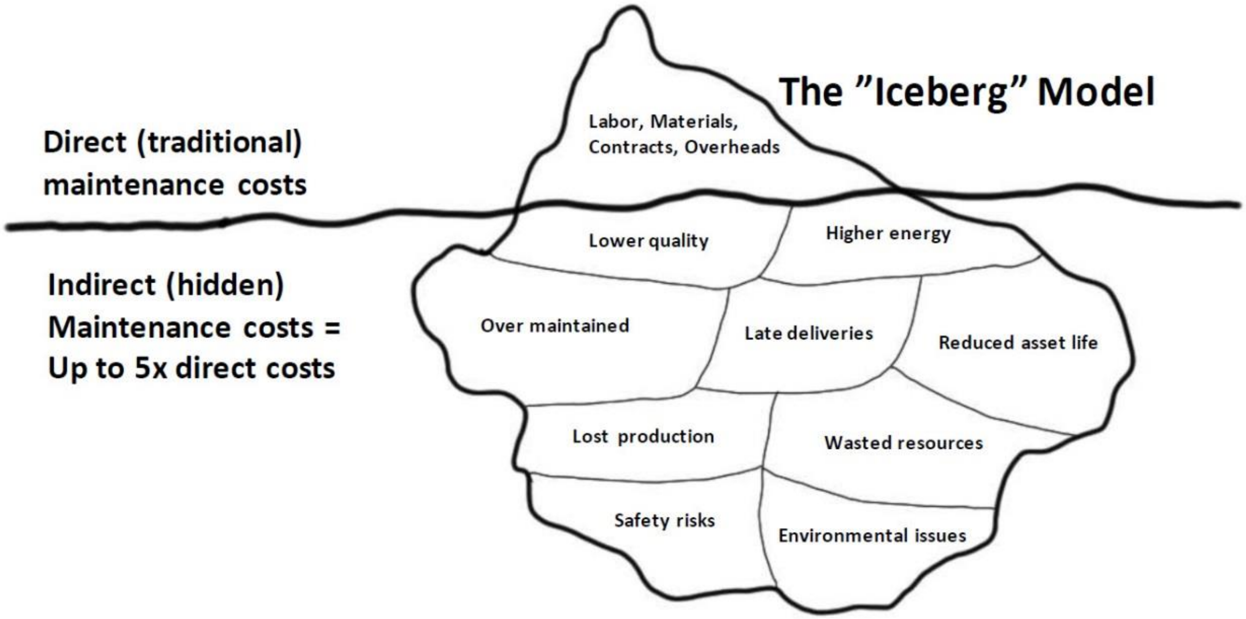
F • *Infant mortality followed by indefinite useful life.*

CBM
Condition Based Maintenance

- Based on management and decisions through information collected from condition monitoring.
- In CBM, the lifetime (age) of the equipment is monitored through its operating condition, which can be measured based on monitoring parameters such as *vibration, temperature, lubricating oil, contaminants, and noise levels*.
- Identify and solve problems in advance before product damage occurs.
- Attractive method for an industry operating high-valued assets.
- CBM is needed to ensure equipment health management, lower life cycle cost, and avoid catastrophic failure.

Total costs of maintenance

- Total costs of maintenance - the "Iceberg" Model (Wienker et al., 2016, p.414)



Cost effectiveness of CBM

- Reduced maintenance costs, damage limitation, and avoided production losses should be compared to the cost of CBM.
- Cost of CBM is set-up cost and operation (measurement and analysis) cost.

- Two significant benefits of CBM:
  - Reducing probability of having maximal damage in production equipment
  - Reducing production losses particularly in high production volumes

CBM objectives

- Improved Maintenance Performance
  - Increased productivity
  - Shorter maintenance cycles
  - Lower costs (no downtime, no catastrophic failures, no secondary damage, reduced parts inventory,…)
  - Increased process quality
  - Improved availability
  - Enhanced reliability

Condition monitoring

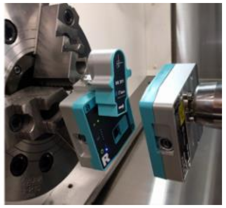
- Most equipment failures are preceded by certain signs, conditions, or indications that such a failure was going to occur, including:
  - The vibration level and pattern will change.
  - The performance can change. The motor current will change.
  - The wear in lubricated surfaces can be detected via the lubricant.
  - The temperature of some parts will increase.

