ST

Maintenance Management Standard

Chapter 9: Advanced Preventive Maintenance

Corporate Cement Industrial Performance

Version 1.0 January 9th, 2017

LafargeHolcim

1.1 Content

2. Purpose

This chapter of the manual will deal with the MAC element 13 Preventive Maintenance Level #2, which comprises Condition Monitoring techniques, such as Oil analysis, Vibration analysis, Non-Destructive Testing.

The pre-requisite for a successful Condition Monitoring program is to have the 'basics' in place (walk-by inspections, lubrication, time-based Preventive Maintenance Routines). This aspect was already covered in Chapter 8, Preventive Maintenance Management, of this Manual.

3. Introduction

Each plant presents different requirements and scenarios; in addition plant targets are always upgrading and all this represents a great challenge for the Maintenance Department to provide high availability and low sustainable cost. The evolution of maintenance takes us to the use of technology and techniques that help us to determine the condition of the equipment and to detect and predict failures in order to avoid catastrophic damages and consequently costly repairs.

Preventive Maintenance is integrated by three groups of activities:

- Maintenance services (e.g. Lubrication, calibration)
- Systematic replacements (e.g. time-based replacement of components)
- Condition monitoring.

This chapter is focused on the definition of Condition Monitoring and the description of each one of the tools and techniques suggested for LafargeHolcim cement plants.

4. Condition Monitoring

The British Standards Institute (1974), "BS 3811", Glossary of Maintenance Terms in Terotechnology, BSI, London" defines Condition Monitoring as "The continuous or periodic measurement and interpretation of data to indicate the condition of an item to determine the need for maintenance".

Condition monitoring is part of the maintenance strategy that integrates skills, technology and techniques in order to:

- Create awareness of equipment condition
- Allow recognition of deviations and initiate appropriate measures
- Allow cost effective maintenance by targeting identified problems
- Optimize overall availability with the prevention and prediction of failures.
- Reduce loss of production due to machinery breakdown
- Create the base for further analysis
- Create a platform for informed maintenance decision making

Most of these technologies and techniques offer accurate data collection; nevertheless the critical phase is the precise data interpretation and analysis to find and execute the solutions which will eliminate the root cause. Training and skills development becomes a very important and constant issue; for that reason the Training topic is reviewed in detail on a different chapter of this manual.

4.1 Condition monitoring process

All Condition Monitoring techniques follow the DADA process.

1. Data: Data collection, sampling and measurements in the field.
2. Analysis: Organize all the information and compare with the required standard and in the case of any deviation, detect the cause or causes.
3. Decision: Determine the actions required to restore the condition of the equipment and eliminate the causes.
4. Action: Schedule and execute the defined actions.

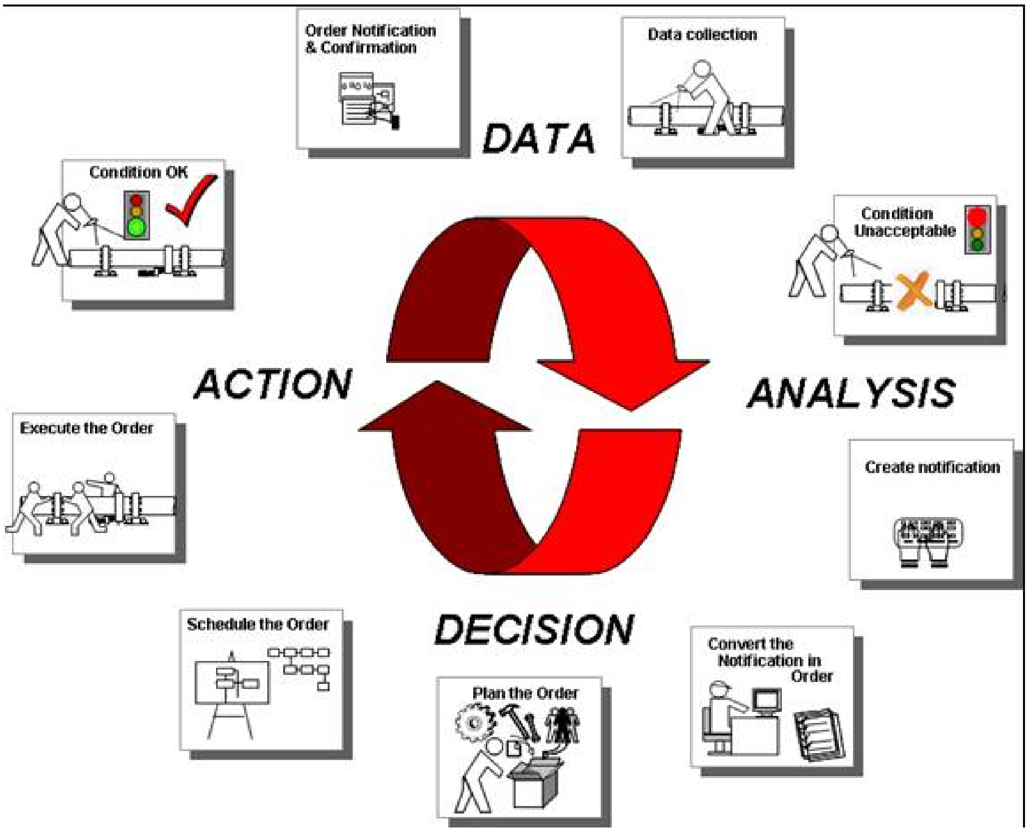


Figure 1 Condition Monitoring follows DADA process.

The whole process must be applied and executed systematically. Notification and Work Order confirmation are as well part of the data phase within the DADA process; this information is part of the equipment history and is helpful for future analysis and references.

4.2 P-F curve.

Condition Monitoring relies on the fact that most failures do not occur instantaneously, but rather over time; at the beginning of a failure, the magnitude may be so small that is undetectable, but at some point the magnitude reaches a level in which it is measurable. Once observed, the equipment can still operate and in the mean time maintenance prepares for correction. But if not corrected, the component will fail completely. This correlation is better known as P-F (Potential- Functional) curve:

- The function of the curve is not necessarily age related. It can start at any time. But when a failure starts to occur it will progress according to that curve
- The P-F-Interval is the time taken between the occurrence of a potential failure (detection possible) and its decay into the failure itself (functional failure)
- In reality P-F-Intervals are not necessarily consistent. In fact they can vary over a considerable range of values. For most purposes the shortest P-F-Interval should be taken into account

Understanding this correlation is key to determine how often it is required to inspect in order to predict and / or detect early a potential failure.

<u>Point P:</u> Is the deviation of the normal condition which can be detected

<u>Point A:</u> Failure starts to occur, but can not be detected yet

<u>Point F:</u> Break down of the equipment

<u>T:</u> Time of failure

<u>T/4:</u> Inspection interval should be roughly a quarter the time between P and F, which gives the opportunity to maintenance department to act in order to correct the root cause or extend the life of the component. This depends as well on the existing knowledge about the failure detection and its behavior. Another factor is the time available to react; the sooner the deviation is detected, the sooner a corrective measure can be taken.

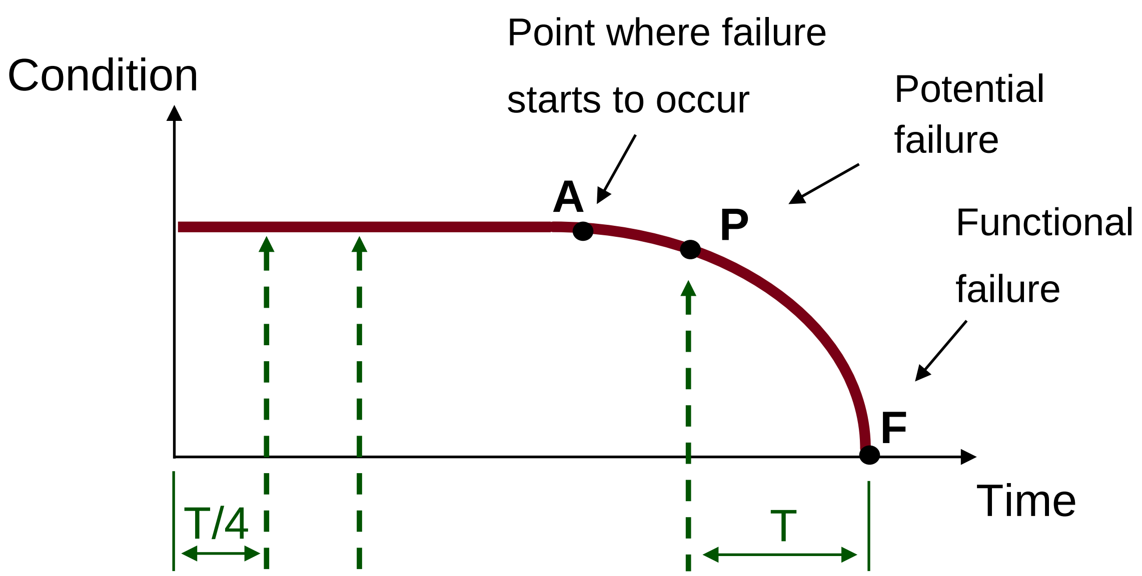


Figure 1. P-F curve

Potential Failure curve is somehow generic; nevertheless it is very useful to understand the correlation between the failure mode behavior, the operational condition of the equipment and time of failure.

Despite Condition Monitoring being a highly reliable strategy used for failure prediction and prevention, there are some limitations to applying it and one has to be aware of them:

- If the failure occurs without warning or too fast to undertake any action (P-F Interval close to zero)
- If the deviations are too small to be detected or if it is impossible to establish limits for the condition to be monitored.
- If the P-F-Interval is so inconsistent that no meaningful task interval can be established
- If the cost of the monitoring task is greater than the value gain through detection

The last bullet points is crucial and leads to a technical and economical justification of Condition Monitoring as opposed to a systematic (time-based) component replacement

Condition Monitoring is the preferred solution, whenever technical and economical feasible!

4.3 Purpose and justification

The access to some of these technologies and techniques is not cheap and requires special training to collect data and analysis; in addition some of them are outsourced services and/or only can be performed during shutdowns, so that it is necessary to find the right balance cost vs. benefit.

There are several methods to find the balance, the key issue is to know the consequence of a failure and its probability to occur (RISK) and then determine the most suitable condition monitoring technique to reduce the risk, the less expensive and the easiest to implement.

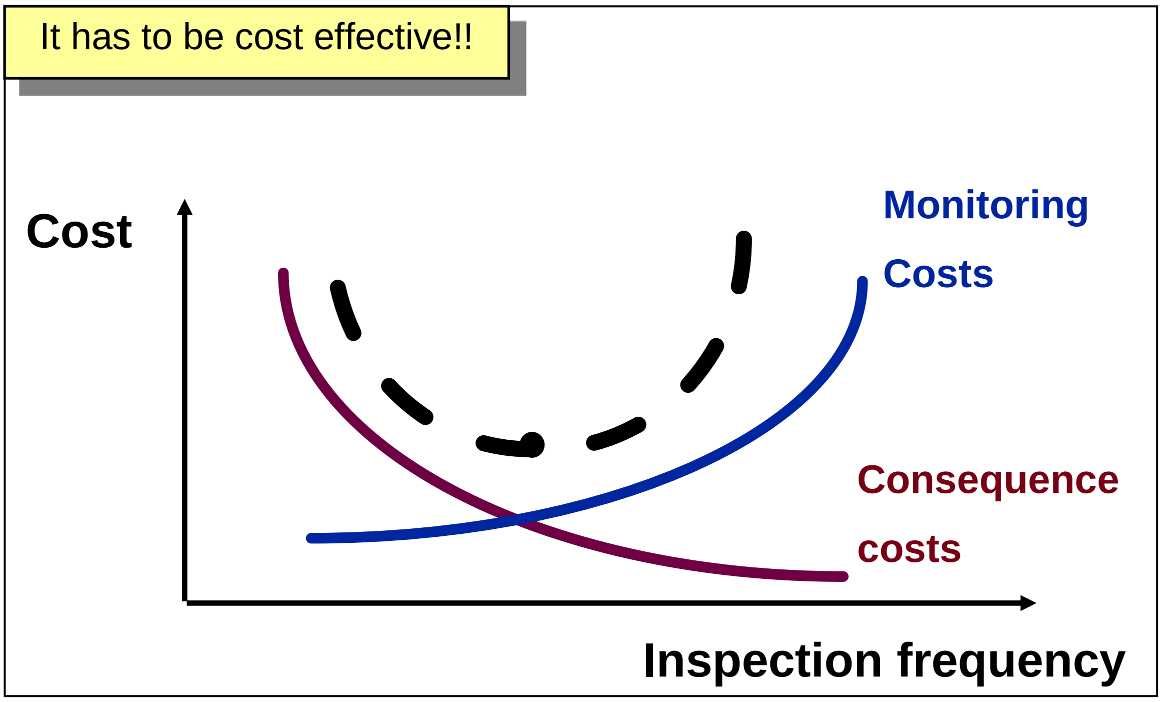


Figure 2. Condition Monitoring cost vs. benefit.

Some of the cost and benefits should be considered are:

Overall costs	Benefit
condition monitoring cost	long life
repair costs	better planning
secondary costs	higher safety

4.3.1 Scenarios

Market scenarios, plant capacity and plant complexity play an important role to define the focus of a Condition Monitoring strategy:

On a high market demand scenario:

- High focus in maximizing equipment availability
- Possible more expensive techniques are justified, if able to reduce risk of failures
    - o On-line condition monitoring

On a low market demand scenario:

- High focus in cost reduction
- “Time is not the main issue”
- Can elevate some risk, due to less impact on market

Scenarios with overcapacity design:

- Some plant designs have excess grinding capabilities (both Raw Milling and Cement Milling)
- Plants must take advantage of such conditions
    - More flexibility in planning
    - Can elevate some risk

Plant complexity:

- Consider design safety factors
- Focus on critical equipments
- New age, modern plants are more complex
- Higher degree of automation
- Tighter control to reach performance

Be aware, the message behind this point is NOT TO STOP CONDITION MONITORING; the message is to adapt the focus of the strategy according to the different scenarios and if possible, take advantage of them.

4.4 Condition Monitoring program implementation

In general terms, the steps of implementation of a condition monitoring program are according the diagram below:

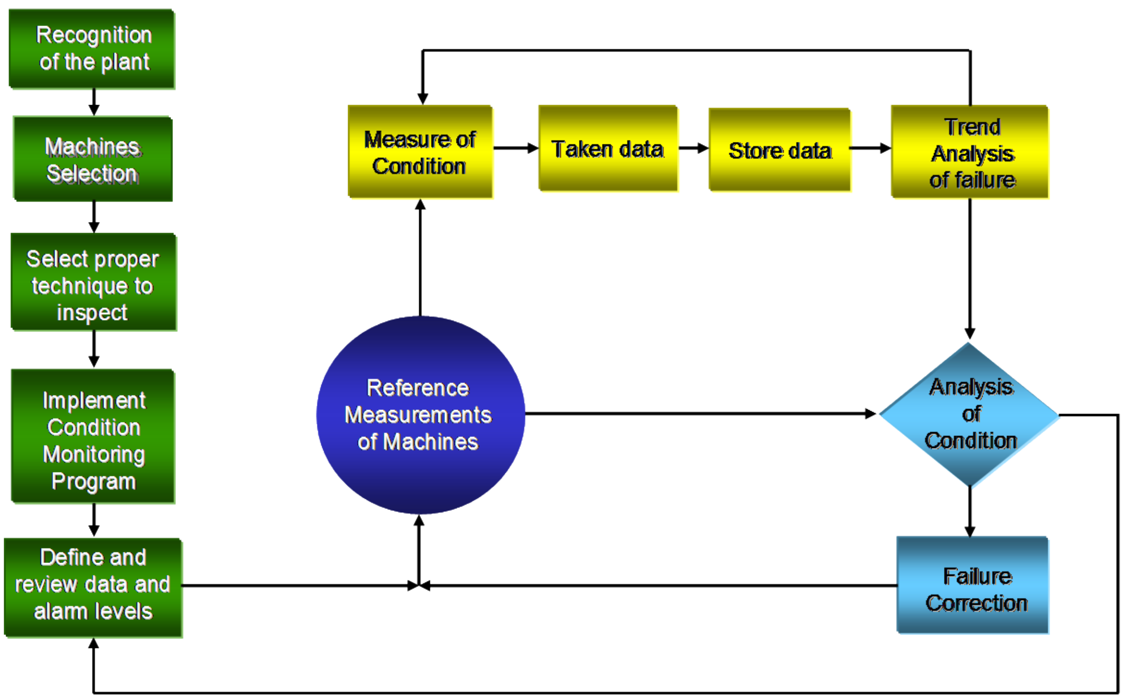


Figure 3. Condition Monitoring Program Implementation.

Important considerations during Condition Monitoring program implementation

1. During plant recognition and machines selection, focus first on critical A equipment and all equipment resulting from the Risk and FMEA analysis process. Condition Monitoring Techniques Matrix provides and overview of available techniques and is very helpful for CM techniques definition for each equipment and its components.
2. During CM technique selection it is important to understand the expectations of each technique and determine if the failure mode detection of the equipment or equipment component is technically feasible and economically justified.

3. Once equipment and the proper condition monitoring technique have been defined, the location points for measurements must be identified and be safely accessible. Mark physically in the field the exact measurement location.
4. Be methodic and inquisitive! Warning and alarm limits must be obtained from OEM (Original Equipment Manufacturer) manuals and international standards. Consider as well the operation conditions and the impact on the process.
5. P-F curve understanding is key when data collection frequencies are determined. Create a schedule for data collection of each measurement point and stick to it! The best practice is setup the routines in SAP-PM to generate WO.
6. Take reference measurements and record the original measurements as a baseline.
7. Document the specific procedure of measurement. The main purpose is to assure that further measurements will be always done in the correct point and in the correct way. Pictures, drawings, schemes and friendly templates for data collection are always welcome by executors and for training purposes.
8. Build and maintain databases were measurements, trends, data and reports can be organized, available and safe.
   Some storage for electronic data can be central servers, Lotus Notes or SAP. Avoid information storage in personal computers or files.
9. Data analysis is the core of condition monitoring to determine the condition of the equipment and the need of maintenance. The outcome must be:

- Identification of the root causes
- Corrective recommendations
- Validation of alarm levels and limits
- Optimization of the system to extend life time of the equipment.

4.5 Condition Monitoring techniques

There are many condition monitoring techniques developed for data collection and diagnosis, but not all techniques are the best option for all failure modes. One must be aware of the limitations and approaches of each one and apply the most effective ones for the detection of the failure mode.

For the suitable selection of a specific condition monitoring task it is crucial to know the characteristics of the failure mode and specifically what is it expected to find with each condition monitoring technique. That means that condition monitored has to have a correlation to the failure; e.g. there is no sense in monitoring the temperature if there will not be a temperature rise before the equipment fails.

Some of most known techniques for condition monitoring are:

- Vibration analysis
- Oil analysis
- Wear measurements
- NDT (PT, UT, MT, VT)
- EMD (Electrical Motor Diagnosis)
- Thermography
- Specific measurements (shell-test, run out & backlash, creep deformation, hardness measurement, etc.)

The description of each one of the techniques can be found on the following chapters of this manual.

5. Oil Analysis

One of the most common procedures for maintaining plant equipment and increasing its reliability and usefulness is lubrication analysis. Reading the results of regular lubrication analysis can help plant engineers and maintenance staff schedule when oil changes are required on each machine based on findings that indicate the presence of abrasives, oxidation, and/or lubricant breakdown.

Oil sampling and analysis is performed to obtain information on:

- Equipment condition
- Oil condition

Main criterion is then the **equipment criticality** and not oil volume itself! (In the past, oil analysis has been performed under such guidelines as ‘for volumes larger than 100 liters; the main objective was to save money on oil and very little focus on equipment condition was given).

However, if the results are inaccurate, oil analysis may lead maintenance technicians to take inappropriate actions. To increase accuracy in sampling, preparation and consistency in testing are key.

Because the results of lubrication analysis will be only as good as the oil sample itself, the sample must contain a representative selection of wear particles found inside the machine. The concern here is that in any lubrication system, wear particles and contaminants usually are not distributed evenly.

Uneven distribution is especially true of particles larger than a few micrometers. While these particles tend to be more easily removed from the lubricant through filtration, they can settle after being separated out. They often settle in pipe nipples and valves where, over time, they may become oxidized or otherwise chemically changed.

If sample lines and valves are not flushed properly, large numbers of old residual particles will find their way into oil samples, yielding invalid results.

Once proper flushing procedures are followed, the concentration and size of wear particles can reveal considerable information about the condition of lubricated wearing surfaces inside a machine. As particle concentration and size increase, the wear process progresses from normal operating condition to incipient failure and finally to catastrophic failure.

The most important key to lubrication analysis is consistency. Results from randomly sampled oil can provide misleading results, often pointing to operating conditions that do not really exist. In the long run, this can lead to costly equipment failure for reasons that could have been detected through proper testing well before the problem reached critical mass.

A widely held misconception among plant personnel is that consistency simply means the lubricant should always be taken from the same place in the lubricating system. While this is true, it is only a small part of the process.

5.1 Oil sampling ports

Oil sampling is the most critical aspect of oil analysis. Failure to obtain a representative sample impairs all further oil analysis efforts. Not all locations in the machine will produce the same data. Some are richer in information than others. Some machines require multiple sampling locations to answer specific questions related to the machine's condition. Look for turbulent zones (e.g. elbows) and always sample with the equipment running. Unless filter efficiency is being tested, samples must be taken from the return line **before** any filter.

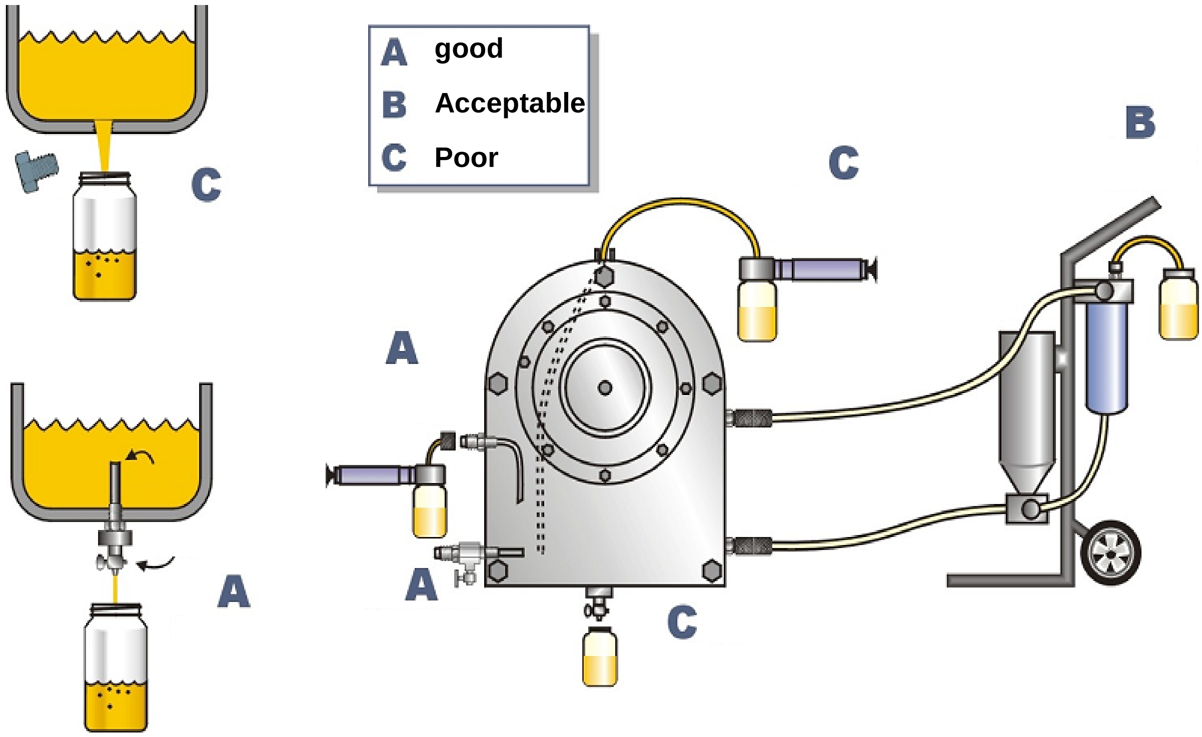


Figure 4. Location of sampling points

5.2 Taking samples and sampling bottle cleanliness

- Take samples properly to avoid contaminating them during this process:
- New and clean bottles to gather the sample (particle counting and ferrography)
- Bottles should be 'superclean' graded, i.e. ≤ 10 particles > 10 μm (for hydraulic systems) or
- "Clean" ≤ 100 particles > 10 μm for all other applications
- Plastic hose for sampling must be new and it should be discarded after taking the sample. Never re-use plastic hoses!
- Flush sampling devices first (vacuum pump, plastic hose, minimess valves)
- Use resealable bags (Zip-lock) to carry devices and bottles to the field and during sampling (see pictures below). The idea behind is to place the bottle inside the bag on a clean location (at the office); take it to the field, unscrew the cap (without opening the bag), puncture the bag with the hose attached to the vacuum pump. Once the sample is taken, the cap must be put back on (without opening the bag).

Figure 5. Taking the sample with the bottle inside a resealable bag all the time

5.3 Interpreting the sample report

The critical factor in oil analysis is the interpretation of the oil analysis results. A lab technician interprets the oil test results and produces a concise summary of the equipment, and oil condition.

The lab technicians extract variables from many sources to produce a valid interpretation of oil analysis results, including OEM wear limits, oil baselines and characteristics, industrial literature, but most importantly a lab technician draws upon the own experience and mechanical expertise to correctly interpret test results into a correct picture of equipment condition.

Plant Preventive Maintenance responsible must work together with the external laboratory analyst when defining the required actions based on the oil analysis report. Do not follow blindly the recommendations written on the oil analysis report; always question them, based on plant's personnel knowledge of the equipment operating conditions and behavior.

The causes of oil contamination are many, and can be classified according to source. Thus there is contamination coming from outside the system - dust (silica); liquids (mixture with other oils, water, other contaminated oil). The second is in open systems - chains, cables, gears in contact with dust, water, and so on. The third is in closed systems.

Impurities can also come from the settings and processes in which the lubricants work, e.g. manufacturing can produce welding debris, assembling involves dust, perhaps also silicones or polishing powder, while maintenance can introduce impurities via dirty rags or deteriorated joints, and lubrication systems may need or involve aspiration, or open tanks.

As your oil 'ages', several things happen to it. The oil chemically reacts with the air. If it combines with oxygen, it is called Oxidation. If it combines with nitrogen, it is called Nitration. Both cause the oil to thicken (see Viscosity) and cause a build up of varnish-like material on component parts.

Viscosity is the measure of the oil's ability to lubricate. If the viscosity changes, the oil no longer lubricates and is unable to protect surfaces efficiently.

- If the oil is running too hot or if the oil change interval is extended, the oil can oxidize. This will cause the oil to thicken and the viscosity to increase.
- If fuel is getting into the crankcase, the oil will be thinned. This will cause the viscosity to drastically decrease.

Oils undergo destructive changes in property when subjected to oxygen, combustion gasses and high temperatures. Viscosity change, as well as additive depletion and oxidation occur to degrade the oil.

5.3.1 Additive Depletion

Oil additives also have a limited lifetime. Some are consumed as oil ages. For example, alkaline additives get used up by neutralizing corrosive acids produced by the combustion process. When the oils reserve alkalinity (TBN) falls below the minimum safe level, higher component wear can be expected.

Make-up oils will increase oil reserve alkalinity only to the extent of the new oil added and has no neutralizing reaction on existing oil acid levels.

Rust and corrosion inhibitors, anti-oxidants and film strength agents also reach a point when they can no longer carry on. Additive "dispersants" suspend contaminants, deposits and other combustion insoluble's until they are removed from the system by oil and filter change out.

Once a dispersant becomes "loaded" any added sludge, resin or soot will cause the oil to dump whatever it has collected... and refuse to collect anymore. This results in a rapid build-up of engine deposits.

5.3.2 Oxidation

All engines, transmissions and drive-axle component oils oxidize. A chemical reaction between oil molecules and oxygen takes place at high operating temperatures. This reaction increases viscosity, causes formation of insoluble engine deposits and corrosive acids which further increases component wear.

Higher operating temperatures, fuel consumption, rapid additive depletion and substantial loss of power can also be expected when oil oxidation takes place. When severe, oxidation makes the oil very hard to pump causing lubrication starvation to moving parts, with inevitable results. Oils that are oxidized have a very pungent, sour odor.

Several methods are used to analyze oil condition and contamination. These include spectrometry, viscosity analysis, dilution analysis, water detection, Acid Number assessment, Base Number assessment, particle counting, and microscopy.

5.3.3 Spectrometry

A spectrometer is an instrument with which one can measure the quantities and types of metallic elements in a sample of oil. The operating principle is as follows. A diluted oil sample is pulverized by an inert gas to form an aerosol, which is magnetically induced to form plasma at a temperature of about 9000°C. As a result of this high temperature the metal ions take on energy, and release new energy in the form of photons. In this way, a spectrum with different wavelengths is created for each metallic element. The intensities of the emissions are measurable for each such element by virtue of its very specific wavelength, calculated in number of ppm (parts per million). An ICP spectrometer can detect the very small metal particles in suspension in the oil, i.e. with a size between 0 and 3 microns.

Those small particles are a good indication of general wear, except in cases of sudden metallic rupture, where there will be relatively more large particles liberated (50 microns and more). The human eye can detect particles of a size starting from 50 microns, which allows them to be visualized using more conventional means. Thus, complementary analysis of such larger particles can be done by spectrometry (after acid attack), by ferrography (or related systems) or by optical or electronic microscopy.

5.3.4 Viscosity (Engine oils)

The viscosity of used engine oil is mostly measured at 100°C, and can drop for reasons of fuel dilution, and/or shearing of the VI improver. Viscosity can increase as a result of heavy contamination of the oil by soot, and/or oxidation of the oil.

5.3.5 Viscosity (Industrial oils)

The viscosity of industrial oils, by contrast, is mostly measured at 40°C, and must correspond with the ISO table below, i.e., the viscosity of an ISO class oil must be within the minimum and maximum for that class. (Moves are in hand to make the viscosity class statement contain more data, to reflect changes in the oil in use.)

The viscosity can be decreased by adding a more fluid oil, or as a result of high water content, of by shearing of the VI-improver. The viscosity can be increased by adding a more viscous oil, and by oil oxidation (e.g. as a result of overheating).

5.3.6 Dilution

Dilution of used engine oil can be measured precisely by gas chromatography (GC) or by Fourier Transform Infrared spectroscopy (FTIR). More common is the use of the SETA-FLASH tester, where the flash point of oil is tested by a certain temperature. When a flashpoint is detected, the dilution is heavy (more than 4%), when not, the dilution is acceptable (less than 4%).

It is evident that heavy dilution of the oil is unfavorable for the engine, since it involves a lower viscosity and reduces the resistance of the oil film. The principal causes of dilution are a defective fuel injection system, a defective air inlet (obstructed air filter), incomplete combustion due to too low a working temperature, and badly regulated valves, or insufficient compression.

5.3.7 Water detection

The water-content of the oil is usually measured by the Aquatest or a Karl Fisher apparatus. The possible causes of water introduction include (a) condensation, due to too low a working temperature, defective crankcase ventilation, ‘stop and go’ in-service usage, and obstruction of the exhaust system; or (b) infiltration, due to leakage at the cylinder head gasket, or damage of the engine block.

Cooling water contains most often an anti-freeze based on glycol. Therefore a glycol test should be performed when water infiltration is suspected. The inhibitor in the anti-freeze agent is usually a sodium borate type.

Acid Number (AN)

The acidity of the oil is measured by titration through a base, and expressed in mg KOH/g. The figure below shows this graphically, showing the evolution of TAN as a function of time.

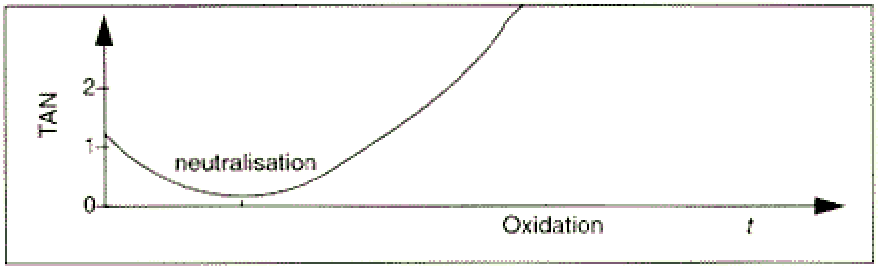


Figure 6. TAN evolution function of time

5.3.8 Base Number (BN)

The alkalinity of oil is measured by titration through an acid, and expressed in mg KOH/g. The comparison between the TBN volume of the fresh oil and that of the used oil allows the determination to be made of whether the used oil is still capable of neutralizing acid residues. These acids are produced by combustion (sulfur in fuel) and oxidation of the oil and oil additives. When the oil is in service too long, the TBN will drop significantly.

Too low a TBN volume can be due to: heavy oxidation of the oil, when the oil has been in service for too long, of the oil level was insufficient, or due to a defective cooling system, producing overheating; use of a fuel containing a high sulfur content; use of an inappropriate lubricant; or contamination of the oil by fuel or water.

5.3.9 Particle Counting

This is an especially useful test for a hydraulic system with high sensitivity (e.g., servo-valves). In such a text, a certain quantity of hydraulic oil flows through a sensor, where all the insoluble material in the oil is detected and counted using the principle of light absorption. The particles counted are classified cumulatively:

- 5µ;>15µ;>25µ;>50µ;>100µ.
  Or differentially:
- 5-15µ;>15-25µ;>25-50µ;>50-100µ;>100µ.

The results of particle counting can be expressed according to either ISO 4406 or NAS 1638. According to ISO 4406:99, the results are expressed cumulatively, and the ISO classification is deduced from the following rates: >4µ, >6µ and >14µ.

According to NAS 1638, the results are expressed differentially, in five classes. In each class one can get a NAS quotation, and the NAS code is the figure given to the first class.

5.3.10 Microscopy

After filtration of a certain amount of oil through a cellulose filter (of 0.8µ), the filter is examined under an optical microscope (magnitude 100x, 200x), and one is able to distinguish:

- white or brilliant metal particles (demonstrating recent wear)
- black metal particles (already oxidized)
- rust particles
- silt (i.e., very small particles below 5µ, responsible for erosive wear)
- silica (sand, dust)
- polymers (from oil additives)
- welds
- paint flakes
- other impurities (fiber, plastics, and so on)

5.3.11 Wear

Wear means the loss of solid material due to the effects of friction of contacting surfaces. It is generally harmful, although in some cases it can also be beneficial, for instance during the running-in of an engine. The deterioration of the surfaces in an engine is generally due to isolated or simultaneous mechanisms, among which we can distinguish the following.

- Aluminum (Al) : Pistons, bearings, housing metal, thrust washers, converter and pump bushings, dirt entry (clay soil).
- Copper (Cu) : Bearings, bushings, thrust washers, discs, cooler cores. Copper levels can vary and usually are present with elevated levels of another metal. Copper is also used as an additive in some oil.
- Chromium (Cr) : Chromed parts such as piston rings, bearings.
- Iron (Fe) : Gears, shafts, cylinders, valve train components, other steel components and rust.
- Lead (Pb) : Overlay on main and rod bearings, turbocharger bearings, camshaft bearing and some bushings.
- Molybdenum (Mo) : Piston rings, also a friction reducing agent in some oils.
- Silicon (Si) : Contamination from dust or dirt, anti-foam agent. Silicon is also found in greases, gaskets, and antifreeze.
- Sodium (Na) : Antifreeze formulas, also an additive in some oils.
- Tin (Sn) : All roller or ball bearings and some engine bearings.
- Zinc (Zn) : Additive packages of some oils, essential in high impact and high stress load areas.

Spectrometer metals

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	Bushings(Bronze Alloy)
Tin	Piston Flashing, Bearing	Bearing Cage Metal	Bearing Cage	

Metal	Engines	Transmissions	Gears	Hydraulics
	Overlay, Bronze Alloy, Babbitt Metal along with Copper and Lead		Metal, Lube Additive	
Cadmium	N/A	N/A	N/A	N/A
Silver	Wrist Pin Bushings(EMD's), 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

Contaminant Metals

Metal	Engines	Transmissions	Gears	Hydraulics
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 Inhibitor, Lube Additive(15 ppm or less)	Dirt, Seals and Sealants, Coolant Inhibitor, 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, Salt Water Contamination, Airborne Contaminate	Lube Additive, Coolant Inhibitor, Salt Water Contamination, Airborne Contaminate
Potassium	Coolant Inhibitor, Airborne Contaminate	Coolant Inhibitor, Airborne Contaminate	Coolant Inhibitor, Airborne Contaminate	Coolant Inhibitor, Airborne Contaminate

Multi source metals

Metal	Engines	Transmissions	Gears	Hydraulics
Molybdenum	Ring Plating, Lube Additive, Coolant Inhibitor	Lube Additive, Coolant Inhibitor	Lube Additive, 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

Metal	Engines	Transmissions	Gears	Hydraulics
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

Metal	Engines	Transmissions	Gears	Hydraulics
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(ZDP), EP Additive(Extreme Pressure)	Anti-Wear Additive(ZDP)
Zinc	Anti-Wear Additive(ZDP)	Anti-Wear Additive(ZDP)	Anti-Wear Additive(ZDP)	Anti-Wear Additive(ZDP)

5.4 How to Read the Oil Analysis Report

Reading an oil analysis report can be an overwhelming and sometimes seemingly impossible task without an understanding of the basic fundamentals for interpreting laboratory results and recommendations. Referring to the report descriptions and explanations below will help you better understand your results and, ultimately, better manage a productive, cost-saving reliability program.

The information submitted with a sample is as important to who is reading the report as it is to the analyst interpreting the test results and making recommendations. Know your equipment and share this information with your laboratory. Accurate, thorough and complete lube and equipment information not only allows for in-depth analysis, but can eliminate confusion and the difficulties that can occur when interpreting results.

The oil analysis interpretation includes a discussion of the equipment wear state, level of oil contamination, and oil condition and includes a recommendation outlining any corrective maintenance actions that are necessary.

Recommendations: A data analyst's job is to explain and, if necessary, recommend actions for rectifying significant changes in a unit's condition. Reviewing comments before looking at the actual test results will provide a roadmap to the report's most important information. Any actions that need to be taken are listed first in order of severity. Justifications for recommending those actions immediately follow.

Test Data: Test results are listed according to age of the sample—oldest to most recent, top to bottom—so that trends are apparent. Significant changes are flagged and printed in the gray areas of the report.

Elemental Analysis : Elemental Analysis, or Spectroscopy, identifies the type and amount of wear particles, contamination and oil additives. Determining metal content can alert you to the type and severity of wear occurring in the unit. Measurements are expressed in parts per million (ppm).

Special (exception) Testing: Special testing is often done when additional, or more specific, information is needed. For example, Analytical Ferrography might be requested when a ferrous metal larger than 5 microns has been detected by Direct Read Ferrography. The AF can determine actual size of the particle, its composition—iron, copper, etc.—and the type of wear it's creating—rubbing, sliding, cutting, etc.

5.5 Sample limits

Wear Debris Analysis (WDA) is an attempt to determine the condition of machinery through examination of the particles generated by wear processes. These particles are extracted from oil samples, filters, or removed from magnetic plugs. The particles are examined with a white light microscope and/or Scanning Electron Microscope (SEM). Energy-dispersive X-Ray, Spectroscopy, can determine the chemical makeup of the particles. Educated guesses concerning the chemical makeup can be made based on knowledge of the equipment, and the appearance of the particles.

What is the Purpose of contamination Analysis?

- To detect potential failures before they occur. This allows the equipment to be scheduled for repair instead of failing in service
- To determine the root cause of failures after they occur.
- To detect abnormal machine or lubricant conditions
- Allows parts to be ordered.
- Allows Labor to be scheduled.

5.5.1 Alarm Limits.

The propose of the alarm is trigger an action, serves as “trip-wire” to tell the analyst that a threshold has been passed and that action is required.

Test	Caution	Critical	Remarks
IR Infrared Analysis			Addresses lube chemistry and degradation process – must be compared to new oil
Viscosity Test cSt 40 ºC (mm^2/s) DIN 51562 or ASTM D445	± 10 %	± 15 %	Change versus the new oil viscosity. It will increase when aged.
TAN - Total Acid No. (mg KOH/g) DIN 51588 or ASTM D974		1.0 increase from new oil	Acid no. is proportional with the degree of degradation. Trending important.
Wear Particle (weight %) DIN 51592		> 0.08 %	Note: Fresh oil is not clean oil and must be filtrated during re-filling
Wear Particle Analysis Direct Read (DR) Ferrography or Spectrochemical Analysis (SMA)		Limits see next page	Normally together with a microscopic evaluation to determine size, composition and wear type of particle
Water (weight %) DIN 51582 or ASTM D1744, D95	> 0.05 %	0.1 % Hydraulic Oil 0.2 % Gear Oil	Most accurate is Karl Fischer (ppm) or distillation test. Excessive water is the second most destructive contaminant.
Flash Point ºC DIN 51794 or ASTM D 92	± 15 %	± 20 %	Lowest limit should be 160 ºC
Density 15 ºC (g/cm^3) DIN 51757		< 2 %	
Foam (ml) DIN 51566 or ASTM D 892	No Foam	No Foam	Mainly used for hydraulic oils.
Air Entrainment (min. with 50 ºC) DIN 51381	< 5 min.	< 8 min.	Mainly used for hydraulic and gear oils
The mentioned rejection limits are for guidance only, as a final judgment of the oil also will be based on their reciprocally relationship.			

Figure 7. Generic alarm limits for oil analysis (lubricant properties)

Test	Caution	Critical	Remarks
Demulsibility ASTM D 1401	< 30 min Complete separation	< 45 min	Test time for specified test for oil-water emulsion to break
Corrosion Test DIN 51355, DIN 51585, ASTM D 130		Failed	Non corrosiveness is not to be confused with rust inhibiting.
Pour Point DIN 51597			Pour point is 3ºC above the temp. to which normally the product maintains fluidity.
Ash Content ASTM D 582, ASTM D874			Since some detergents are metallic salts or compounds, the percentage of ash has been considered to have a relationship to detergence.
RBOT – Rotary Bomb Oxidation Test ASTM D 2272	< 50 %	< 25 %	Change versus the new oil. Test mainly designed for turbine oils.
Fuel Dilution		3 %	
FZG Test DIN 51345		< 12	Mainly CLP, HLP, HK Oil. Special Test DIN 51354 A.276/50 for extreme heavy load condition
Four Ball Test ASTM D 2266, ASSTM D 2596 (EP Test)			To determine the relative wear preventing properties of lube under boundary condition.
Timken Load Test			For extreme pressure properties. Measures the maximum load that can be carried without scoring.
The mentioned rejection limits are for guidance only, as a final judgment of the oil also will be based on their reciprocally relationship.			

Figure 8 Generic alarm limits for oil analysis (lubricant properties), continued

The table below show the alarm limits per type of wear metal and different application. Those limits were defined according with supplier specification, publications and experiences.

Equip Type	Hydraulic System	Transmission	Circulation System	Miscellaneous	Engine
Iron (Fe)	40 Max.	50 Max.	50 Max.	100 Max.	60 Max.
Copper (Cu)	30 Max.	100 Max.	50 Max.	200 Max.	40 Max.
Silicone (Si)	20 Max.	25 Max.	20 Max.	25 Max.	15 Max.
Lead (Pb)	20 Max.	30 Max.	30 Max.	40 Max.	15 Max.
Chromium (Cr)	10 Max.	15 Max.	15 Max.		10 Max.
Aluminum (Al)	10 Max.	30 Max.	30 Max.		15 Max.
Tin (Sn)	10 Max.	20 Max.	15 Max	20 Max.	15 Max.
Sodium (Na)	- - - - - -	50 Max.	- - - - -		50 Max.