- Condition monitoring:
  - Collects the condition data (information) of the equipment.
  - Increases knowledge regarding the causes and effects of failure and the deterioration patterns of equipment

Condition monitoring techniques

- **Vibration analysis** – el-motors, fans, machine tool spindles, gearboxes

- **Performance analysis:**
  - **Geometry alignment** - Laser alignment
  - **Ball bar** – e.g. Ball-screw failure

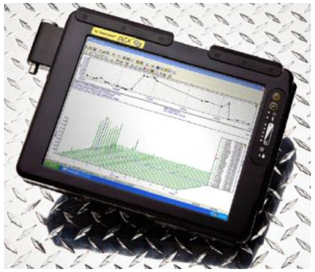


- **Sound analysis** – e.g. Air leakage

- **Oil analysis** – e.g. Gearbox failures

- **Thermography** – e.g. Hot spots in el-cabinets

Vibration analysis



- The most popular condition monitoring technique used in the CBM programme, especially for rotating equipment (e.g., fans, motors, pumps).
- Machines are constantly generating vibrations. Many of these vibrations are linked to:
  - Periodic events in the machine's operation; rotating shafts, meshing gear teeth, and rotating electric fields,…
  - Events that are not entirely phase locked to shaft rotations; combustion in engines,…
  - Other vibrations linked to fluid flow; pumps and gas turbines,…
- A machine in standard condition has a certain vibration signature, and fault growth changes that signature in a way that can be linked to the fault.
- Vibration analysis is able to diagnose failures by measuring overall machine vibration or, more precisely, frequency analysis.
- Vibration measurement can be performed with an accelerometer.
- The signal from the vibration measurement is collected and analysed by a portable metre or computerized analyser.

Fault conditions detectable with vibration analysis

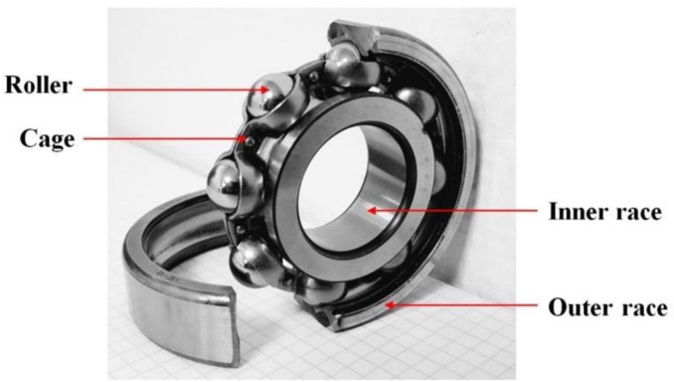
- Bearing problems – both journal and rolling element bearing
- Unbalance
- Misalignment
- Looseness
- Soft foot
- Electrical faults
- Belt and coupling problems
- Gear mesh
- Broken rotor bars

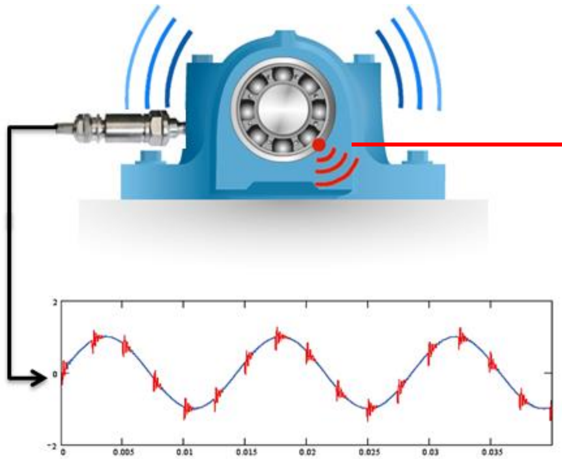
Vibration monitoring of rolling bearings

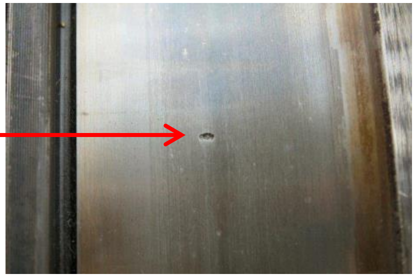
- One of the problems of rotating equipment that is of greatest concern is the bearing condition.
- The majority of bearings fail before the natural fatigue limit of the bearing steel has been reached.
- Bearing failure can result in major damage to shafts, rotors, and housings.
- Three typical outcomes of bearing condition monitoring:

1. Acceptable oil film, no surface damage
2. Thin oil film and reduced life expectancy.
3. Bearing damage; the bearing has to be replaced.