Figure 9 Alarm limits per type of wear metal

5.5.2 Visual Check of Water in Oil

Amount of water, ppm:	Appearance of oil:
0	Bright and clear
100	Trace of translucent haze
200	Slight translucent haze
250	Translucent haze
500	Opaque haze
1000	Opaque haze with slight water drop out

1 ppm = 1ml pro 1000 liter or 1000 ppm = 0.1 %

Figure 10 Amount of water (ppm) in oil (visual estimate)

5.5.3 Recommended limits for cleanliness (ISO 4406:99)

ISO Code (4/6/14 μm)	Component
16/14/11	Hydraulic systems
17/15/12	Planetary gearboxes and lubrication circulation systems
17/15/12	Friction and anti-friction bearings
20/18/14	Gearboxes without circulation system
17/16/13	Diesel engines

Figure 11 Limits for oil cleanliness expressed as per ISO 4406:99

Remark: the above values correspond to critical 'A' equipment; a lesser cleanliness requirement can be adopted for less critical equipment

Machine/ element	<1,500 psi	1500 – 2500 psi	> 2,500 psi
Servo valve	16/14/12	15/13/11	14/12/10
Proportional valve	17/15/12	16/14/12	15/13/11
Variable volume pump	17/16/13	17/15/12	16/14/12
Cartridge valve	18/16/14	17/16/13	17/15/12
Fixed piston pump	18/16/14	17/16/13	17/15/12
Vane pump	19/17/14	18/16/14	17/16/13
Pressure/Flow control valve	19/17/14	18/16/14	17/16/13
Solenoid valve	19/17/14	18/16/14	18/16/14
Gear pump	19/17/14	18/16/14	18/16/14

Figure 12 Specific cleanliness limits for circulation system components

Specific secondary sample points are required to benefit from these more component specific levels.

5.6 Recommended tests and testing frequency

The following charts show the recommended **routine** tests (according to oil application, either gear or hydraulic oil) and the recommended equipment and testing frequency.

Gear Oil	Hydraulic Oil
IR - Infrared Spectrum	IR – Infrared Spectrum
Appearance / Color	Appearance / Color
Viscosity cSt	Viscosity cSt
TAN – Total Acid Number	TAN – Total Acid Number
Water Content (Karl Fischer)	Water Content (Karl Fischer)
Spectroscopy (ppm)	Spectroscopy (ppm)
Particle counting - ISO 4406:99 (for selected equipment)	Particle counting - ISO 4406:99
Direct Read ferrography	Foam

Figure 13 Recommended tests according to oil application.

Particle counting is to be applied only to the equipment shown in **bold text** in the following table. For all other applications (or in case it is not possible to perform particle count, due to water content or oil darkness), perform a Direct Read Ferrography.

Analytical ferrography is an **Exception testing (**based on results of Direct Read or Particle Counting). As a routine, it will only be done for VRM Main gearbox and mill roller bearings, where it should be performed as a routine every 6 months.

Generic Equipment	Freq	Note
Hydraulic Drive	3M	
Kiln Bearing support	3M	Start monthly and modify frequency according to trend; at least 3M
Kiln Drive Pinion bearing	3M	Start monthly and modify frequency according to trend; at least 3M
Main Drive Gearbox VRM	1M	If cleanliness level maintained, perform complete analysis every 3M
Main Filter Fan Cement area	3M	
Main Mill Fan Cement area	3M	
Main ID Fan Clinker area	3M	
Main Filter Fan Clinker area	3M	
Main Filter Fan raw material area	3M	
Main Mill Fan Raw Mill area	3M	
Main Motor Bearing	3M	
Thrust Bearing	3M	Start monthly and modify frequency according to trend; at least 3M
Ball Mill Bearing (trunnion)	3M	
Drag Chain gearbox	3M	
Gearbox Belt Conveyor	3M	
Gearbox Bucket Elevator	3M	
Gearbox crusher feeder	3M	
Gearbox Pan Conveyor	3M	
Gearbox Rotary Valve	3M	
Gearbox Screw conveyor	3M	
Hydraulic Coupling	3M	
Hydraulic system	3M	
Kiln Drive Gearbox	3M	
Main Drive Cement Mill	3M	
Main Drive Roller Press	3M	
Gearbox Separator Roller Press	3M	
Gearbox Separator Mill	3M	
Auxiliar Mill Drive	6M	
Emergency Generator	6M	
Thermal Oil	6M	

Figure 14 Recommended sampling frequencies, according to equipment type

Describe how this Standard is integrated with our Health and Safety rules, what are the specific H&S procedure or document used.

Risk, hazard and precautions needed.

6. Oil Analysis for Transformers

For all oil filled power transformers it is necessary to perform an appropriate condition monitoring to be able to identify failure modes and to estimate the remaining lifetime for replacement planning. On a new power transformer a complete oil analysis (including all 3 tests below) needs to be performed before commissioning to receive a baseline for the trending.

A registry of all transformers in the plant needs to be set up containing all the relevant data of the transformers. This registry should also be used to trend the measurement results as well as to record all repair or improvement actions performed on the transformers. This is very important to be able to interpret the trends accordingly.

The following tests need to be performed on the oil samples taken:

Basic 6-part Test	Quality of the oil as an insulating medium and heat transfer agent - amount of contaminants including water in the oil - dielectric properties of the oil
Dissolved Gas Analysis	Operating condition of the transformer - was the transformer overheated or overloaded? - did any type of discharge occur (arcing, sparking, corona, PD)
Furanic Acid Analysis	Condition of the paper insulation - approximate remaining lifetime based on the degree of polymerization of the insulating paper

Figure 15: Three types of tests and their application

Basic 6-part test and Dissolved Gas Analysis should be performed on all transformers every year.

6.1 Basic 6-part Test

The Basic 6-part test determines the physical condition of the transformer oil. The following tests on the transformer oil are performed according to IEC 60499:

6.1.1 Dielectric breakdown voltage

The dielectric breakdown voltage is the insulating basic behavior of the transformer oil. To avoid insulation breakdown and discharges inside the transformer it is necessary, that the breakdown voltage is above a certain limit. Due to the fact, that the breakdown voltage is strongly depending on the test arrangement, the test needs to be performed according to the appropriate standard. We recommend performing this test according to IEC 60156.

In case the laboratory is not able to perform the test according to IEC, the test should be performed according to ASTM D1816.

The test result is very much depending on the contamination of the transformer oil with water and fibers.

6.1.2 Water content

The water content of the transformer oil is influenced by the effectivity of the drying agent in the breather of the conservator, the tightness of the transformer and the degradation level of the paper insulation. Decomposition of the paper creates water which is increasing the humidity in the paper which dissipates into the oil. An increase of moisture in the paper causes a 10 times faster degradation of the paper. Therefore the moisture in the paper is the most important information we need.

The moisture content in the paper and in the oil has an equilibrium which depends very much on the temperature. The following graph shows the relation of humidity in the paper and in the oil at different temperatures. To calculate the humidity in the paper it is necessary to know the temperature of the oil during sampling. The dissipation process is rather slow, so the transformer temperature needs to be more or less constant for a month to reach the equilibrium.

6.1.3 Acidity

The acidity of the transformer oil increases due to oxidation of insulating material. It affects the insulating properties of transformer oil as well as the paper insulation. The rate of increase is a good indicator for the ageing process in the transformer.

6.1.4 Dielectric dissipation factor and/or resistivity

These are very good indicators for the identification of polar contaminants and ageing products in the transformer oil. Even very low levels of contaminants show an influence on the dissipation factor and the resistivity. It is sufficient to measure only one of these values, because they depend on each other. These values are very much depending on the temperature and should get worse with higher temperature.

The measurement at ambient temperature and at 90° C can be used to get more information about the oil quality. If the results at both temperatures are not satisfactory the oil quality is poor and can probably not be recovered by reconditioning.

6.1.5 Interfacial tension

The interfacial tension is an indicator for soluble polar contaminants and degradation products. It changes rapidly during initial ageing stage and stays almost stable under moderate ageing levels. In case of incompatible materials used inside the transformer or mixing of transformer oils it changes very fast.

It can also be used to identify overloaded transformers with high deterioration.

6.1.6 Oil appearance and color

Transformer oil must be clear and free from sediment or clouds. The color is coded (0...5) in ISO 2049 and if the color code is higher than 2 the sludge content in the transformer oil is too high. this will result in sludge contamination of the windings, which reduces the heat transfer from the windings to the transformer oil.

Sludge is a degradation product either from oil or paper and mainly caused by high temperature.

6.2 Interpretation of the results of the Basic 6-part test

According to IEC 60422 the values derived from the basic 6-part test are categorized as good, fair or poor. In case the result of a value is fair it is recommended to reduce the period of oil testing. this can also be indicated if a severe change of one of the values can be identified and no particular reason can be found for this change.

In case of values getting in the range of poor condition an action needs to be taken to avoid further deterioration of the insulation and to recover the oil quality to avoid premature ageing. For very old transformers it can also be an indication, that the transformer has reached the end of its lifetime.

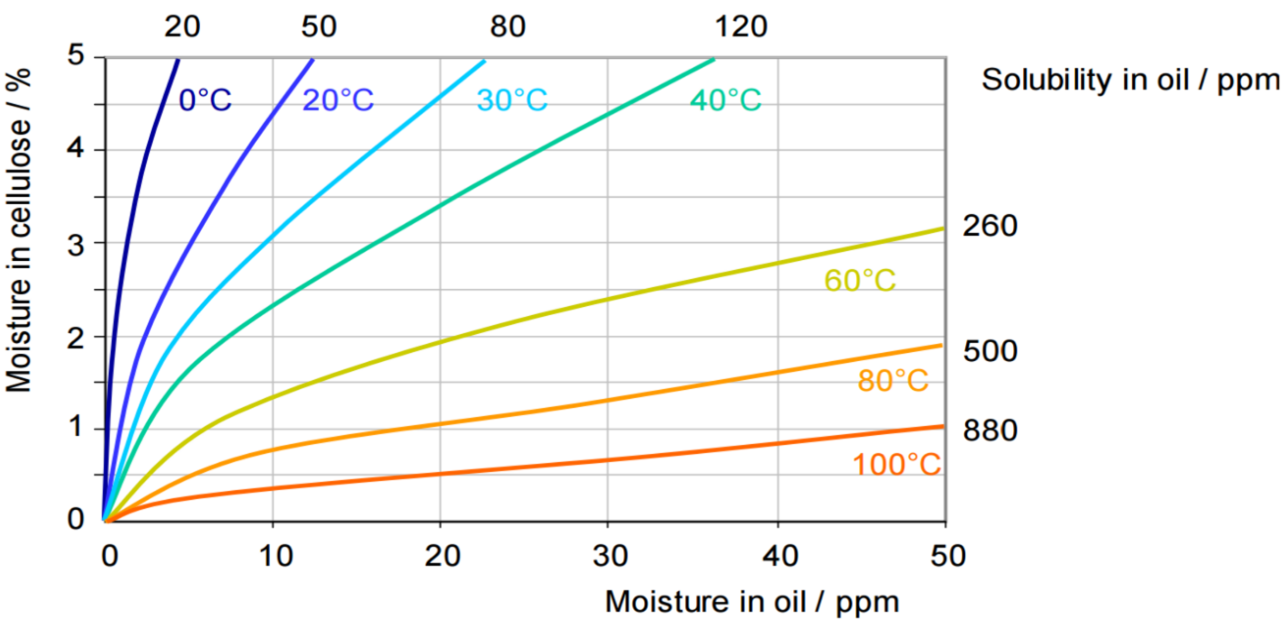


Figure 16: Ratio between moisture in oil and cellulose as a function of the temperature

		Limits					
Test Item	Standard	U≤69 kV	U>69 U≤ 288	U>288 kV	Unit		Significance
Dielectric Breakdown voltage	D 877-87	26	30	--	kV		Ability of the oil to withstand electric stress without failure
	D 1816-	20		25		min	
Intefacial tension	D 971-91 or D 2285-85	25			dynes/cm	min	Presence of soluble contaminants
Neutralization Number	D 1534-90	0.2	0.15		mg KOH/gm	max	Amount of Acid
Oil Moisture	D 1553	35	25	20	ppm	max	Amount of water
Power factor @ 25°C	D 924-92	0.5			%	max	Dielectric losses of the oil
Oil Color	D 1500-91						Simple Indicator of oil quality

Figure 17: ASTM standard limits for the Basic 6 part test

		Limits					
Test Item	Standard	U≤72.5 kV	U>72.5 U≤ 170	U>170 kV	Unit		Significance
Dielectric Breakdown voltage		30	40	50	kV	min	Ability of the oil to withstand electric stress without failure
Intefacial tension		15			mN/m	min	Presence of soluble contaminants
Neutralization Number		0.5			mg KOH/gm	max	Amount of Acid in oil
Oil Moisture		35	25	20	mg/kg	max	Amount of water in oil
Power factor @ 25°C		0.5			%	max	Dielectric losses of the oil
Oil Color							Simple Indicator of oil quality

Figure 18: IEC standard limits for the Basic 6 part test

STATUS	Intefacial tension, Dynes / cm.	Neutralization Number, mg KOH/mg oil	Power factor @ 25°C	ACTION
Condition 1	>25	<0.05	<0.5	Acceptable
Condition 2	>=22 < 25	>0.05 >=.15	>0.5 >=1.0	Investigate, oil may require treatment
Condition 3	>=16 > 22	>.15 >=0.5	>1.0 >=2.0	Investigate, oil may require treatment, or replacement
Condition 4	<16	>0.5	>2.0	Shutdown and investigate, oil may require treatment, or replacement

Figure 19: Recommended actions according to results of Basic 6 part test

6.3 Dissolved Gas Analysis (DGA)

Gas	Symbol	Corona		Pyrolysis, Heating				Arcing
		Oil	paper, wood	Oil		Paper, Wood		
				High	moderat	modera	severe	
Hydrogen	H_2							
Methane	CH_4							
Ethane	C_2H_6							
Ethylene	C_2H_4							
Acethylene	C_2H_2							
Carbon Monoxide	CO							
Carbon Dioxide	CO_2							

Each failure mode has its own gas signature

Major concentration

Minor concentration

No or insignificant concentration

Figure 20: Simplified Gas Formation table

Status	Hydrogen H_2	Methane CH_4	Acethylene C_2H_2	Ethylene C_2H_4	Ethane C_2H_6	Carbon Monoxide CO	Carbon Dioxide CO_2	Oxygen O_2	Total Dissolved Combustible Gas
Condition 1	100	120	35	50	65	350	2500		720
Condition 2	101-700	121-400	36-50	51-100	66-100	351-570	2500-4000		721-1920
Condition 3	701-1800	401-1000	51-80	101-200	101-150	571-1400	4001-10000		1921-4630
Condition 4	>1800	>1000	>80	>200	>150	>1400	>10000		>4630

Status	Actions
Condition 1	Continue normal operation, maintenance schedule and samplig frequency
Condition 2	Analyze individual gases to find cause. Determine if the cause is load dependent
Condition 3	Exercise extreme caution, monitor more frequently. Plan maintenance very soon
Condition 4	Shutdown and call manufacturer or consultant to investigate.

Figure 21: DGA warning limits (no indication of the nature of the fault)

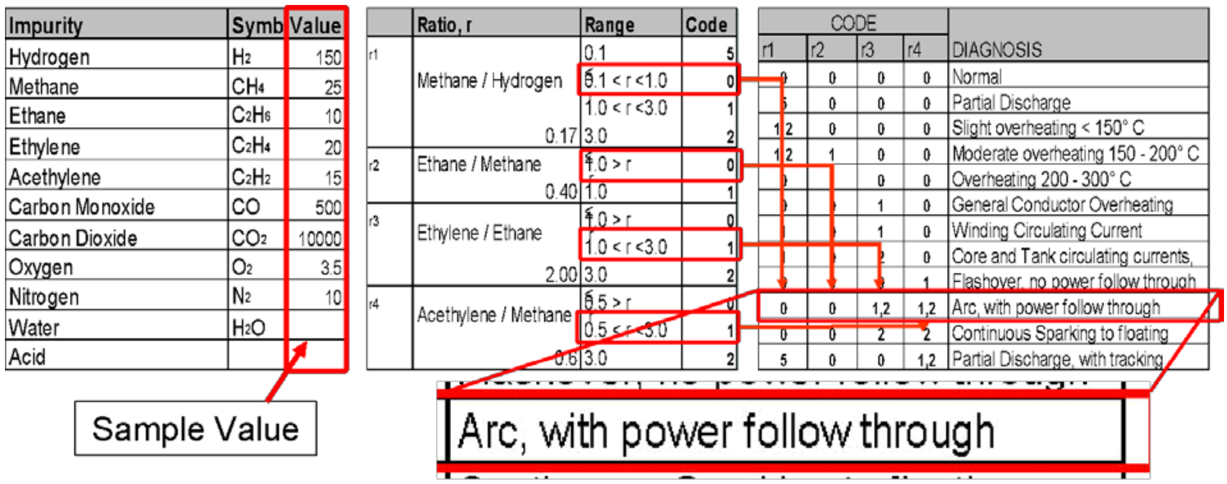


Figure 22: Fault Analysis by Ratio Method

- Fault Codes
  - PD : Partial Discharge
  - T1 :Thermal Fault, > 300°C
  - T2 : Thermal Fault, 700°C>T>300°C
  - T3 : Thermal fault, < 700 °C
  - D1 : Low Energy Discharge (Spark)
  - D2 : High Energy Discharge (Arcing)
  - DT : Mix of Electrical and Thermal Fault

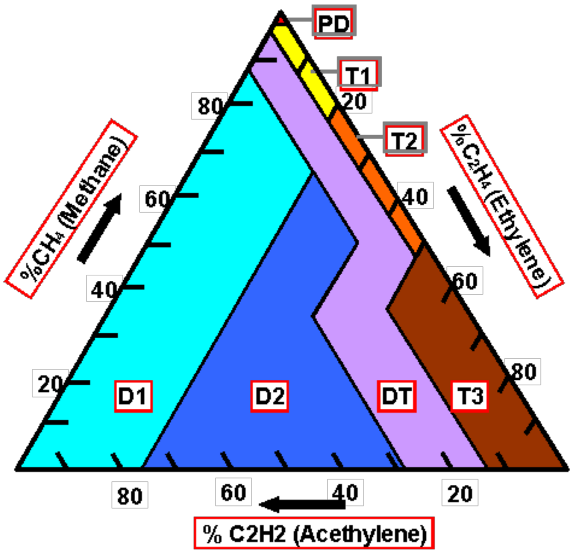


Figure 23: Fault Analysis by Duvall Triangle Method

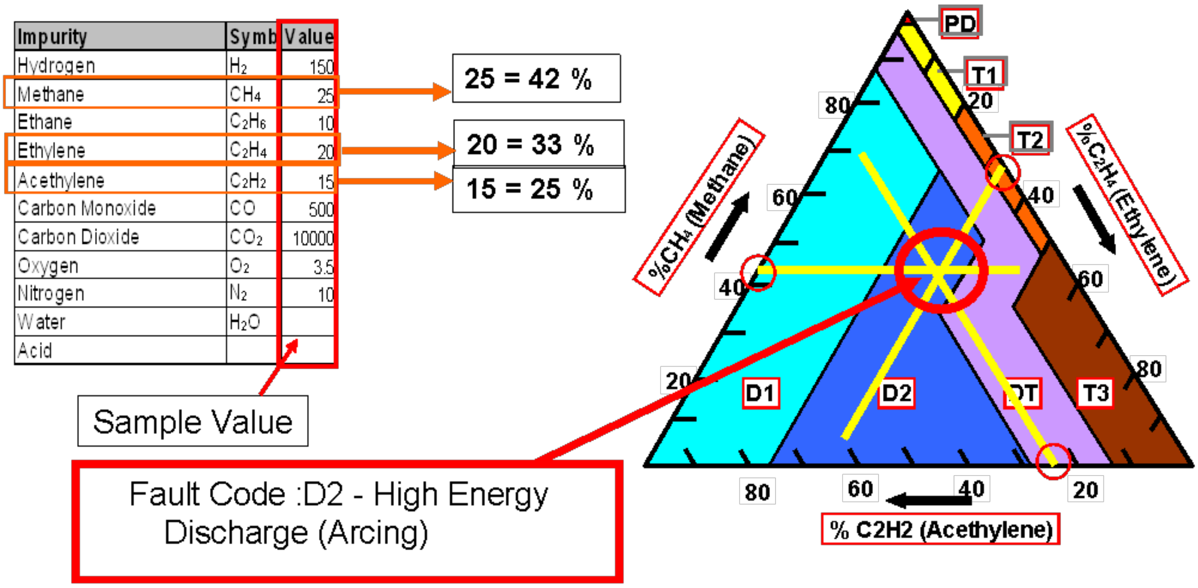


Figure 24: Example of Duvall Triangle Method

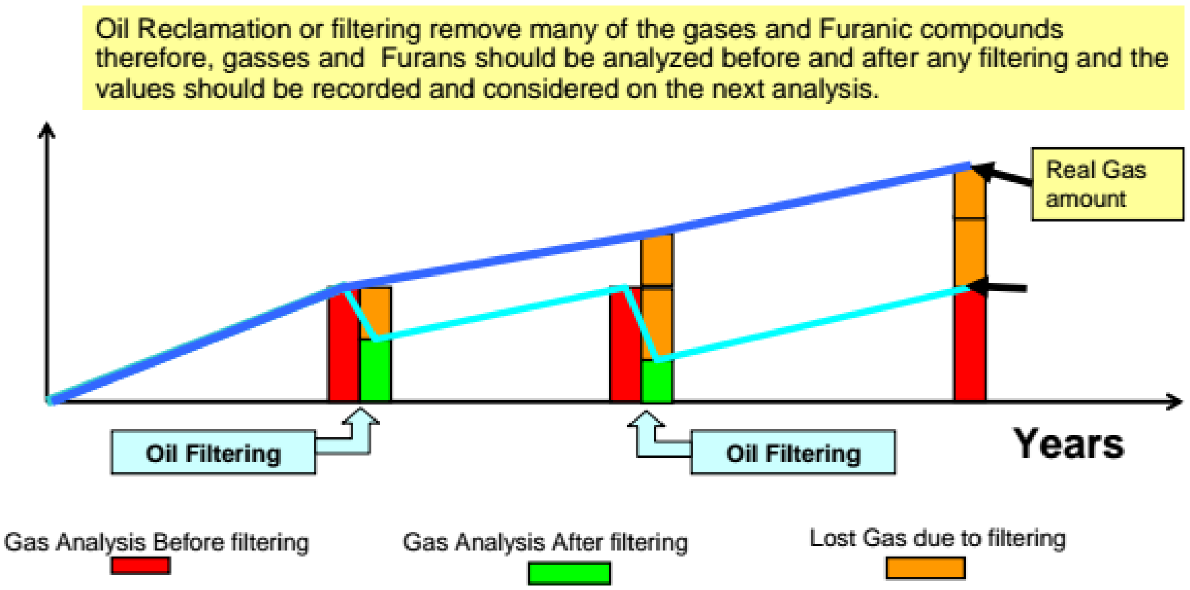


Figure 25: Effect of oil filtering on dissolved gases

7. Vibration analysis

All rotating machines exhibit a characteristic vibration behavior, which is caused by temporally variable forces. The dynamic operating forces, caused by excessive vibration, affect the condition of the machines negatively and lead to a reduction of the service live. Different procedures of vibration measurements permit a high reliable orientation and give important indications to the condition of the machinery.