https://www.youtube.com/watch?v=w9QeqCQ_EWA





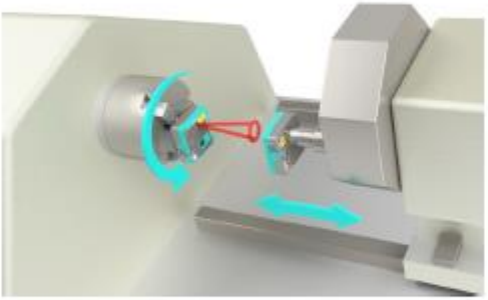


Performance analysis

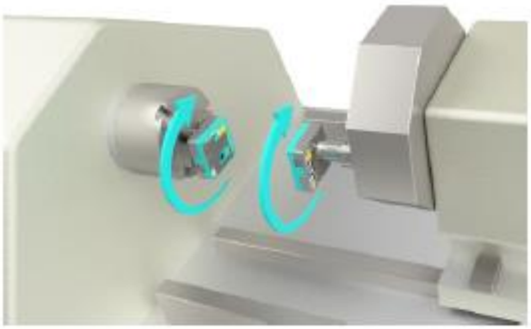
- For certain types of equipment, such as machine tools performance analysis, is an effective way to determine whether the machine is functioning correctly.

    - **Geometry alignment of machine tools (with laser alignment tool)**
    https://www.youtube.com/watch?v=u8Akk5VyTV0

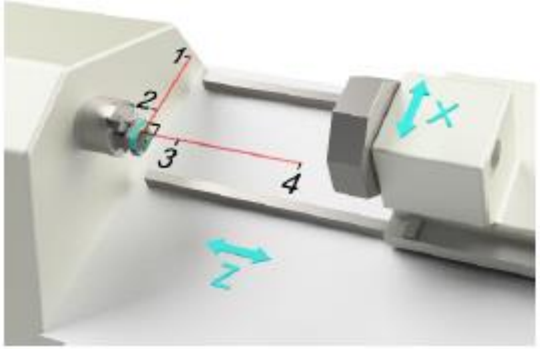
Straightness and angular movement



Spindle alignment



Coaxiality



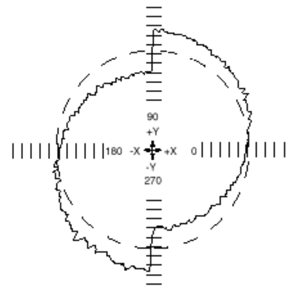
Squareness

- **Ballbar (Circularity test of machine tools)**

Ball-bar method involves using a length measuring sensor in the ball end of a measuring bar that is registering machine movement and via an interface sends the data to a standard laptop. The results are then evaluated through software in the computer.

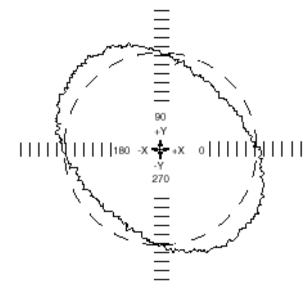
http://www.renishaw.com/en/qc20-w-ballbar-system--11075

Measurement with Ballbar



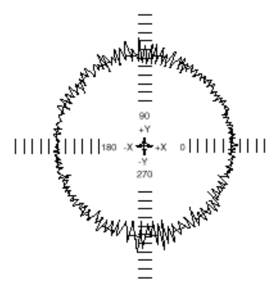
Backlash (M)

Ball-screw or bearing damage



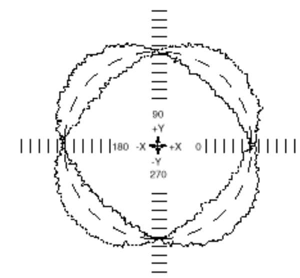
Squareness (M)

Geometry misalignment



Vibration, machine (M)

Machine damage or external vibrations



Servo mismatch (M)

Servo problem

Failure models in Ballbar measurement

Sound or acoustic monitoring

- It has a strong relationship with the vibration monitoring technique. Vibration sensors register local motions, acoustic sensors "listen" to the equipment.

- As in vibration monitoring, sound or acoustic monitoring is executed on-line, either in periodic or continuous ways.

- Fault detectable with sound analysis:
  - Air leaks
  - Boiler, Heat exchanger, and Condenser leaks
  - Detecting faulty steam traps
  - Ultrasonic and electrical problems
  - Bearing faults and lubrication
  - Mechanical fault detection

  https://www.youtube.com/watch?v=Dx4HfyYaQVI

Oil analysis or lubricant monitoring

- The condition (quality) of the oil is evaluated to determine whether the oil is suitable for further use

- Can show the wear conditions of internal oil-wetted components, such as engine shafts, gears and bearings.