Although frequently vibrations can be caused by more than one problem, the causes of excessive vibrations can be divided into three groups:

- Vibrations due to mechanical defects, such as unbalance, bent shafts, misalignment, mechanical looseness etc. that is called forced vibration.
- A vibration due to resonance vicinities, i.e. a natural frequency of the system is close to an exciting frequency; that is called free vibration.
- Vibrations caused by electric phenomena

Identify the cause(s) of the vibration is our main target; this is a complex process where physics laws, technology, skills and equipment knowledge must be integrated to perform vibration analysis.

7.1 Machines selection and analysis frequency

In the process of deciding on and mapping out the machinery to monitored, certain logical divisions of equipment will probably have suggested themselves. These major divisions are most often made at the cost center level; consider defining a separate database for each area or cost center.

The routine consist in a group of machines ordered in logical sequence by productive area in order to measure every collecting point of each machine

- Selection of rotary machines must be done by:
  - Criticality on production flow
  - Affect production quality
  - Risk of injure someone by broken pieces
  - Affect the environment
  - Effect in reduction cost by less maintenance intervention

Start in the higher and farthest machines and put in a logical order during the walk around

- Define the frequency to be measured considering:
  - Criticality of the equipment (focus on A equipment)
  - Probability of failure (P-F Curve)
  - Stiffness of construction
  - Design load capacity again working conditions

Frequencies are based on 7 days per week, 28 days per month and 84 days quarterly.

Equipment	Data analysis Frequency
Main drives (planetary gears, pinion – girth gear systems)	every 2 weeks
Main fans (main process, including primary air)	every 2 weeks
Clinker cooler Fans	every 2 weeks
Bucket elevators and belt conveyors, critical (A)	monthly
Other critical equipment (A)	monthly
Bucket elevators and belt conveyors (B)	monthly to 2-monthly
Other critical equipment (B)	2-monthly

Figure 26 Recommended frequencies for vibration analysis

It is highly recommended to follow the vibration analysis frequencies suggested in the figure above considering the machinery criticality and severity on the operations in case of failure.

7.2 Alarm limits

With the purpose to determine if the vibration is excessive or not we first must know which parameter we need to measure. When perform vibration analysis basically the focus is on amplitude and frequency. Amplitude give us an idea of the relative severity and frequency tells what is wrong in the equipment. The diagram below shows how depending on the type, size and speed (frequency) of the machine component we can define which amplitude parameter measure and track:

- Displacement
- Velocity
- Acceleration
- Shock pulses

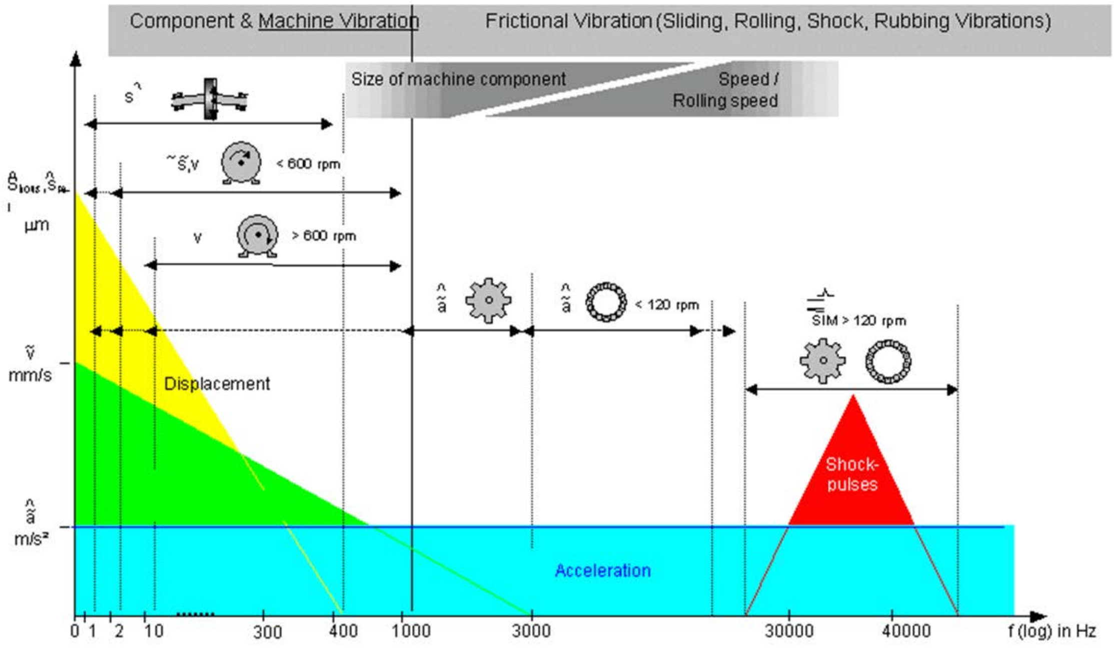


Figure 27 Measurement parameters definition for vibration analysis.

Most of the problems in determining if is vibration is excessive can be eliminated by strict adherence to standards. Over the years many severity charts and standards have been developed and applied to determine vibration limits.

It is common engineering practice that the vibration severity of industrial gear drives are assessed in accordance with the ISO 10816-1 1995 (former ISO 2372) standard that is more or less identical with DIN 45665 or the VDI 2056 guide-line.

Vibration severity for gear reducers and fans

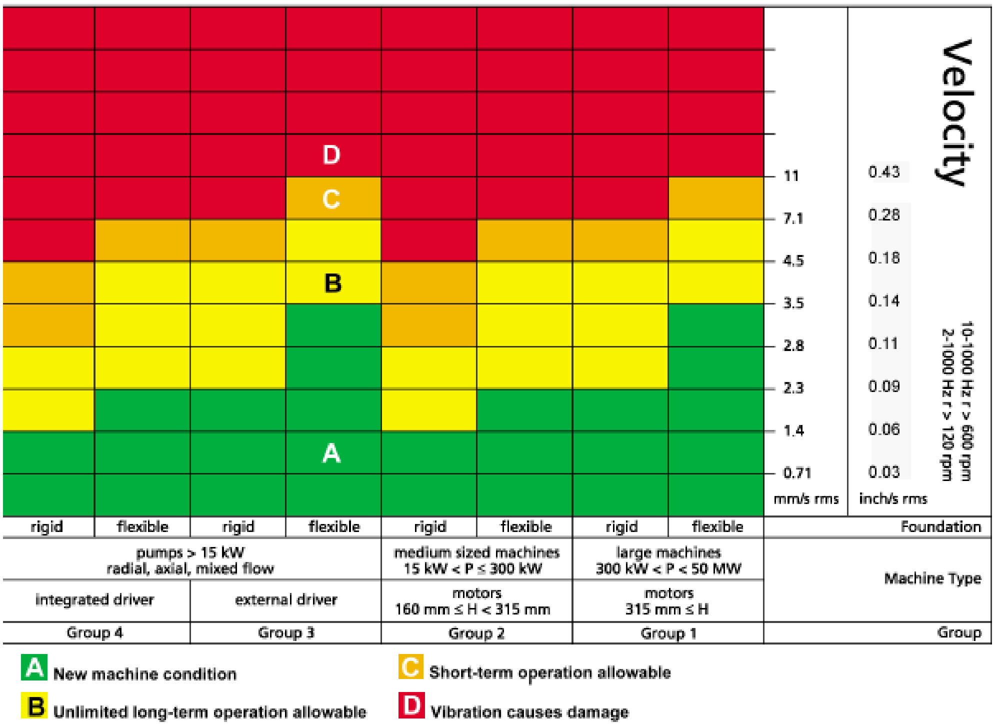


Figure 28 Reference values for vibration for gear drives

It is recommended in the relevant standards that for fans the residual unbalance is also assessed, the balance quality grade be outlined in the standard ISO 1940.

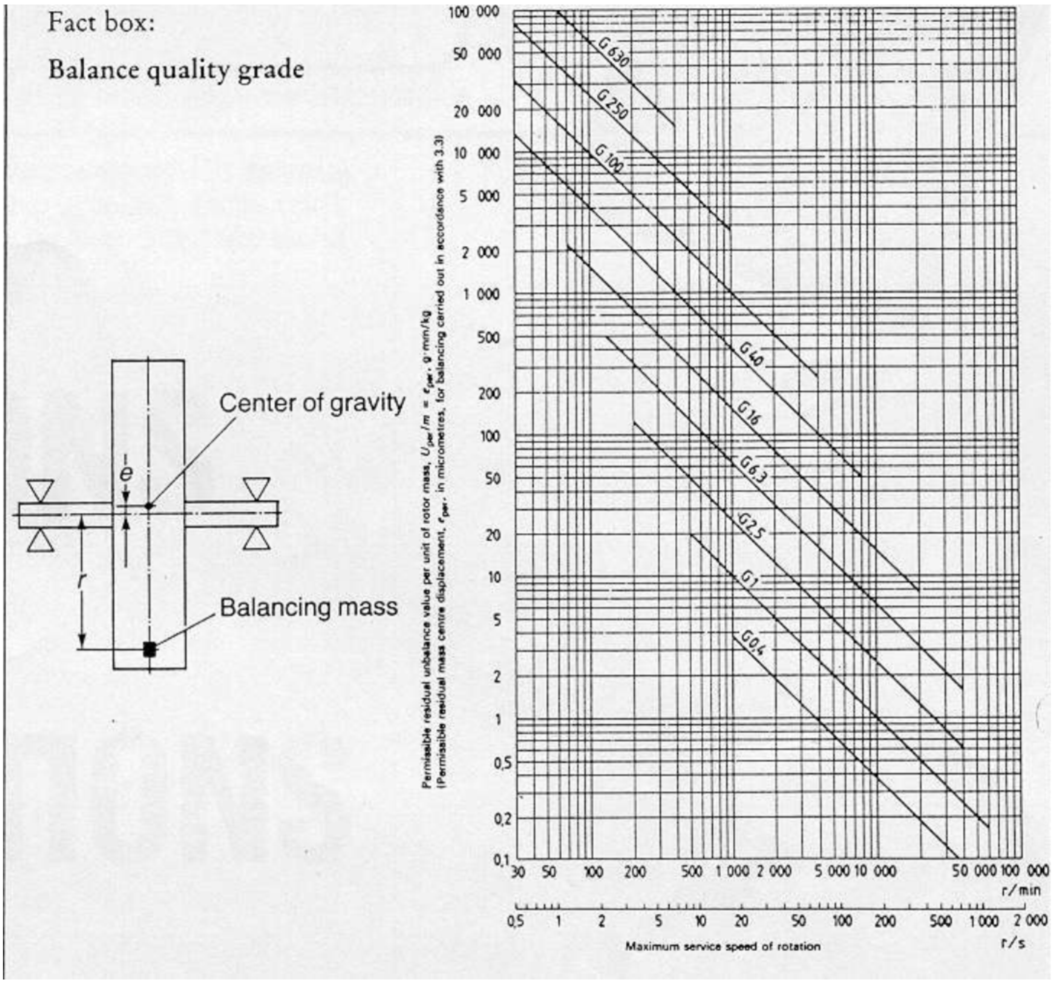


Figure 29 Guidance values for the permissible residual unbalance. (Quality grade G 6.3 is generally used for big fans in the cement industry.)

Vibration severity for girth gear drives

For open girth gear drives the above mentioned guidelines are definitely not applicable. The vibration severity guide-lines, as recommended in the following for fans, gear reducers and open girth gear drives are based on the ISO 2372, for open girth gear drives the severity guideline is based on own experience and digress from the standards.

	Pinion with friction bearings	Pinion with roller bearings
Very good	< 5 mm/s RMS	< 2.5 mm/s RMS
Fair	5 – 10 mm/s RMS	2.5 – 5 mm/s RMS
Usable	10 – 15 mm/s RMS	5 – 10 mm/s RMS
Just tolerable	15 - 20 mm/s RMS	10 - 15 mm/s RMS
Not permissible	> 20 mm/s RMS	> 15 mm/s RMS

In case that the vibration severity in a gear drive system was found to be “not permissible” this should be the reason for more detailed investigations. Possible causes are mechanical defects (forced vibrations) or resonance vicinities (free vibrations) that requires an extended investigation procedure by experts including analytical studies, field measurements and an analysis in the time and frequency domain.

7.3 Frequency Analysis

In vibration analysis, some problems can be diagnosed in the time domain. For a complete and accurate analysis, we must use of both the time domain and the frequency domain spectra.

All generated frequencies due to mechanical defects are multiples of speed. As a guideline some frequency spans are recommended to perform the frequency analysis.

Guideline					Example		
Vibration of	Variable	Frequency Span	Resolution	averages			
Shaft	RPM	10*RPM		4	1800	18000	Cpm
Gearbox	GMF	3.25*GMF	1600 3200	4	600	1950	Hz
Rolling bearing	BPFI	10*BPFI	800	4	300	3000	Hz
Sleeve Bearing	RPM	10*RPM	800	4	3600	36000	Cpm
Pump	VPF	3*VPF	800	4	420	1260	Hz
Motor Rotor problems	2LF	3*2LF (line frequency-CD) RBPF (rotor bar pass frequency)	3200 1600	2 8	120	360 6000	Hz
Generator	2LF	3*2LF	3200	4	120	360	Hz
Fan	BPF	3*BPF	800 1600	4	240	720	Hz

Figure 30 Typical Useful Frequency Spans

Where:

- *RPM: Revolutions per minute*
- *GMF: Gear mesh frequency = Speed x Number of teeth*
- *BPFI: Ball pass frequency of Inner Race = Number of balls x Speed of inner race*
- *VPF: Vane pass frequency = Speed x Number of vanes*
- *BPF: Blade pass frequency = Speed x Number of blades*

All available data about equipment is useful when determining measurement parameters, vibration limits and vibration analysis such as:

- Size and type of bearings
- Number of vanes (pumps and fans)
- Number of teeth (gearboxes and gear drives)
- Weight of the rotor
- Operation conditions (temperature, streams, etc)
- Drawings, etc.

Unknown ledge of this information can affect negatively the analysis and diagnostic accuracy. It is highly recommended systematic collection and update of equipment data in each opportunity E.g. during major services or repairs of equipment.

As was told before amplitude gives us an idea of the relative severity and frequency tells what is wrong in the equipment, some common detectable failure modes are:

- Imbalance: a peak at shaft speed.
- Misalignment: typically 1x, 2x & 3x shaft speed
- Looseness : often at 1x or 2x shaft speed
- Bearing Damage: higher frequency peaks typically between 2 KHz and 5 KHz depending on shaft speed and transducer resonance.
- Electrical Problems: synchronous frequency and side bands.
- Gear Damage: gear mesh frequency depending on shaft speed and number of teeth and side bands.
- Oil Whirl: approximately half shaft speed.
- Blade Damage: number of blades by shaft speed.
- Cracked Shaft: typically 2x, 3x shaft speed.

7.4 Transducers

Transducer selection should be done considering the parameter of measuring. As displacement and acceleration are parameters related to frequency, but in an opposite behavior as is shown in the graph below; low frequencies generate low levels of displacement and high frequencies generate low levels of displacement so that we can get more accurate data using displacement transducer for low frequencies and acceleration transducers for high frequencies. Velocity is not frequency related so that is the most accurate measurement for frequencies between 10 Hz and 2000Hz.

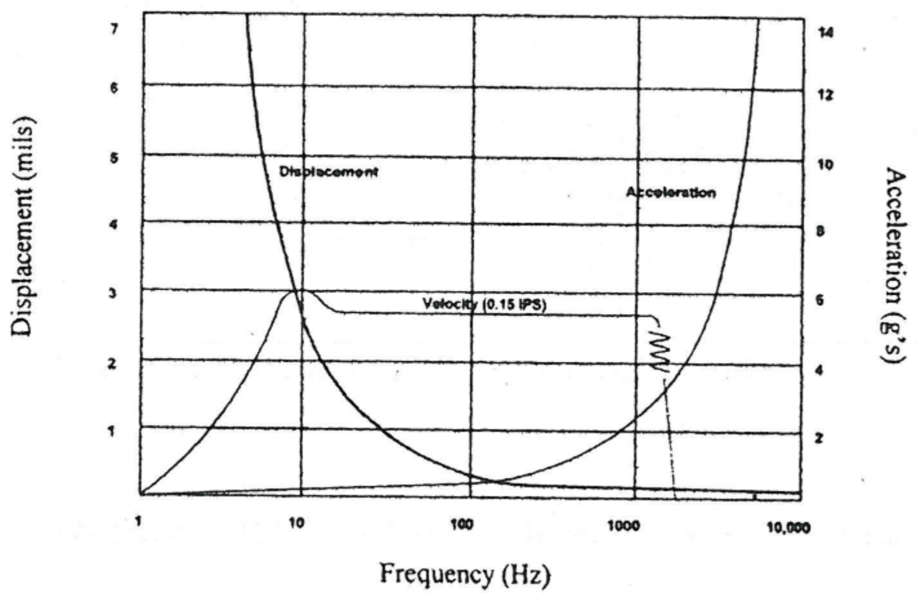


Figure 31 Frequency Response Curve

It is important to consider that often two types of transducers for accurate diagnosis are required

Transducer	Frequency range
Displacement: non-contacting contacting	10 – 1000 Hz 0 – 600 Hz 0 – 200 HZ
Velocity	10 – 2000 Hz
Acceleration	2000 – 20000 Hz

Figure 32 Transducers and accurate frequency range

7.5 Measuring Points

Vibration measurements should be done in the load zone. However, data must be taken in the horizontal, vertical and axial directions when baseline is being established and when some abnormality has been detected.

With the selection of the measuring points it is important to know how the machines are built and where signals can be measured. An overview is depicted in the following diagram.

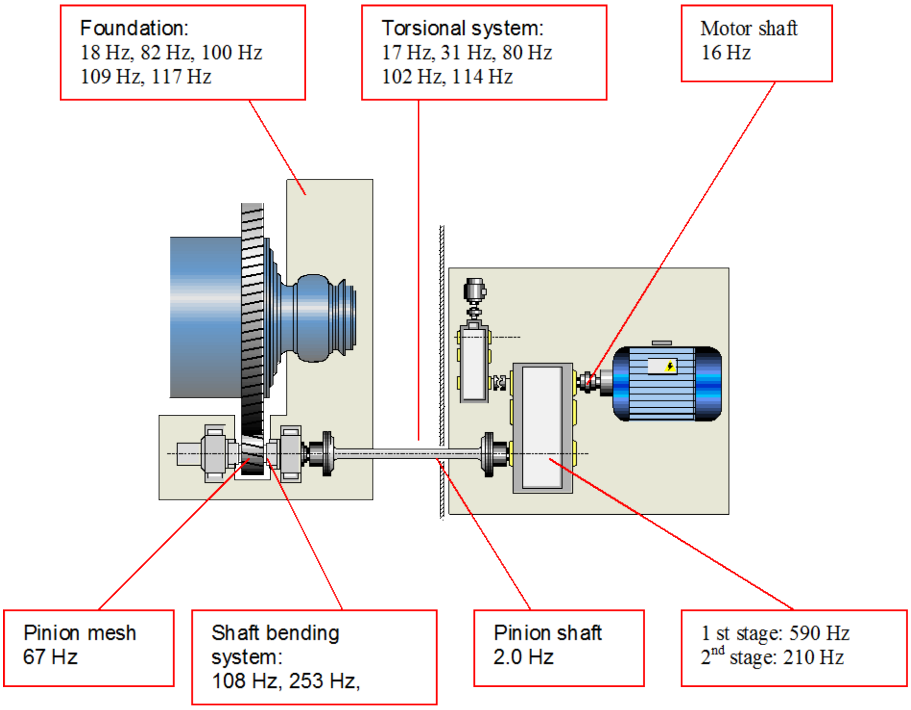


Figure 33 Measuring points selection.

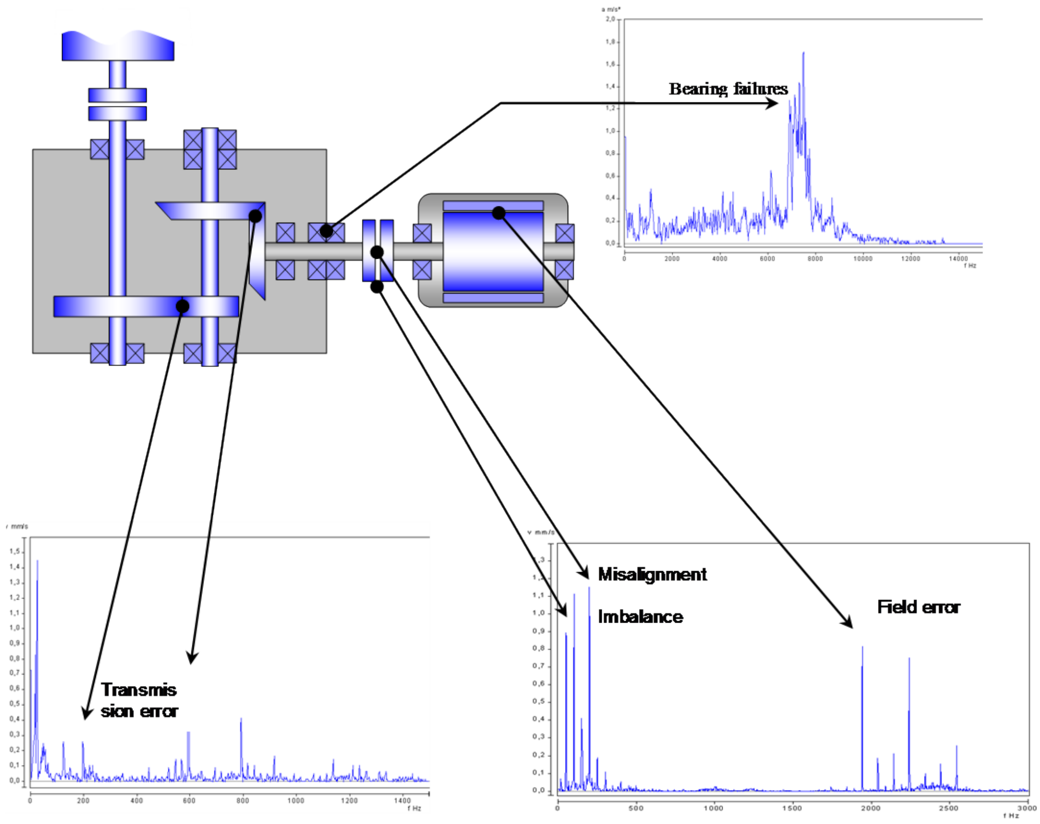


Figure 34 Sources of the oscillation and noise components

Following points are to be standardized for consistency purposes and ease of comparison within the LafargeHolcim Group. These points concern **routine** measurement only. In case of detected problems/anomalies, additional points will have to be measured as required.

Symbols:

- NDE : Non-Drive End
- DE : Drive End
- (X) : alternate measurement, in case of space restrictions for the horizontal measurement

For database codification, the points are numbered starting from the motor, NDE until the last driven element is reached (see below). Besides the number, a letter indicating the direction is added, e.g. 1H for Motor, NDE, horizontal direction.

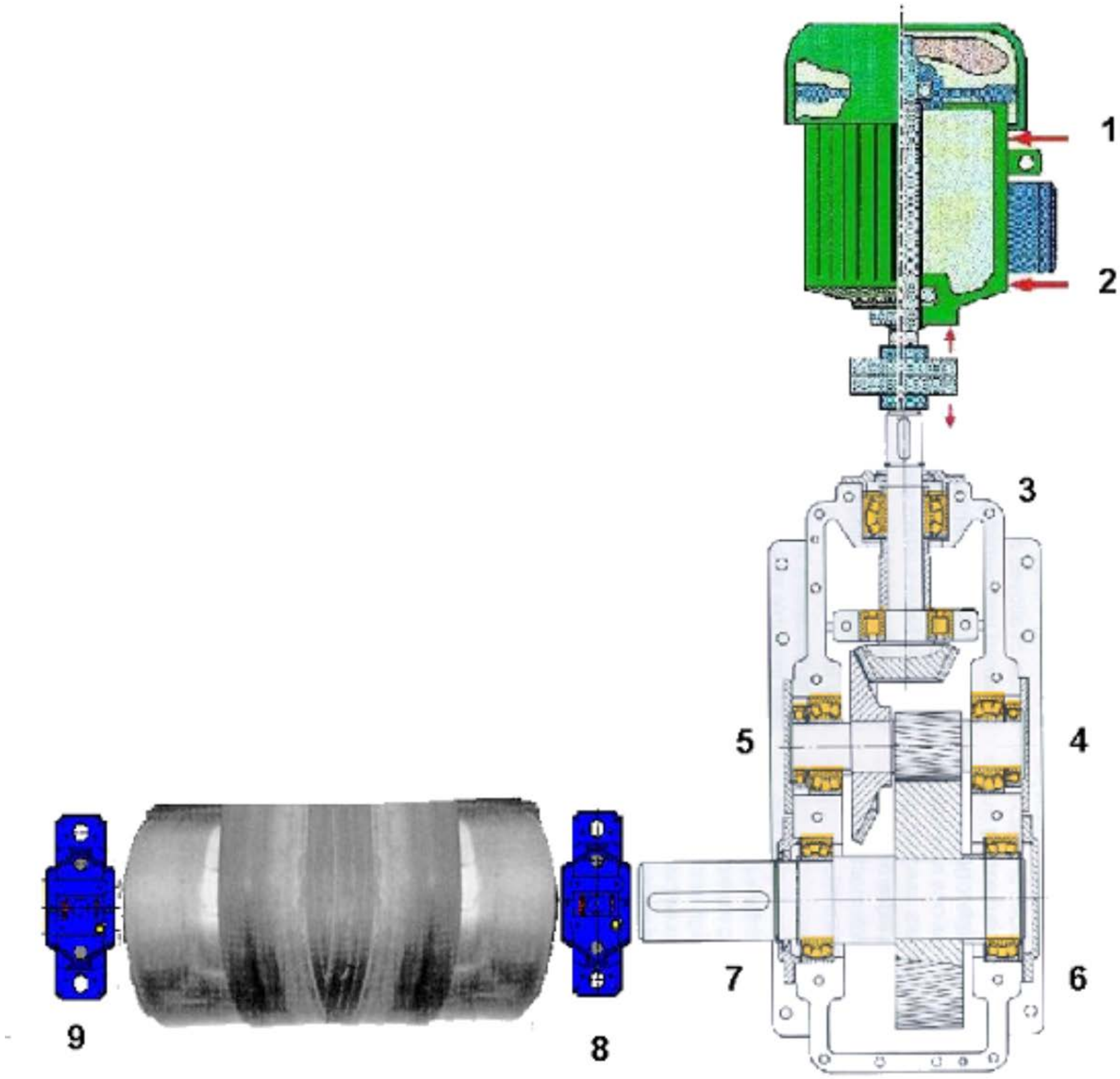
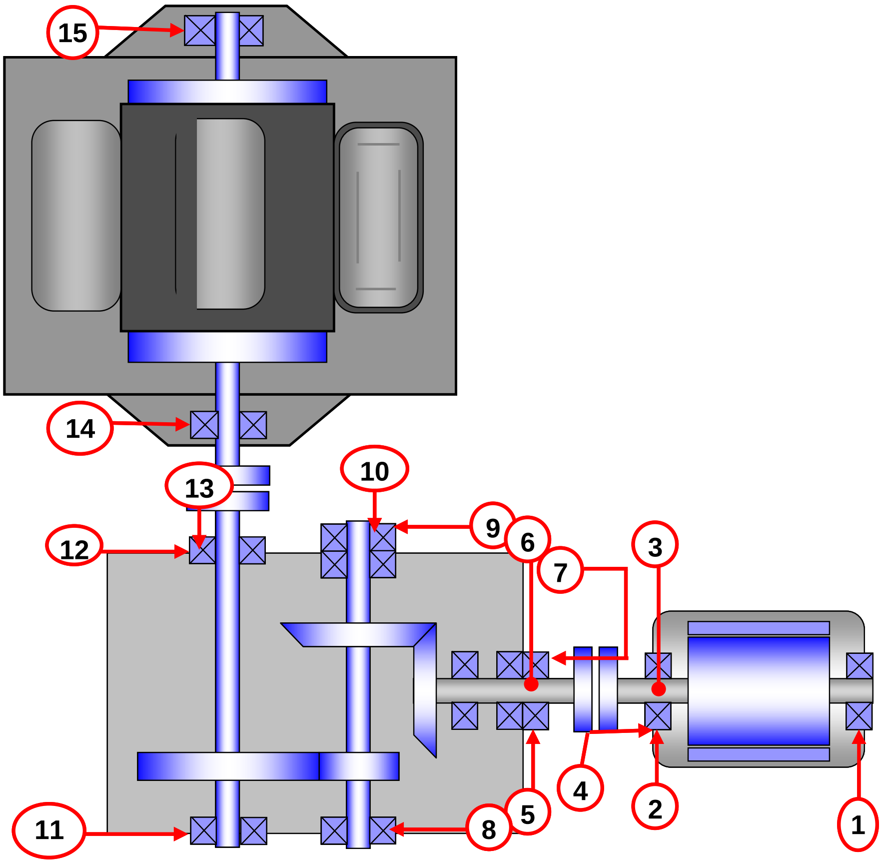


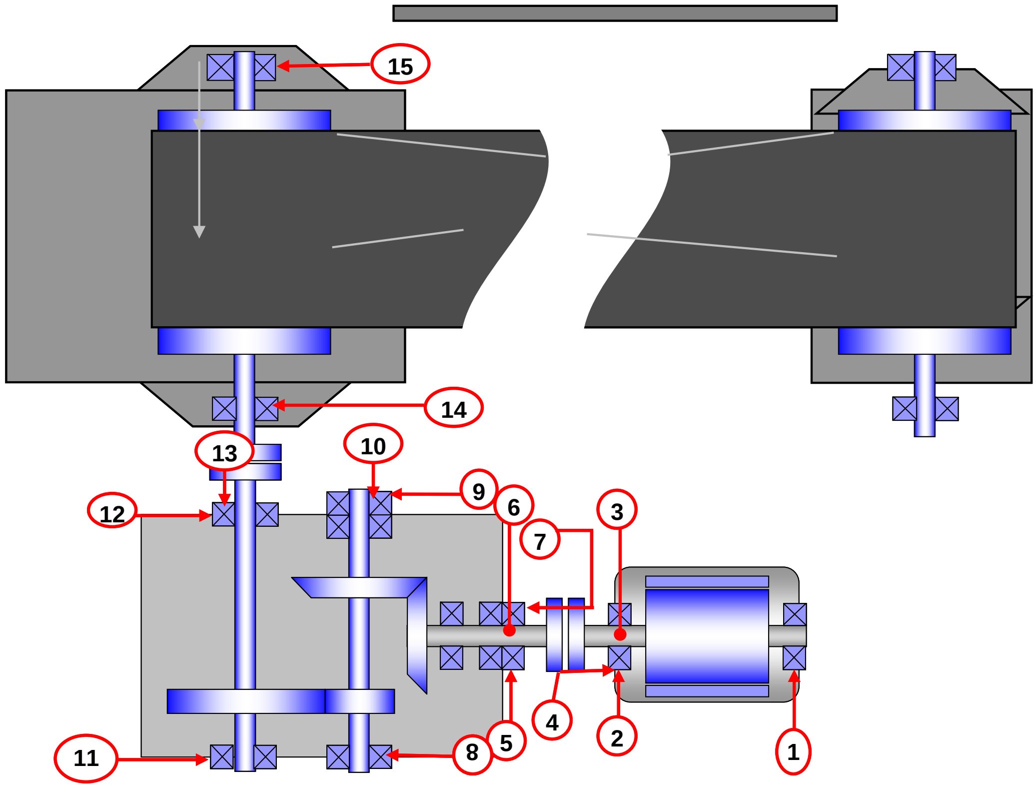
Figure 35 Numbering of points for vibration data collection

7.5.1 Measuring points of bucket elevator



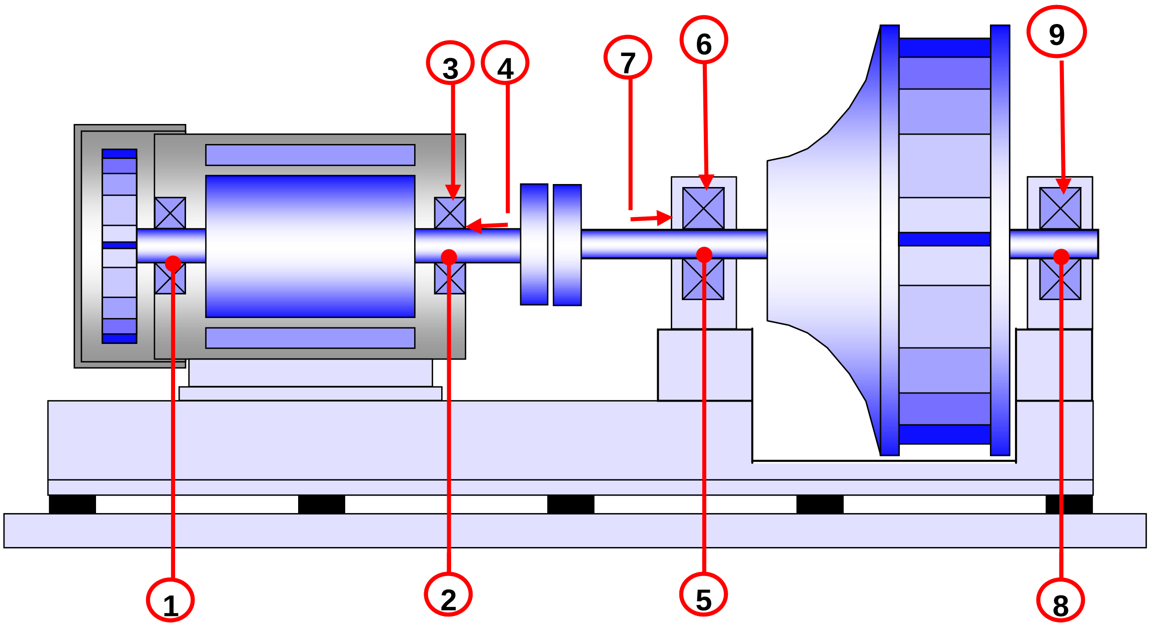
#	Location	Direction			Parameter	
		Horizontal	*Vertical*	*Axial*	*SPM (gSE)*	*Velocity (mm/s, RMS)*
1	Motor, NDE	X			X	X
2	Motor, DE	X			X	X
3	Motor, DE		X			X
4	Motor, DE			X		X
5	Reducer, inlet	X			X	X
6	Reducer, inlet		X			X
7	Reducer, inlet			X		X
8	Intermediate, NDE	X	(X)		X	X
9	Intermediate, DE	X	(X)		X	X
10	Intermediate, DE			X		X
11	Red, Outlet, NDE	X			X	X
12	Red, Outlet, DE	X			X	X
13	Red, Outlet, DE			X		X
14	Drive shaft, DE	X			X	X
15	Drive shaft, NDE	X			X	X

7.5.2 Measuring points of belt conveyor



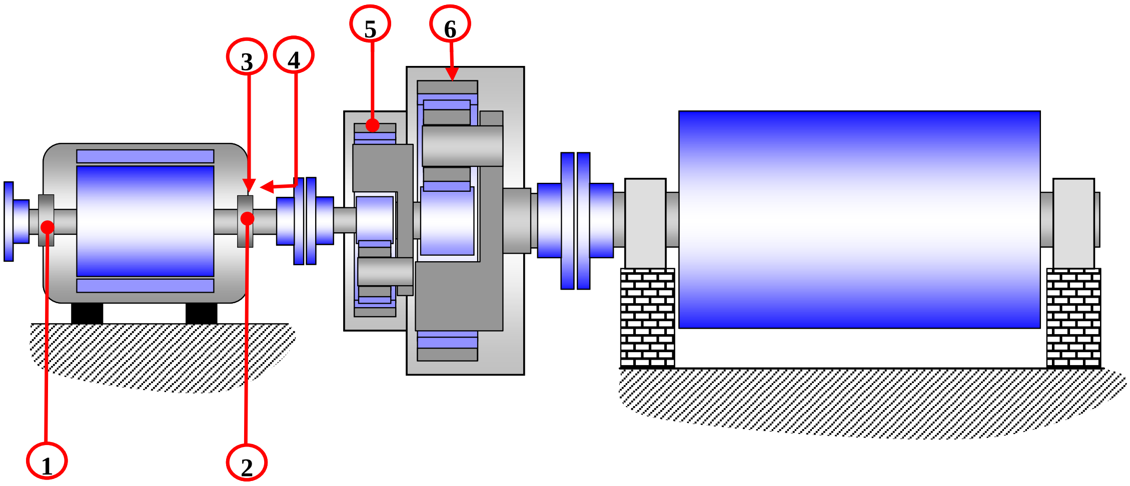
#	Location	Direction			Parameter	
		Horizontal	*Vertical*	*Axial*	*SPM (gSE)*	*Velocity (mm/s, RMS)*
1	Motor, NDE	X			X	X
2	Motor, DE	X			X	X
3	Motor, DE		X			X
4	Motor, DE			X		X
5	Reducer, inlet	X			X	X
6	Reducer, inlet		X			X
7	Reducer, inlet			X		X
8	Intermediate, NDE	X	(X)		X	X
9	Intermediate, DE	X	(X)		X	X
10	Intermediate, DE			X		X
11	Red, Outlet, NDE	X			X	X
12	Red, Outlet, DE	X			X	X
13	Red, Outlet, DE			X		X
14	Drive shaft, DE	X			X	X
15	Drive shaft, NDE	X			X	X

7.5.3 Measuring points of fans with supports on both sides.



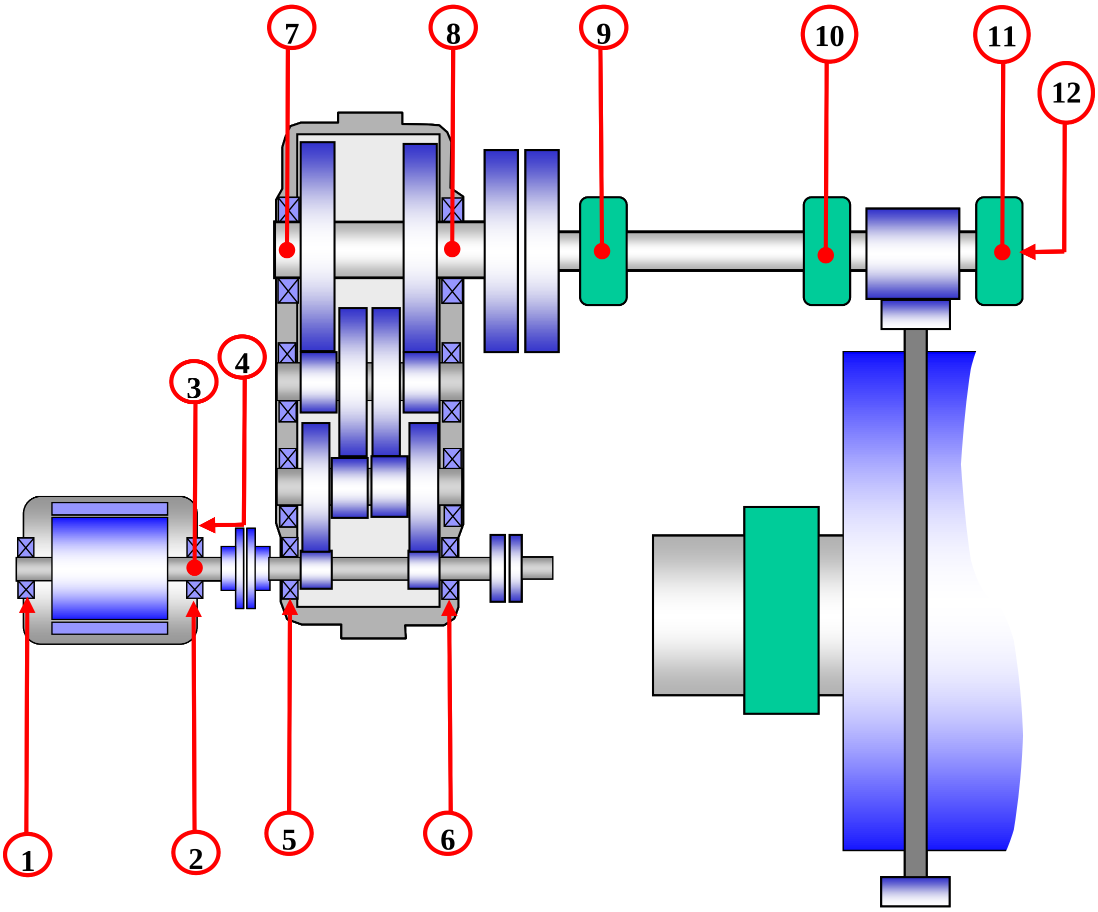
#	Location	Direction			Parameter	
		Horizontal	*Vertical*	*Axial*	*SPM (gSE)*	*Velocity (mm/s, RMS)*
1	Motor, NDE	X			X	X
2	Motor, DE	X			X	X
3	Motor, DE		X			X
4	Motor, DE			X		X
5	Fan, DE	X			X	X
6	Fan, DE		X			X
7	Fan, DE			X		X
8	Fan, DE	X			X	X
9	Fan, DE		X			X

7.5.4 *Measuring points of main drive (central drive) of ball mill.*



#	Location	Direction			Parameter	
		Horizontal	*Vertical*	*Axial*	*SPM (gSE)*	*Velocity (mm/s, RMS)*
1	Motor, NDE	X			X	X
2	Motor, DE	X			X	X
3	Motor, DE		X			X
4	Motor, DE			X		X
5	Reducer, 1st planetary stage	Radial (3 o'clock)				X
6	Reducer, 2nd planetary stage	Radial (12 o'clock)				X

7.5.5 *Measuring points of main drive of kilns and ball mill with girth gear drive.*



#	Location	Direction			Parameter	
		Horizontal	*Vertical*	*Axial*	*SPM (gSE)*	*Velocity (mm/s, RMS)*
1	Motor, NDE	X			X	X
2	Motor, DE	X			X	X
3	Motor, DE		X			X
4	Motor, DE			X		X
5	Reducer, inlet DE	X			X	X
5	Reducer, inlet DE		X			X
5	Reducer, inlet DE			X		X
5	Reducer, inlet NDE	X			X	X
6	1st Intermediate shaft, NDE	X	(X)		X	X
6	1st Intermediate shaft, DE	X	(X)		X	X
6	1st Intermediate shaft, DE			X		X
7	2nd Intermediate shaft, NDE	X	(X)		X	X
7	2nd Intermediate shaft, DE	X	(X)		X	X

7	2nd Intermediate shaft, DE			X		X
8	Reducer, Outlet, NDE	X			X	X
8	Reducer, Outlet, DE	X			X	X
9	Drive shaft	X			X	X
10	Pinion, DE	X			X	X
10	Pinion, DE		X			X
11	Pinion, NDE	X			X	X
12	Pinion, NDE		X			X
12	Pinion, NDE			X		X

7.6 Typical spectra of common problems

During frequency analysis, the main task is detecting the root cause of the high vibration; each cause has its own “signature”. Tables such as the ones provided by Technical Associates of Charlotte, PC, show some of the most common problems, their typical spectrum, phase relationship and some remarks.