Gear failure

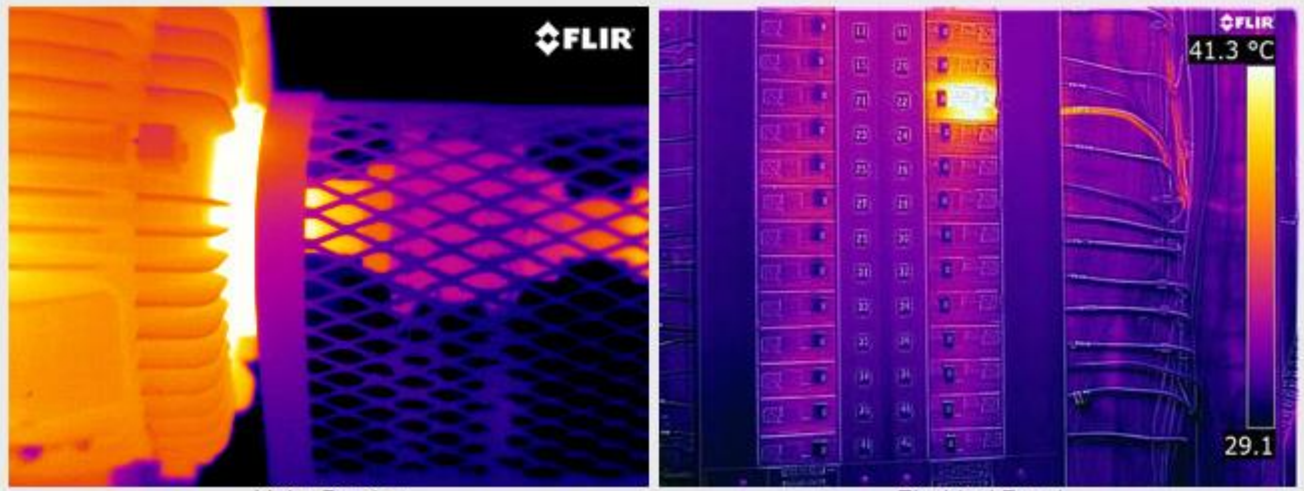
Ball bearing failure

- Its use is mainly confined to circulating-oil lubricating systems. And, some analyses can be performed on grease lubricants.

Thermography

- Sensitive instruments are employed to remotely measure temperature changes in comparison with a standard condition.

https://www.youtube.com/watch?v=lPPNpMVKgdU



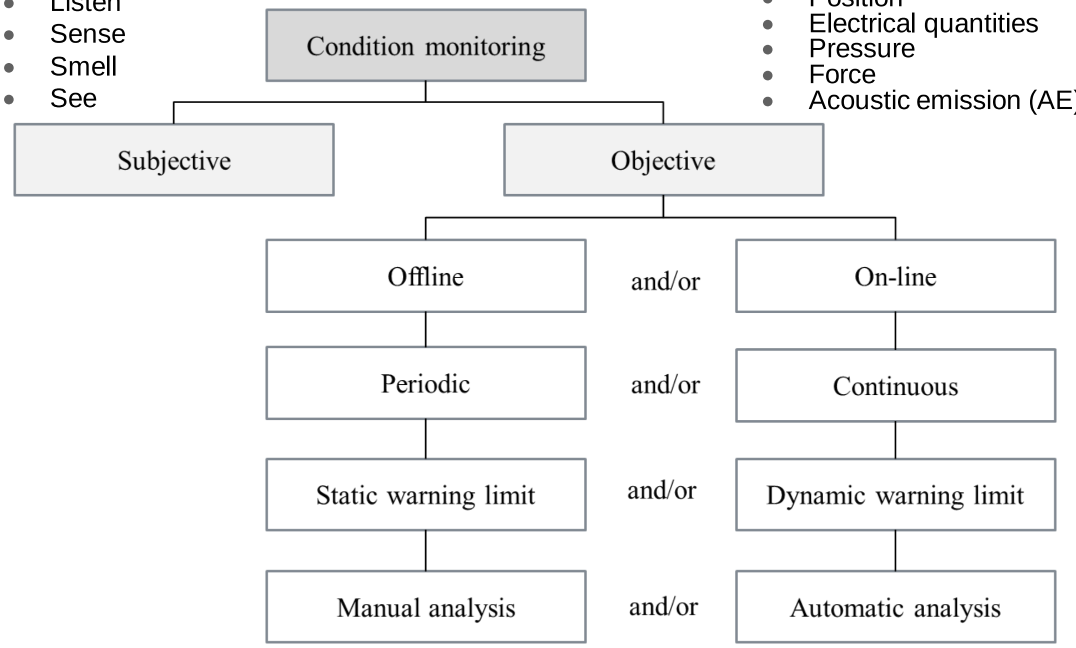
Motor Bearing Electrical Panel

- Infrared thermography is typically used in the following applications
  - Mechanical
  - Machines, pipes, bearings, belts
  - Electrical
  - Overhead lines, transformers motors, control panels
  - Steam systems
  - Piping, steam traps
  - Refractory plant