These table references are very useful but in for accurate evaluation of machinery condition always have in mind the following questions:

- Are the frequencies in the spectrum related to machine operating speed?
- What is the value of the amplitude? Is the amplitude value acceptable?
- Is there any change since the last measurement?
- Which is the relation / comparison between the peaks?
- Which is exactly the source of the generated frequency?

Some frequencies spectra can be produced from various time domain signals and some frequencies can be caused by more than one cause, for those reasons vibration analysis is a very complex technique but at the same time provide a huge potential to determine the condition of the machine and anticipate failures.

See link: http://www.technicalassociates.net/index.html

8. Thermography

Thermographic analysis provides a high-resolution, non-contact means of monitoring the condition of electrical and electromechanical equipment, roofing and wall insulation and kiln refractories. Infrared scanners, similar in appearance to video cameras, detect differences in surface temperatures and highlight those differences in B/W or color images that are displayed on a screen. These images, called thermograms, are downloaded to a computer software and are used to analyze patterns of heat gain or loss.

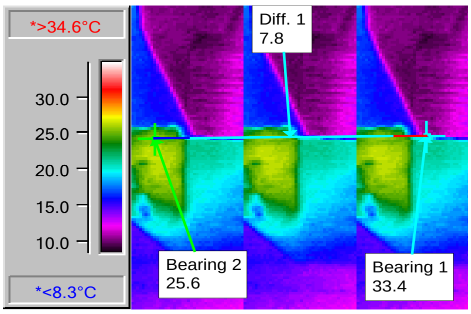


Figure 36 Thermogram of bearing housings, showing a difference in temperature of 7.8 °C

Thermographic analysis is an effective predictive maintenance tool because mechanical or electrical breakdowns are often preceded or accompanied by changes in operating temperatures. This information can be particularly important in electrical machinery where circuits and connections may show no visible signs of deterioration until moments before a complete failure. Thermographic analysis can also detect cracks or deterioration in roof or wall insulation and kiln refractories, which can increase heat loss or reduce the efficiency of production processes. Infrared scanning is non-destructive and it can be performed at a distance for machinery that is difficult or awkward to reach. Since surveys are best done while the equipment is in operation, there is no need for machine downtime and lost production. In addition, to helping avoid costly or even catastrophic equipment failures, thermographic analysis can be used to help prioritize repairs prior to planned maintenance, to evaluate completed repair work and to check new installations prior to start-up.

8.1 Recommended inspection frequencies

Spot checking (monitoring a measurement point once each year or less) is used primarily when maintenance or operations personnel suspect that a problem exists or prior to planned maintenance to identify developing problems and prioritize the work.

One advantage of thermographic analysis of electrical equipment is that the scan provides an immediate and quantifiable indication of the temperature difference between a properly functioning circuit or connection and one that is overheating. This means that the technician can often determine the seriousness of the electrical problem without having a review historical patterns or past analysis. This quantitative analysis can also be helpful in determining how long the equipment can continue to operate before there is a catastrophic failure.

Information can be obtained by performing thermographic analysis on a periodic basis, for example once a year or after each major overhaul or plant turn-around. Periodic thermographic analysis can provide a more subtle indication of electrical deterioration, bearing or coupling wear, roof deterioration or leakage and refractory cracking. This can allow personnel to project acceptable performance for the coming six months or one year. Advance notice of developing problems means that they can be resolved or repaired during normal shutdowns, rather than allowing a catastrophic failure to occur. Since problems are detected when they are relatively minor, they are usually much less expensive to repair. Long-term thermographic analysis over a period of several years can be used to identify improper maintenance or repair practices. These can include improper roof installation or repair; improper bearing or coupling installation or lubrication; poor quality electrical installation or repair and improper refractory installation or repair. This information can be particularly useful in reducing or eliminating recurring problems and improving personnel safety. Long term trends can also be used to identify improper operating conditions, such as operating equipment beyond design specifications (i.e. at higher temperatures, speeds or loads). The trends can be used to compare similar equipment from different manufacturers to determine if there are design benefits or flaws that can result in increasing service life, improved operation or reduced maintenance costs.

The following table summarizes the recommended inspection frequencies:

Equipment to be scanned	Recommended frequency
High Voltage system in Main Substation Transmission Line Connection Porcelain Insulators, Surge Arresters Transformer connections (if accessible) Transformer insulators, cooling systems	Every 6 months
Medium and Low Voltage System Bus Bars, Switchgear connection MCC Contactor and Breaker Local MCC, Motor Terminals (Critical 'A' motors above 250 kW)	Every 6 months, except motors (every 3 months)
Rotating equipment (e.g. gearboxes, bearings) and other mechanical components (e.g. hydraulic cylinders)	Every 3 months
Refractory on static structures (e.g. cyclones, calciner, clinker cooler, kiln hood)	Every 6 months

8.2 Alarm limits

The following table summarizes the recommended alarm limits for thermal inspection.

Temperature measured (both conditions must be true)			**Indication**
Above similar object	And	Above Ambient	
1 °C - 3 °C		1 °C - 10 °C	Possible Deficiency
4 °C - 15 °C		11 °C - 20 °C	Probable Deficiency
> 15 °C		21 °C - 40 °C	Deficiency
		> 40 °C	Major Deficiency

N.E.T.A

Figure 37 Alarm limits for thermography. Source: N.E.T.A.

8.3 Advantages/limitations

Thermographic analysis has found particular application in scanning large, distant or hazardous surfaces for temperature variations. This includes roofs and walls, kiln or pre-heater/calciner refractory linings, overhead power lines or cables, high voltage transformers or electrical connections.

There has been limited application in mechanical troubleshooting (for example, identifying hot bearings or couplings). It is strongly recommended that the same person(s) doing Thermography are inspecting the different types of applications (electrical, mechanical, process related) and sharing their findings and knowledge (avoiding silo mentality).

Infrared scanners can only measure the temperature of visible, radiating surfaces (i.e. they cannot take readings through glass or metal housings or covers unless the metal covering is thin enough for secondary heat patterns to appear). Readings are also affected by the reflective nature of the surface being measured and this reflectivity value must be taken into account when scanning different objects or surface materials.

Nowadays there are infrared windows that allow thermography inside enclosed cabinets. This eliminates as well the safety risk of opening these cabinets while energized.

8.4 Associated costs

Because of the significant drop in prices of thermal imagers in the last few years, many plants are considering acquiring their own equipment instead of hiring third parties to do the job. Due to its low price and increased capability, owning a thermal camera has a clear advantage over hiring a third party to do the service.

Current price is about USD 5'000 for a low resolution device, about USD10'000 – 15'000 for a suitable model and up to USD 30'000 for the top-end models

For normal application in cement plant maintenance, modest equipment costing about USD 10'000 is sufficient.

Scanner operation is relatively easy; however, interpretation of the scanned images requires a moderate amount of training/experience. Training and certification can be obtained from either the scanner manufacturer or one of several independent certification companies. For companies with limited budgets, there are service companies that will perform thermographic analysis on a contract basis.

Note: the whole topic of thermography is covered in detail on the LafargeHolcim Electrical Maintenance Manual

9. Non destructive tests (NDT)

The section dealing with NDT is divided in two parts. First of all, the recommended techniques and frequency of application on a cement plant will be presented. Out of this table, the personnel already familiar with the NDT tests can easily find the suggested technique according to the component.

On the other hand, the bulk of this section explains the main principles and application tips of each technique. This is meant for those who are not that familiar with each technique and provides a sound basis. By no means is the intention of this manual to replace a proper certification process for each technique, depending on the knowledge degree required.

In general terms, the techniques recommended for a cement plant to apply with own personnel are:

- Visual Test (VT)
- Dye Penetrant Test (PT)
- Magnetic Particle Test (MT)
- Ultrasonic thickness measurement

The following techniques should be outsourced to specialized companies:

- Ultrasonic Test (UT)
- Eddy Current Testing

In all cases, a certification of Level II or equivalent is required for the inspector to perform the inspections on a competent and professional way.

9.1 Recommended tests and frequencies for cement plants

Component / NDT Methods	VT extensive	PT	MT	UT	UT thickness
Kiln tire incl. fixation	**once/year**	once/2 years More if VT or known defects ↔	**once/2 years More if VT or known defects**	**once/2 years More if VT or known defects**	
Kiln roller	**once/year**	once/year ↔	**once/year**		
Kiln roller shaft	**once/year**			**once/year**	
Kiln shell (incl. planetary cooler outlets and supports)	**once/year**	Main Welds Manholes once/2 years ↔	**Main Welds Manholes once/2 years**	**once/2 years More if VT or known defects**	**once/2 years More if corrosion is issue (AFR)**
Cyclones					**once/2 years More if corrosion is issue (AFR)**
Ball mill trunion and head	**once/year**	**Internally when changing liners**	**once/year**	**once/2 years More if VT or known defects**	
Ball mill shell	**once/year**	Main Welds Manholes once/year ↔	**Main Welds Manholes once/year**		**once/2 years** Only where shell liners have fallen out
Ball mill wall/diaphragm	**Upon liner change**				
Girth Gear	**once/year**	**once/year** ↔	once/year		
Pinion	**once/year**	**once/year** ↔	once/year	**Shaft once/year**	
VRM table	**Upon liner change**	Upon liner change ↔	**Upon liner change**		
VRM table wear segments	**twice/year**		**once/year**		
VRM pull rod and piston rod	**twice/year**	once/year ↔	**once/year**	**once/year**	
VRM frames, fork, rocker arm, yoke, roller carrier, etc...	**twice/year**	once/year critical areas ↔	**once/year critical areas**		
VRM roller	**Upon liner change**	**Upon liner change**		**Shaft when accessible**	
VRM roller wear segments	**twice/year**		**once/year**		
Roller press shaft	**once/year**			**once/year**	
ID fan / Raw mill Fan	**once/year**	Welds once/year	**Welds once/year**	**Shaft once/year**	**Rotor Blades once/year**
Bucket Elevator Shaft	**once/year**			**Shaft once/year**	
Ducts				**Shaft once/year**	**once/2 years More if corrosion is issue (AFR)**

↔ **Means 'either PT or MT', whereby MT is always the preferred choice**

Figure 38 Recommended NDT tests with suggested frequencies.

The frequencies will vary according to the service life of the equipment (e.g. kiln tires with less than 20 years will require a test less often) and must be adjusted accordingly!

9.2 Introduction to the NDT techniques

The nondestructive testing are those test procedures that are carry out without damage of the piece. They also don't belong to the mechanical testing methods (tensile test, notches bar impact test, etc.). The main purpose of the NDT is to proof, that there are no defects, which could reduce the use or the applicability of a part.

Other purposes of the NDT are:

- monitoring of specific material properties (grain size, chemical composition, hardness)
- determination of the material structure

9.2.1 Type of defects

The defects which occur in components can be divided in three main groups:

- fabrication's defects (manufacturing technology, product shape)
- machining defects (process technology)
- operations-related defects (operational stress)

9.2.2 Testing methods

By the establishment of the test procedure, of the test method as well as of the amount of inspection (100%, random sample test) and of the inspection interval there are several points to be taken into account:

- legal regulations (standards, codes, rules)
- economy, profitability
- machining reliability, damage frequency
- occurring defects
- strain, wear
- importance of the part (risk degree, consequential damages)
- product responsibility

The NDT methods that are resumed in the next page are described in the following sections

9.3 Visual Testing (VT)

Visual testing are sight controls of the surfaces of parts or components, which are accomplished without or with the help of optical devices. By the visual testing essential findings should be held, which are not recorded by other nondestructive methods.

The visual inspection has to be carried out before all other NDT -tests. The VT allows the detection of defects, which can't be found with other NDT -methods or with complicate measuring methods.

Goals of the examination are:

- comparison of nominal and effective values with the aid of specified requirements
- determination of fabrication's and machining defects
- evaluation during revisions of the general situation of a part

9.3.1 Equipment and auxiliary devices

For the visual testing the following equipment's and auxiliary devices can be used:

- standards, rules, specifications
- reference pictures or samples for comparison
- catalogue of defects
- drawings
- lamps, magnifying glasses, endoscopes, TV-systems
- gauges, measuring tapes, depth gauges, protractors, limit gauges, profile gauges and profile projections,...
- check lists
- sampling schedules
- examination's programs

9.3.2 Execution of the examination

The execution of the examination, specially the working technique, is strongly dependent of the actual examination's purpose, however some basic aspects applies, which have to be taken into account.

- Sufficient illumination of the surfaces to be examined
- Systematic procedure (step by step)
- For mass products, examinations have to be considered together with the qualitative equipment of the work places also enough rest times, because a concentrated examination's work over a long time is not possible.
- For the examination of castings, forgings or welds and for revisions, the product specific knowledge (fabrication's technology, operation's conditions) is essential.
- For the examination of complex objects, specially also for revisions, check lists with the parts to be examined are essential to assure a systematic procedure.
- Verification of uncertain results (for example crack suspicion) with complementary NDT -methods.
- Availability of special equipments (endoscopes, camera, ...).
- Handling's possibilities (crane, turning gear) have to be available.
- Record of the examination

Content of the record:

- object's identification
- examination's conditions (production or in service inspection)
- amount/scope of inspection
- used equipment and devices
- valid instructions, standards, guidelines
- result (sketch, photos, replica, comparison between nominal and actual values) acceptance standards and decision
- inspection's locality , date, operator

9.3.3 Limits of the method

The limits of the method are given by:

- the visual acuity of the man eye
- the power of resolution of the optical instruments
- the possibilities of magnification of pictures and photos.

9.3.4 Range of application of the visual testing

The visual testing has an exceptionally broad range of application which goes wide over the classical area of the NDT.

- Identification and sorting testing: marks, punches, optical pattern
- dimension control: lengths, diameter or circumference, radius, missing or additional steps and grooves
- shape control
- verification of completeness: missing parts
- test of coarse fabrication's or machining defects: mechanical damages, cracks, scales, missing connections (brazing points)
- general surface controls: damages of paint layers or of protective films
- roughness comparison plates (RUGO, CTIF): Ra, Rz, Rmax

9.4 Dye penetrant testing (PT)

9.4.1 Description of the technique

Basically the penetrant testing is an easy testing method. A strong colored liquid (penetrant) with a very high creeping capability is applied (sprayed, brushed, by immersion ...) on the surface to be inspected. After a certain time this liquid has filled also the thinnest cracks. Afterwards the excessive penetrant is removed by cleaning the surface again. A second substance (developer), which has a different color than the penetrant and exercises a strong attraction on the penetrant, draws the penetrated colored liquid from the open defects to the surface. The penetrant spread out in the developer layer and due to the strong color contrast the defects appear as lines or spots which can be seen with the naked eye.

The range of application of the penetrant testing is very various. Because this inspection can be done without large installations (indeed by some methods the water protection regulations have to be respected) and therefore the applications are not related to a fix work place, it will be employed very often and in different cases. Especially by very large parts and in the field it is often the only possibility to reach good results without too much works and expenses. Furthermore the penetrant testing is widely independent of the material. Only by porous materials (wood, porous ceramic materials, some sintered materials ...) this method fails.

Many variants allow the penetrant testing to match the purposes of the examinations. Different types of penetrants, together with the corresponding developers and cleaning agents, fit the inspection to the requirements and to the practical conditions. Visible (colored) and fluorescent penetrants are both available as solvent-removable, water-washable and post-emulsifiable.

For examination of warm parts there are special products.

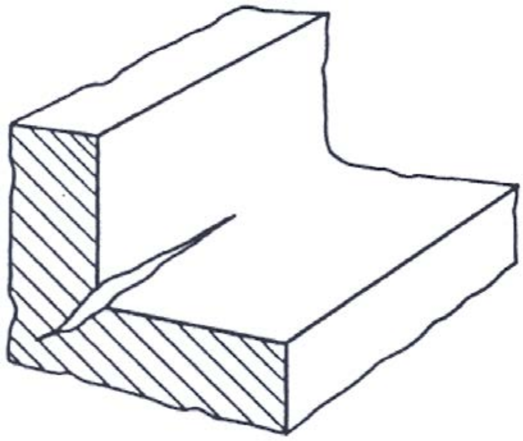
As requirements to the examination the following important points have to be taken into account: the surface to be examined must be very clean, have a roughness equal or better than R 10 and must specially be free of rolling skins, forge scales, free flying rust, paint or residual of paint and galvanic overlaying. In parts that have been grit previously, it is possible that the defects at the surface have been closed and the examination becomes ineffective. Similarly in parts that have been for long time in oil, there is the risk that the defects are filled with oil and that the penetrant cannot enter. Also other substances and especially deposits in pipes can have a similar effect.

The penetrant testing has a very high **sensitivity** for the detection of surface defects. Very fine separations can be made visible. Of course it is in all cases necessary, that the defects are open to the surface. Cracks that are filled with oxidation's products or discontinuities that are closed by grit blasting are not detectable with penetrant testing.

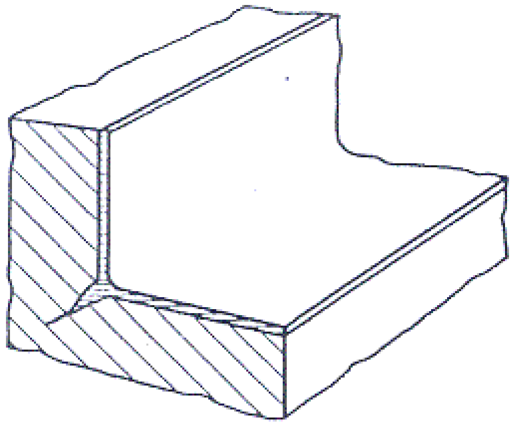
The **time schedule** of the nondestructive examinations has to plan the penetrant testing. It is clear that a penetrant testing has always to be done before an ultrasonic examination, because of the risk, that the ultrasonic couplant could fill the defects. Also a pressure test can produce the same effect.

It can be summarized that the penetrant testing as well as the magnetic particle testing have advantages and disadvantages and that these two methods don't exclude each other. In extreme Cases they are Complementary examinations. Under standard Conditions these two methods will however not be applied together to the same part. By the penetrant testing it is very important, that the operator follows strictly the instructions for the use or the products, which are usually delivered by purchasing or can be required from the manufacturer.

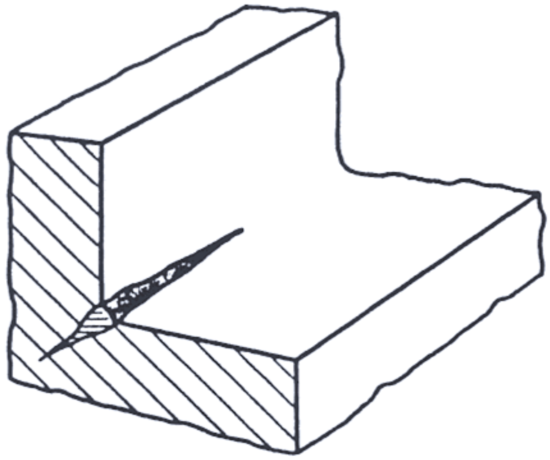
9.4.2 Examination sequence (Water washable system)



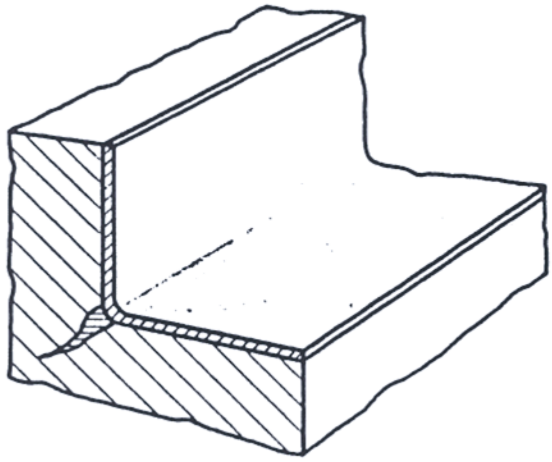
Step 1 cleaning with subsequent drying



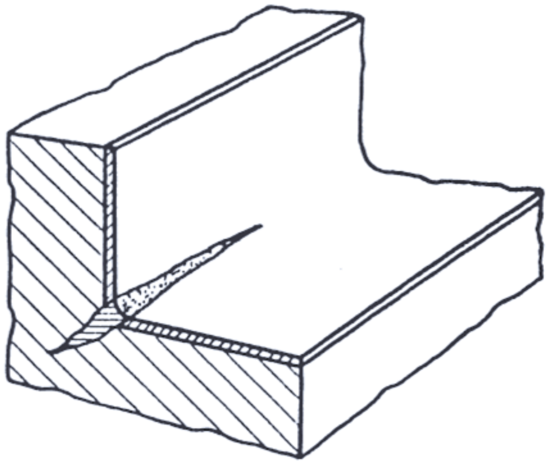
Step 2 applying the penetrant dye



Step 3 cleaning with water spray



Step 4 application of the developer (after drying)



Step 5 evaluation

Defects can be divided according to the causes of their formation in the following three main groups:

9.4.3 Fabrication defects

- casting defects
- forging defects
- defects in semi-finished products (bars, billets, profiles)
- plate defects
- weld defects

9.4.4 Processing defects

- scratches, score marks
- heat-treat cracks
- hardening cracks
- grinding cracks

9.4.5 Service defects

- fatigue cracks
- stress corrosion cracks
- thermal shock cracks
- fatigue fractures or breaks

9.4.6 Evaluation

Because it is difficult to establish the type of a defect only with nondestructive testing methods, the evaluation of defects by the penetrant testing is limited to an evaluation of the indications. Characteristics of the indications to be evaluated are basically:

- location and orientation
- pattern (rectilinear, crack-Iike)
- shape (linear, rounded)
- length
- arrangement (random, in lines, in rows, in groups)
- number of indications pro surface unit

9.4.7 Range of application of the penetrant testing

The range of application of the penetrant testing is large. This method is the only possible surface examination by not ferromagnetic materials as well by parts with very complicate surface shapes. The only restriction is that the possible defects must be open to the surface.

9.4.8 Summary of the ranges of application

- welds
- claddings
- castings
- forgings
- bonding between bearing metal and basic material

9.5 Magnetic particle testing (MT)

9.5.1 Description of the technique

The magnetic particle testing is used for the detection of surface defects.

All ferromagnetic materials (and only then) can be examined with magnetic particle testing. The part is magnetized or put in a strong magnetic field and at the same time magnetic particles are applied, either as dry powder or mixed with a liquid vehicle. If there are defects at the surface of the part, then the lines of the magnetic flux at these places are disturbed and secondary poles are created, where magnetic particles adhere making the defects visible to the naked eye.

The **direction of magnetization** in the part plays a very important role in the detection of the defects. The mentioned formation of poles at discontinuities (defects) at the surface appears only if the discontinuities are perpendicular or at maximal 45° to the direction of the magnetic field. Discontinuities parallel to the magnetic field are no obstacle to the flux lines: for this reason no disrupted lines and no secondary poles occur and these surface defects can't be detected. Consequently for the detection of all defects a part must be always magnetized in two magnetizing directions which are 90° turned to each other. If defects are present, they will appear either by one or by the other magnetizing direction.

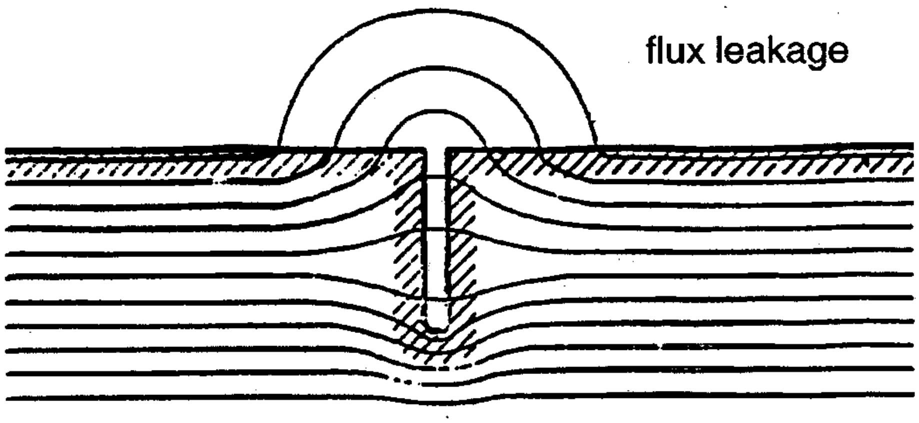


Figure 39 Defect at the surface perpendicular to the flux lines

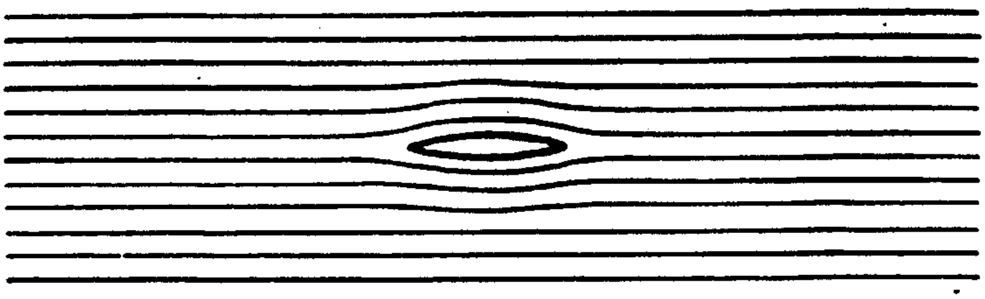


Figure 40 Defect in the direction of the flux lines ➔ No Detection

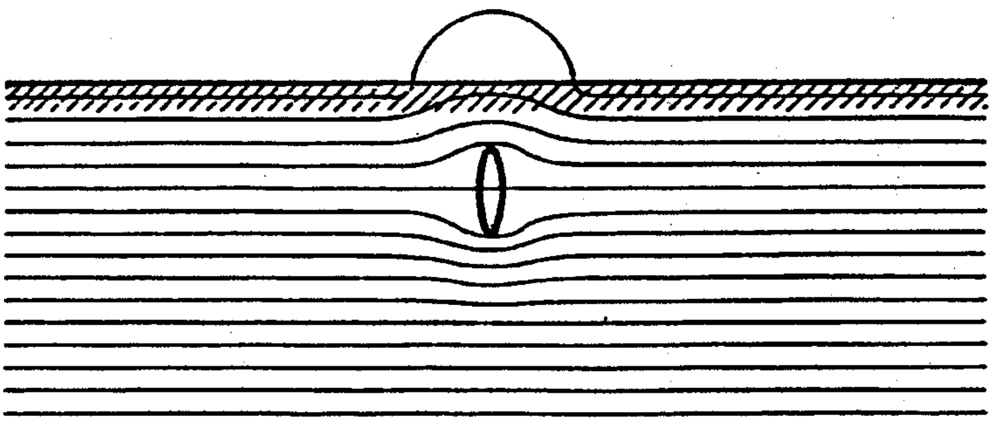


Figure 41 Defect under the surface perpendicular to the flux lines

The field intensity is decisive for the defect detection. If it is not high enough, then only a very week or no indication at all will be visible even by existing defects and right magnetizing direction. Because the required field intensity can't be easily estimated or calculated, it is necessary to check the sensitivity of each specific examination with a special field indicator (Berthold cross, ASME pie gauge). If the required indication appears on the indicator, then the field intensity and the magnetizing direction in the parts are right and strong enough.

9.5.2 *Portable and stationary equipment*

The **magnetic field** can be produced in different ways. By thin flat parts already a horseshoe permanent magnet can give useful results. If a strong magnetic field is required, then a magnetic yoke is in a lot of cases the appropriate equipment.

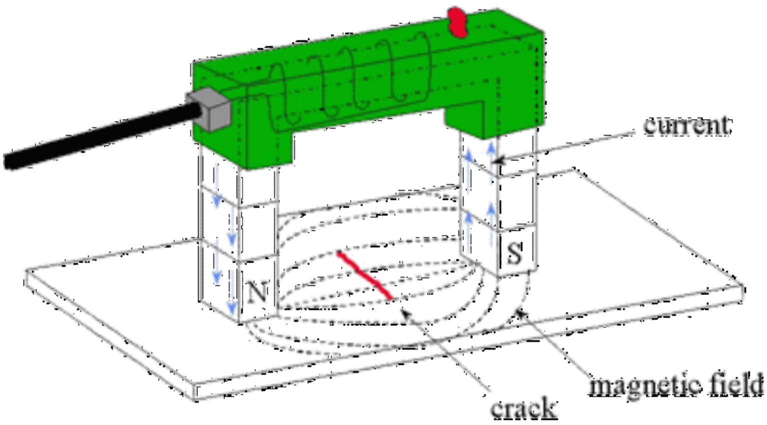


Figure 42 Magnetic yoke

For large castings a very high current (many hundreds till some thousand amperes) is usually sent through contact electrodes (prods) into the part, where it produces a magnetic field between these electrodes.

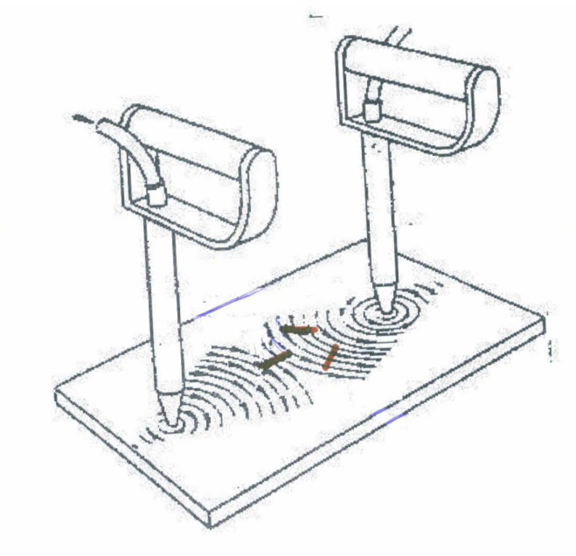
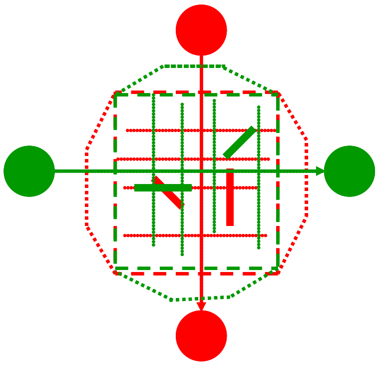


Figure 43 Magnetic contact electrodes

With these methods the requirement of two 90° apart magnetic directions can easily be reached: the poles of the yoke respectively the electrodes are simple turned by 90° and put again on the same place of the part.

Electrode Magnetization: Yoke Magnetization:



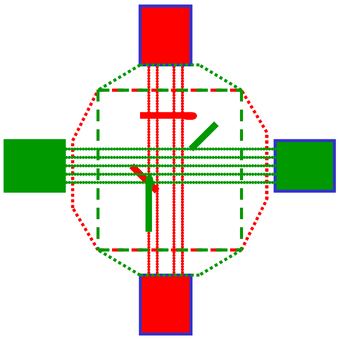


Figure 44 Magnetization patterns

Long parts like shafts are fixed at their ends between two contact heads. Then a high current is sent through the longitudinal axes. This produces a circular magnetization with flux lines in circumferential direction which can detect longitudinal defects in the parts.

For the detection of transverse defects it is necessary a magnetic field in the longitudinal direction of the part. This is reached when a coil is shifted along the part or especially by large objects when a cable is wrapped around the part.

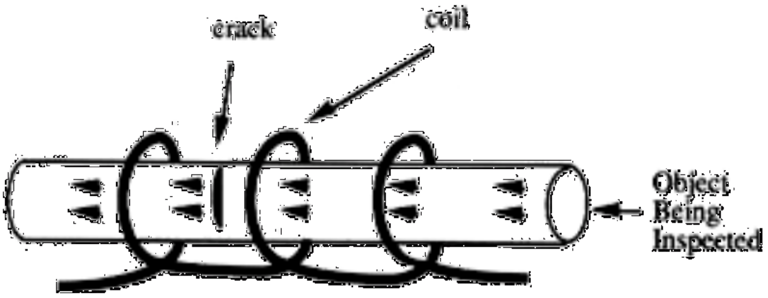


Figure 45 Magnetization with a coil

Complicated parts need often the combination of many different types of magnetization.

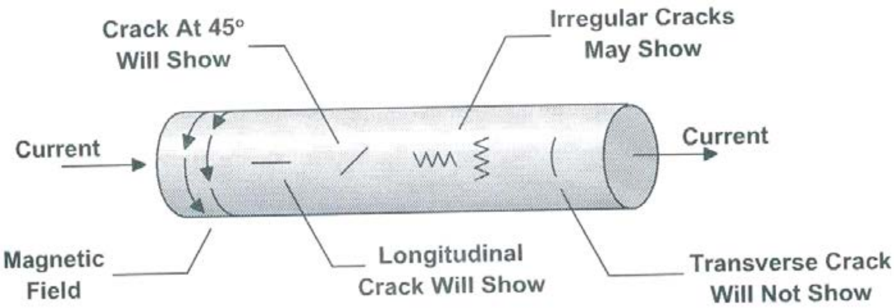


Figure 46 Different orientation of cracks

The demagnetization of the parts at the end of the examination is important with regard to a following machining, as well to the late use in operation.

The testing medium (magnetic particles) is different depending on the purpose of the examination and on the equipment. Other small differences exist in relation to the sensitivity to the indications.

Fluorescent particles, which produce clear brilliant indications to be easily detected under ultraviolet light, are often used.

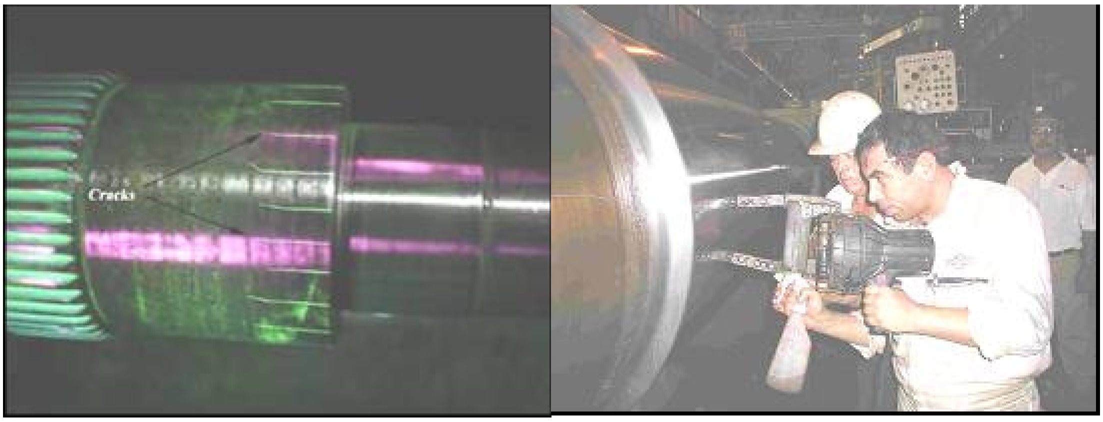


Figure 47 Black particles are used on bright surfaces, colored particles on dark surfaces.

Usually the magnetic particles are suspended in liquids; this enables good flow of particles on the test surface.

Dry magnetic particles, which can be poured or blown over the surface manually (without blast engine), are mainly used on hot castings or forgings in early stage of manufacturing.

Figure 48 Upper left: wet magnetic particles. Lower left: hand-pump for dry magnetic particles. Right: cracks detected on welding seam

Coated surfaces are usually no impediment to the magnetic particle testing. Chromium-plating or cadmium-plating are no restriction to the measurements. By paint layers it is difficult to reach an electrical contact e.g. with contact electrodes.

The detection of defects with the magnetic particle testing is limited directly to the surface defects (till about 0.5 mm depth). It is however not necessary that the defects are open to the surface. In the same way there are no special requirements to the cleanness of the surface to be expected. DC. Up to 2 mm Documentation of indications: transparent tape transfer, blotting-paper, photography

9.5.3 *Range of application of the magnetic particle testing*

The range of application of the magnetic particle testing is limited to the examination of ferromagnetic materials. This method is used principally by the final examination of finished parts.

Applications:

- welds
- ends of plates
- castings
- forgings
- finished parts (grinding cracks)
- in-service inspections

9.6 Ultrasonic testing (UT)

The localization and assessment of reflectors in the volume of a work piece by ultrasonic testing can be compared with the echo range measurement of water depth in the navigation. Today, mainly the pulse-echo technique is applied. A short ultrasonic pulse is sent into the work piece and the returning echo is measured. After a while, the next pulse is released. Receiving a reflection from inside of the material one can deduce that this echo indication is caused by a defect. Experience showed that based on the characteristics of an indication it is possible to make certain statements about the defect. A defect assessment mainly leans on the following information: Exact localization of the position of the defect based on the measured sound path and the known angle of refraction of the transducer; amplitude of the indication compared with a reference reflector as an estimate of the size of the defect; determination of the direction from which the maximum indication is attained and which allows a conclusion on the orientation of the defect (possibly even on the kind of defect); measurement of the echo dynamic giving same ideas about the length and width of a defect. The ultrasonic testing can mainly be divided in two techniques, the straight beam inspection and the angle beam inspection.

9.6.1 *Straight beam inspection*

The straight beam inspection uses as direction of sound the direction normal to the contact surface of the transducer on the work piece. This inspection direction allows the detection of defects lying parallel to the contact surface (e.g. laminations and segregations in sheet metals and so on).

The straight beam inspection works mainly with longitudinal waves.

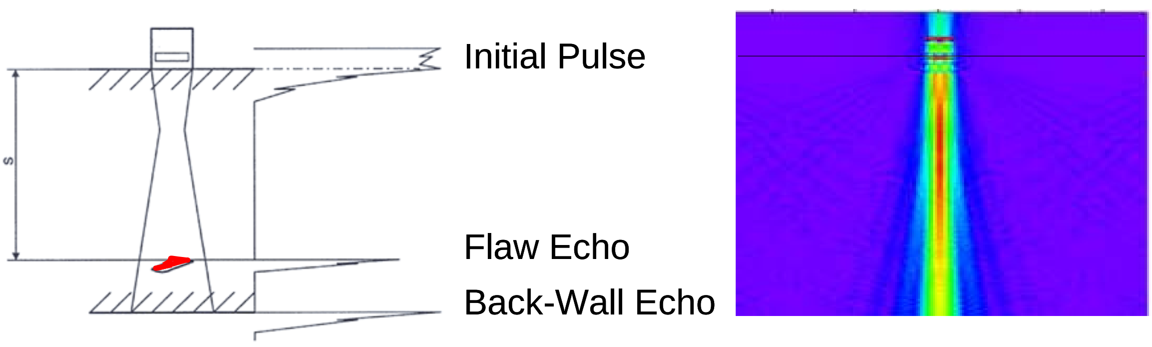


Figure 49 Principle of ultrasonic straight beam inspection

9.6.2 *Angle beam inspection*

Doing an angle beam inspection the sound beam sent into the material is inclined in respect to the contact surface. The angle of refraction is always defined as the deviation from the normal. The inspection allows to detect defects of any orientation (weld chamfer and so on) or if a straight beam inspection is not possible because of the weld geometry (e.g. weld crown not ground). The angle beam inspection works mainly with shear waves.

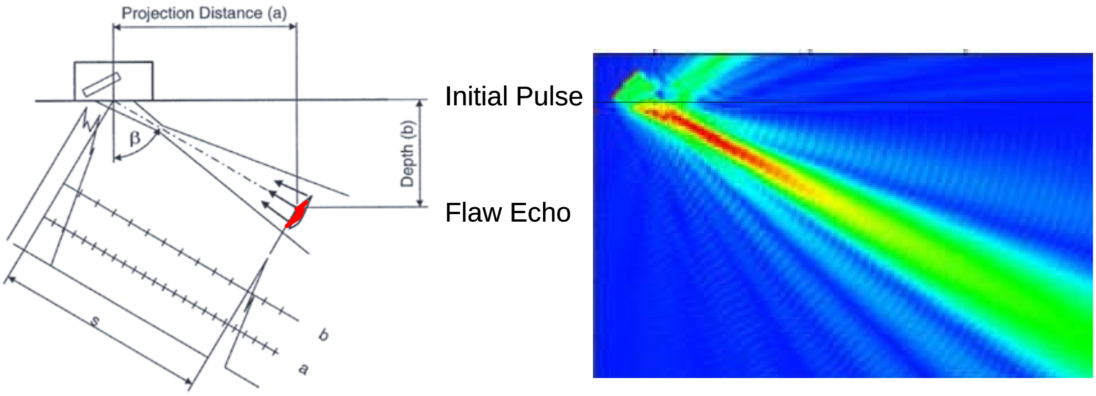


Figure 50 **Ultrasonic principle of angle beam inspection**

9.6.3 Description of the technique

The main principle of the ultrasonic testing is based on a piezo crystal producing mechanical oscillations. These oscillations can be emitted as high frequency sound waves into the work piece where they move on. Similar to the audible sound echoes arise at a reflector and return as high frequency sound waves to the crystal. This piezo crystal has the feature to transform these sound waves again in electrical pulses which are amplified and made visible as a signal on the screen of the flaw meter.

9.6.4 Limits of ultrasonic testing

The applicability of ultrasonic testing ends if the sound transparency is not guaranteed any more. This is the case with coarse grain structures (austenitic material) or heterogeneous material (gray iron casting). In addition, the shape of a component has to be suitable for inspection.

That means that the ultrasonic testing might take place at an intermediate stage of production (e.g. rough machined condition, after annealing and so on). Thereby the surfaces (contact surfaces) have to be rather clean and not wavy. Big differences in the quality of the contact surface of the reference block and the component can cause difficulties of interpretation (correction of transfer).

9.6.5 Choice of ultrasonic testing technique

The defect type to be expected should be known as well as possible in order to choose an efficient and convincing technique. The choice of transducers and directions of sound is of special importance. Having geometrically difficult components or if a complete proof of quality is necessary the inspectability has already to be considered during designing of the component. Therefore, contacts between the designer and NDT experts are necessary in an early stage.

9.6.6 Documentation

The ultrasonic testing has a disadvantage compared with radiography concerning documentation. With the exception of modern equipments, e.g. the Tomoscan system or digital flaw detectors, there are no images which can be archived as proof for several years. The documentation of an inspection consists here only of a report which has to be written by the inspector. Thereby, it has to be assured that in this written report everything is contained in order to be able to reproduce the inspection years later. If necessary these reporting have to be complemented with sketches and pictures.

9.6.7 Decision criteria

The decision criteria have to be fixed for each inspection in an inspection procedure and the inspector has to be instructed. It has to be considered that during an inspection probable indications are assessed by the inspector. Further decisions of how to proceed are often taken based on the findings and the report of the inspector. Therefore, it is very important that the inspector gets clear instructions and decision criteria.

9.6.8 Comparison of radiography and ultrasonic testing

Both inspection techniques have a different probability of detection and it is not possible to replace one technique by the other without problems. Therefore, both techniques are applied on some highly stressed components. The ultrasonic testing is very sensitive to all, even very fine and small, plane separations (cracks, lack of fusion, sometimes even grain boundaries and grain decay). However, in order to get a maximum reflection, the flaws to be detected have to be oriented as much as possible normal to the sound beam.

On flaws oriented oblique to the sound beam the ultrasonic waves often are reflected away and only weak or no indications at all are obtained. In order to get a complete flaw detection it is often necessary to do the inspection with different angles of refraction and orientations (highly stressed welds with up to ten ore more scanning directions). For special cases the tandem technique is applied additionally.

Round and spherical flaws are bad reflectors for ultrasonic waves. Such flaws are often underestimated based on their ultrasonic behavior (bubbles, pores and slag inclusions).

If the inspector gets diffuse or suspicious indications he is obliged to adapt the inspection technique to the conditions for this area (application of other transducers, angles of refraction and scanning directions) and to extend locally the extent of the inspection. Is it nevertheless not possible to define an indication sufficiently radiography is often applied in such areas. This is also true for areas where no ultrasonic testing is successful because of high sound attenuation of the material.

Radiography is very sensitive to voluminous flaws (slag inclusions, pores, shrinkage, bubbles and sand inclusions). Cracks and lack of fusion can be detected badly or not at all. This is mainly true for fine cracks or if the plane of separation is oblique to the orientation of the X-ray. The same can also be said for strongly indented cracks.