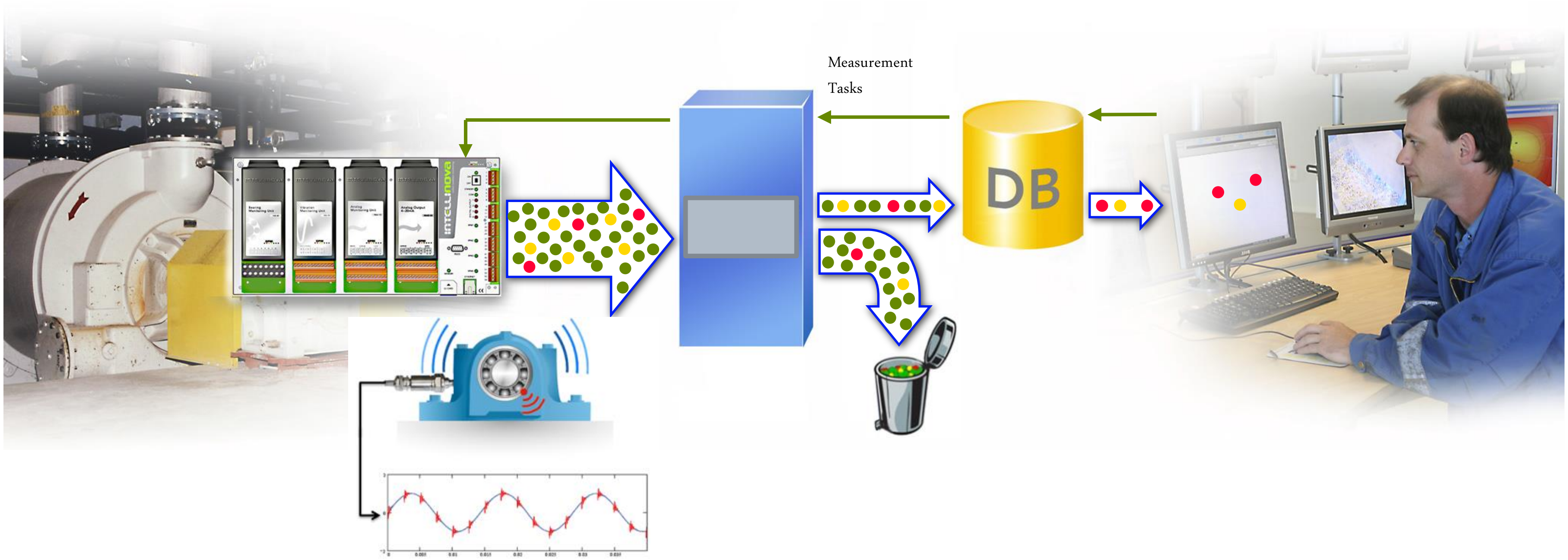
Condition monitoring technologies

- Listen
- Sense
- Smell
- See

- Vibration
- Tempreture
- Speed
- Location
- Position
- Electrical quantities
- Pressure
- Force
- Acoustic emission (AE)



Online condition monitoring



On-line condition monitoring compare to off-line condition monitoring

- On-line (or real-time) monitoring:
  - Continuously monitoring and trigger warning
  - It is often expensive

- Periodic monitoring:
  - Possibility of missing some failure events that occur between successive inspections
  - Time consuming
  - Low cost

Implementation of CBM

- Feasibility test.
- Assignment of responsibilities and competence.
- Identification of maintenance assets.
- Failure analysis to determine the parameters to monitor.
- Selection of appropriate techniques to detect failures.
- Selection of technologies.
- Production of a selection process to determine the CBM strategy.
- Cost effectiveness evaluation.
- Management evaluation.

Main challenges in implementing CBM

- Management support
- Change the culture of the companies from reactive to proactive strategies.
- Increase in competences to use these techniques effectively

Theory vs. reality, concerning CBM

- Theory:
  - By CBM, the maintenance costs are reduced, and profit is increased because there is no downtime, no catastrophic failures, no secondary damage, reduced parts inventory and all work is planned.
  - It assumes that all machines are fully monitored, and all failures follow a convenient pattern giving us a few months' notice before failing.

- Reality:
  - It is difficult and expensive to monitor every machine this way, and machines do not always give as much warning as you would like.

Thank you!

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