An X-ray inspection is also a problem if the work piece has very different wall thickness. On principle, the remark made above for ultrasonic testing is also valid here. The two techniques are not competitors but they rather complement each other.

9.6.9 Application fields of ultrasonic testing

As an inspection technique which is able to detect flaws in the volume the ultrasonic testing is applied where plane, ideally reflecting flaws are expected. Provided that the surfaces are optimally prepared (no spatter and loose scales, surfaces machined at least to N 10, waviness maximum 0.5 mm on a length of 50 mm), weld junctions down to a wall thickness of 10 mm can be inspected. If thinner welds have to be inspected special techniques would have to be developed. It is important to inspect the weld bevels in advance of the inspection in order to be sure that in this area there are no delaminations. Otherwise, it will be very difficult during the following ultrasonic testing of the weld to characterize ultrasonic indications. Therefore, it is recommended to do a straight beam inspection of the weld bevels in advance using a time-base sweep of about three times the wall thickness.

Another task of ultrasonic testing is the inspection of build-up welds and the assessment of the bonding quality of bearing metals.

For cast materials like gray cast iron components the inspection is limited to the detection of big flaws like shrinkage, sand inclusions, segregations and cracks. Because of the reduced sound transparency the characterization of small flaws is more difficult. The ultimate tensile strength of gray cast iron can be assessed by the measurement of the sound velocity.

Steel castings and nodular cast iron can be inspected without problems; but it has to be considered that the reflectivity of typical casting flaws (shrinkage, inclusions, pores) is not ideal. The amount of graphitization in nodular cast iron can also be determined by the sound velocity.

In the field of cast inspection the main scope is to detect all "voluminous" flaws like gas and air bubbles, sand and slag inclusions, shrinkage but also hot cracks, cold cracks, not melted chaplets and weld marks.

Radiography of weld junctions is suited especially for voluminous flaws, mainly slag and metallic impurity, pores of all kind and lack of fusion provided they are parallel to the X-ray beam.

9.6.10 Summary of possible applications

- Semi finished products:
  - o Inspection of sheets
  - o Inspection of rods
- Forged components:
  - o Rough machined forged slugs (annealed)
  - o Finished forged pieces (simple shapes)
- Castings:
  - o Steel castings
  - o Looking for flaws in nodular cast iron
  - o Quality of nodular cast iron (measurement of sound velocity)
- Welds:
  - o Welds with wall thickness of 10- 300 mm
  - o Claddings
- In-service inspection:
  - o Welds
  - o Fatigue cracks kiln tires, rollers, roller shafts
  - o Fatigue cracks VRM parts
  - o Measurement of wall thickness

9.7 Radiography

9.7.1 Description of the technique

Since the discovery of the high energy, very short electromagnetic waves by Roentgen and Rutherford it became possible to make voluminous flaws visible in the form of shadow image projections. These waves -for inspection usually called radiation -have the capability to penetrate even solid materials of considerable thickness and to produce an image and a photographic film or a fluorescent screen. In modern applications of radiography the following radiations are used in the technical field:

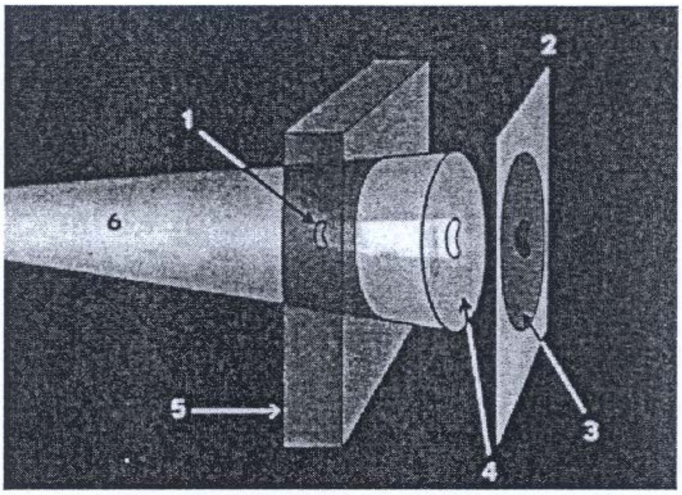
- Gamma-Rays which originate by a spontaneous decay of radio nuclides (Ir192, Co60 , Se75 and so on)
- X-Rays which are formed in a X-ray tube when accelerated electrons crash into the anode
- X-Rays which are formed in a linear accelerator (up to 8 MEV)

At first sight the use of "natural" radiation of radioactive isotopes seems easier because it is always available having well known properties and not needing electricity. In contrast to the natural are the "artificial" X-rays which have to be produced by very expensive equipments. Nevertheless, the much broader spectrum (this radiation consists of portions of different wave lengths at the same time) is an enormous advantage producing images with much more contrast. In addition, the kind (X-ray hardness) and the amount of radiation and the irradiation time can be adjusted to the examination object by choosing the correct high voltage of the tube, the current of the tube and the time of exposure. By these three parameters the quality of the image can be optimized.

In principle, two kinds of radiation are available. On the one hand the mainly "hard" and very energy rich monochromatic radiation of radio nuclides which in general cannot be changed in its characteristics and on the other hand the adaptable decelerated radiation of X-ray tubes which can be adjusted to the inspection problem in the range of extremely soft radiation (medical equipments) to extremely hard radiation (linear accelerator).

On a film or a fluorescent screen an image is produced because the radiation which penetrated the object is capable of exposing the grains in the emulsion layer of the film. In the case of a screen the consequence of the radiation is the fluorescence of the layer The radiation is absorbed different I y when passing through objects of different material thickness and therefore the remaining radiation arriving at the film produces a proportional image of the transverse material thickness. A cavity in the material (shrinkage, bubble, separation) produces a smaller attenuation of the radiation compared with the full material in the neighborhood. The remaining radiation is locally higher and the blackening of the film in this place is stronger. Therefore, areas with flaws will always show up as darker spots on the film if they are caused by separations or cavities. Protruding parts (weld crowns, weld spatter, weld roots) however cause lighter spots.

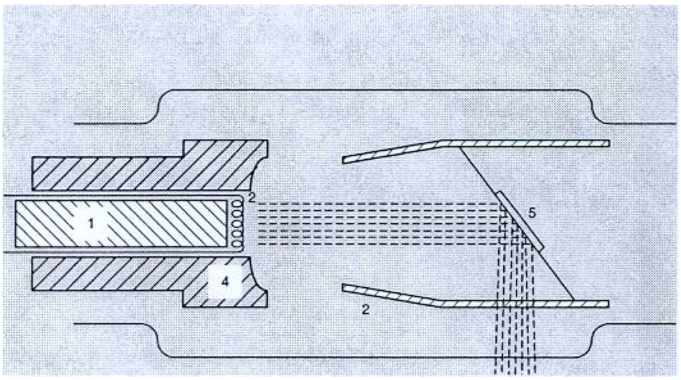
9.7.2 The radiation pattern and the film image



1. Flaw
2. Film
3. Image on the film
4. Radiation pattern in the plane of the film
5. Work piece
6. Radiation beam

Figure 51 Working principle of radiography

9.7.3 X-ray tube



1. Cathode
2. Anode
3. Heating filament
4. Direction cylinder
5. Anticathode

Figure 52 Components of an X-ray tube

9.7.4 Application fields of radiography

- Inspection of welds
- Inspection of cast components

9.8 Eddy current testing

9.8.1 Description of the technique

The eddy current testing is based on the principle of the magnetic induction.

A coil through which an alternating current passes develops a magnetic alternating field.

When a test coil is placed above a conducting material, the coils magnetic field induces eddy currents with the same frequency but with another phase into the material.

These currents generate a magnetic field too, which is directed against the change of the magnetic field of the coil and therefore against a change of the resistance of the coil (impedance).

The resulting impedance of the coil is indicated by the equipment.

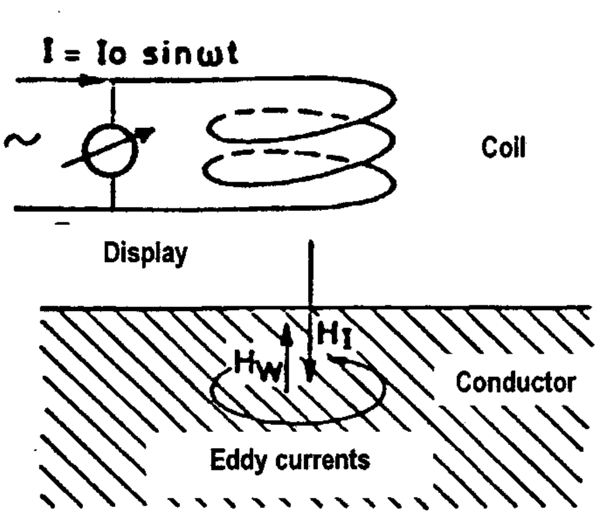
Possible material defects, geometrical variations, changes in electrical conductivity as well as differences of the penetration of the eddy currents produce another distribution of the current, another magnetic field and at the end a new value of the coil impedance.

Only electrical conducting materials can be examined with eddy current, especially non-ferritic materials and stainless (antimagnetic) steels.

The measured value (change in the coil impedance) results from different origins: electrical conductivity, magnetic permeability, geometrical shapes.

By two materials with about the same electrical conductivity and magnetic permeability an overlap of the values could occur, which will made the sorting of the two materials impossible. Likewise geometrical depending variations of the cross section could cover relevant indications (for example a crack signal).

9.8.2 Principle of the eddy current testing



A coil with alternated current produces an alternated magnetic field.

When the alternated magnetic field is placed near to the part, it induces there electrical eddy currents with the same frequency but with a changed phase.

The eddy currents produce its own magnetic field.

This magnetic field causes a change of the magnetic field of the coil and a change of the impedance of the coil.

Figure 53 Working principle of Eddy Current testing

The new impedance of the coil gives information about the part:

- ☐ By a material without irregularities or defects the impedance has a constant value.
- ☐ By a material with different material properties or with defects the impedance is changed. This is indicated by the equipment.

The interpretation of the values is not easy. Reference pieces facilitate a correct evaluation.

9.8.3 Type of coils

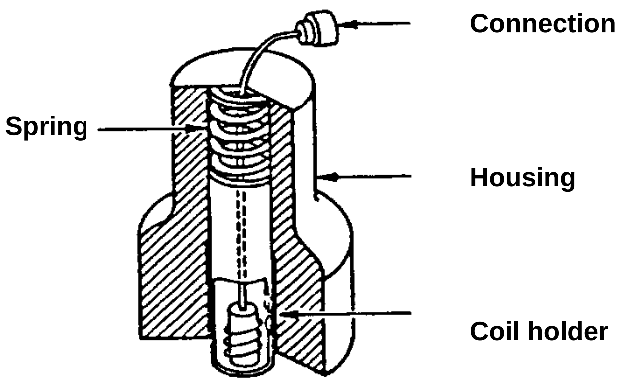


Figure 54 Surface coil

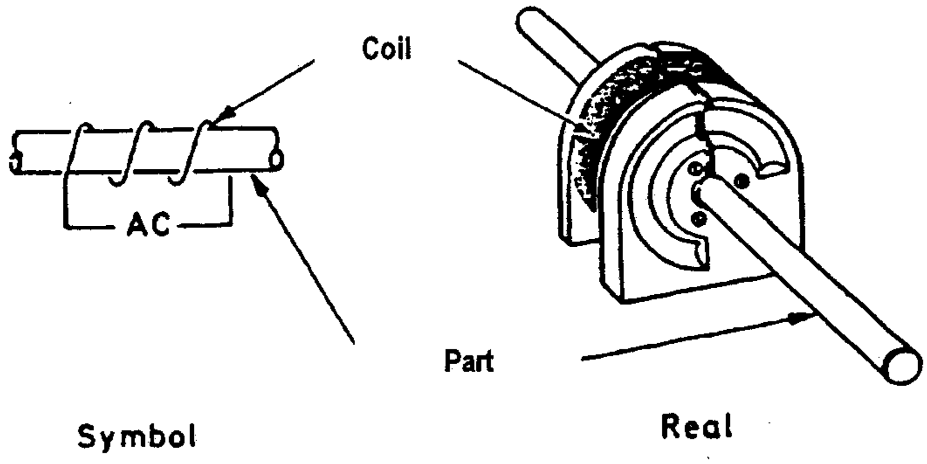


Figure 55 Encircling coil

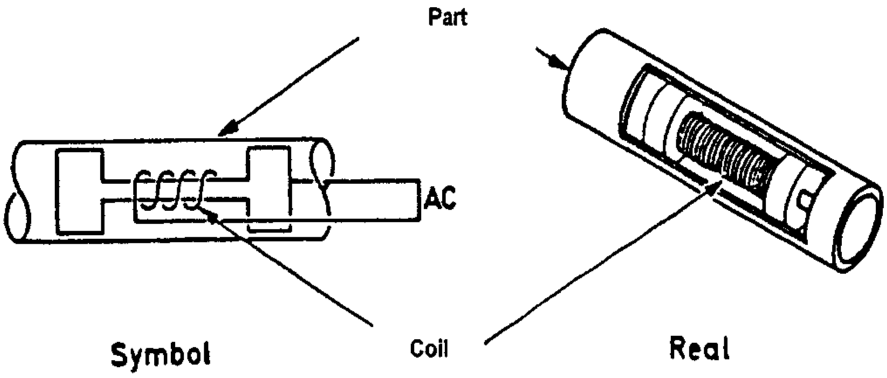


Figure 56 Inside coil

9.8.4 Range of application of the eddy current testing

- sorting (for example identification of different materials, measurement of conductivity)
- pipe examination (principally austenitic material)
- detection of defects at specific places of machine components (for example cracks in turbine blades)
- in-service inspections (for example hub of landing gear of airplanes)

10.Wear measurement

Wear can be defined as a process in which interaction of the surfaces or bounding faces of a solid with its working environment results in dimensional loss of the solid. In general wear can be classified in:

- Adhesive wear
- Abrasive wear
- Surface fatigue
- Fretting wear
- Erosion wear
- Corrosion

Wear is especially important in our industry where a high amount of material under various conditions of stress, speed, chemical and temperature is handled. Under normal operating parameters the property changes during usage normally occur in three different stages as follows:

1. Primary or early stage or run-in period, where rate of change can be high.
2. Secondary or mid-age process where a steady rate of aging process is maintained. Most of the useful or working life of the component is comprised in this stage.
3. Tertiary or old-age stage, where a high rate of aging leads to rapid failure.

With increasing severity of environmental conditions such as higher temperatures, strain rates, stress and sliding velocities, the secondary stage is shortened and the primary stage tends to merge with the tertiary stage, thus drastically reducing the working life.

10.1 Wear solutions

There is a wide range of possibilities to improve in order to optimize the life time of components through.

- Design Solutions
  - Review design to lower stresses and friction in ducts and pipes
  - Review design for material protection in critical points
  - Application of the cascade principle in chutes and transfer points
  - Reduction of stresses with change of geometry
  - Improve maintainability (easier/faster)
- Ceramic material solutions
- Elastic material solutions

Hardness of rubber	Most suitable for	Example of practical application
Low (35-55°IRH)	Rinsing wear from particles < 5 mm Wet wear Sliding and jet wear from fine grained materials (<1mm)	Flotation equipment Pump or pipe linings Sandblasting equipment
Medium (50-70°IRH)	Fatigue wear ("normal wear")	Car tyres, belt conveyors, mill lining (normal operating conditions)
High (65-85°IRH)	Dry, abrasive wear Macroscopic wear (damage from cutting and crushing) Wear from very coarse material (>100 mm)	Dumper body linings Mill lining (large grinding balls and rods, coarse material, rod mills) Tracks for tracked vehicles Ducts and chutes for coarse bulk material (> 100 mm)

Figure 57 Rubber, suitable for impact erosion at high angle, unusable at low angle

- Metallic material solutions
  - Heat treatment
  - Hardfacing

Welding method	Consumable type	Deposit rate	Usage flexibility	Alloys available	Weld integrity	Equipment cost
Gas welding	Rod or wire	Very low	High	Low	High	Low
TIG	Rod or wire	Very low	High	Low	High	Medium
MMA	Coated rod	Low	High	High	High	Medium
PTA	Powder	High	Low	Low	High	Very high
Arc spray	Solid or cored wire	High	High	Medium	Low	High
MIG/MAG	Solid or cored wire	Medium	Medium	Medium	High	Medium
Sub arc	Solid arc cored wire	High	Low	Medium	High	High
Open arc	Cored wired	High	Medium	High	High	Medium

Figure 58 Hard facing by welding procedures

No.	Description	Strength kp/mm^2 approx.	Elongation %	Wear resistance
1	Low alloy austenitic manganese steels	60	15	Very low
2	Austenitic manganese steels	55	50	Moderate
3	Unalloyed steels	42	20	Extremely low
4	High tensile low alloy steels	50	18	Extremely low
5	Fine perlitic steels	50-60	12	Extremely low
6	Martensitic steels	50-60	15-20	Moderate
7	Ledeburitic steels	60	2	High
8	Heat treated cast iron	25	<0.5	Very low
9	Heat treated nodular cast iron	50	3	High
10	Perlitic white cast iron	25	<0.5	Very high
11	Martensitic white cast iron	35	<0.5	Very high
12	High-chrome white cast iron	50	<0.5	Very high
13	Cobalt-chrome-tungsten carbon alloys	50	<0.5	Very high
14	Hard metal	50	<0.5	Extremely high

Figure 59 Metallic material resistant to wear characterize by their composition, heat treatment, and the resulting hardness

10.2 Wear management

If any of these solutions is economically feasible and justifiable, wear management can strongly improve the maintenance in our plants in terms of both cost and availability.

In the results of standard wear tests, the loss of material during wear is expressed in terms of volume and weight. The volume loss gives a truer picture than weight loss, particularly when comparing the wear resistance properties of materials with large differences in density. However for practical situation we apply the specific net wear in terms of weight.

Specific net wear V1 of a wearing part can be calculated as follows:

$$V\mathbf{1} = \frac{G\mathbf{1N}}{T\mathbf{IN}} \cdot 10^{-3} \text{ (g/t)}$$

As was explained at the beginning, in most cases wear is a gradual process, which provides the opportunity of measure and trending in order to determine the need of maintenance. Under this frame wear management can be implemented as a condition monitoring program.

In the process of deciding the machinery to be monitored the focus should be done in those which high impact in terms of cost and availability.

- Selection machines must be done by:
    - Criticality on production flow
    - Affect production rate and quality
    - Effect in reduction cost by anticipation and less maintenance intervention
    - Items with long delivery time
- Define the frequency to be measured considering:
    - Criticality of the equipment or component
    - Wear rate and delivery time
    - Availability of the equipment to perform inspections

The frequencies for wear measurement below are general guidelines and must be adjusted according to the plant local circumstances (type of equipment and material handled).

Main wear points measurement	Recommended frequency for wear measurement
Bucket elevator	
Chain (elongation)	24 - 48 weeks
Belt (hardness)	24 - 48 weeks
Head pulley liners	24 - 48 weeks
Sprocket and traction wheel	48 weeks
Ball Mill	
Mill diaphragm plates	12 - 24 weeks
Mill chamber shell liners	12 - 24 weeks
Kiln	
Kiln Shell	48 weeks
Inlet - outlet seal	Major shutdown
Refractory (concrete-brick)	Major shutdown
VRM	
Table liners	12 - 24 weeks

Main wear points measurement	Recommended frequency for wear measurement
Roller liners	12 - 24 weeks
Housing liners	48 weeks
Dynamic separator	
rotor blades	12 - 24 weeks
lining	24 - 48 weeks
Grate cooler	
Plates	Major shutdown
Roller press	
Rollers	4 - 12 weeks
ID Fan	
Impeller blades	6M or major shutdown
Chimney / ducts	2 years
Hammer crusher	
Rotor hubs	24 weeks or Major shutdown
Hammers	24 weeks or Major shutdown
Impact crusher	
Roller discs, liners	4 weeks
Drag Conveyor	
Chain	24 - 48 weeks
Planetary Cooler	
Shell	48 weeks
Conditioning Tower	
Shell	48 weeks
Pan Conveyor	
Chain	48 weeks
Preheater	
Refractory (concrete & bricks)	Major shutdown
Reclaimer	
Sprocket	24 weeks
Chain	48 weeks
Static Separator	
Body and cyclone shell	12 - 24 weeks
Gyratory & Cone crusher	
shell / liners	48 weeks

Figure 60 Main wear points to be measured and suggested frequencies.

10.3 Measuring points

Measuring points should be defined in the critical zones of each component and the best practice is measure always in the same point versus a reference point. Drawings, schemes, visual aids on field, etc. become in a basic tool to assure accurate measurements. Best practices consist on:

1. Creation of a baseline of each measuring point

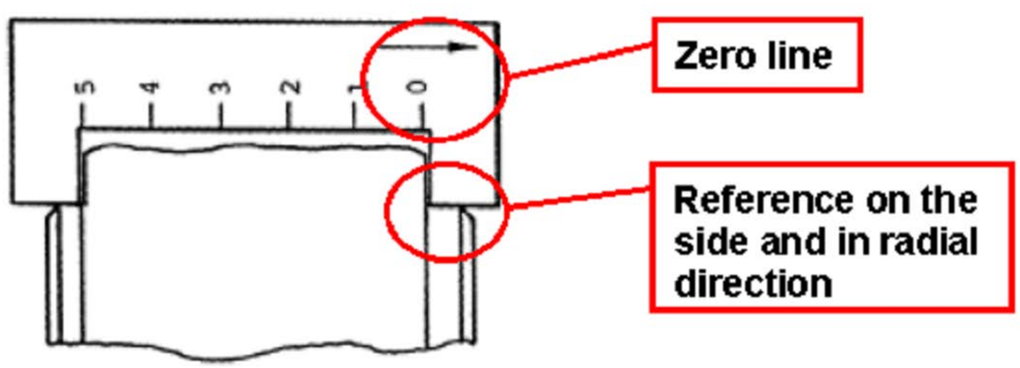


Figure 61 Identification on field and in procedures

2. Documentation of standard procedures of measurement

Remember SAFETY FIRST!!!, all safety considerations must be included in the procedures and all measuring points must be safely accessible.

The best practice is measure according supplier recommendations and document in SAP the specific procedure of measurement to generate work orders.

3. Identification in drawings, scheme and/or on site the measuring point

Some examples are:

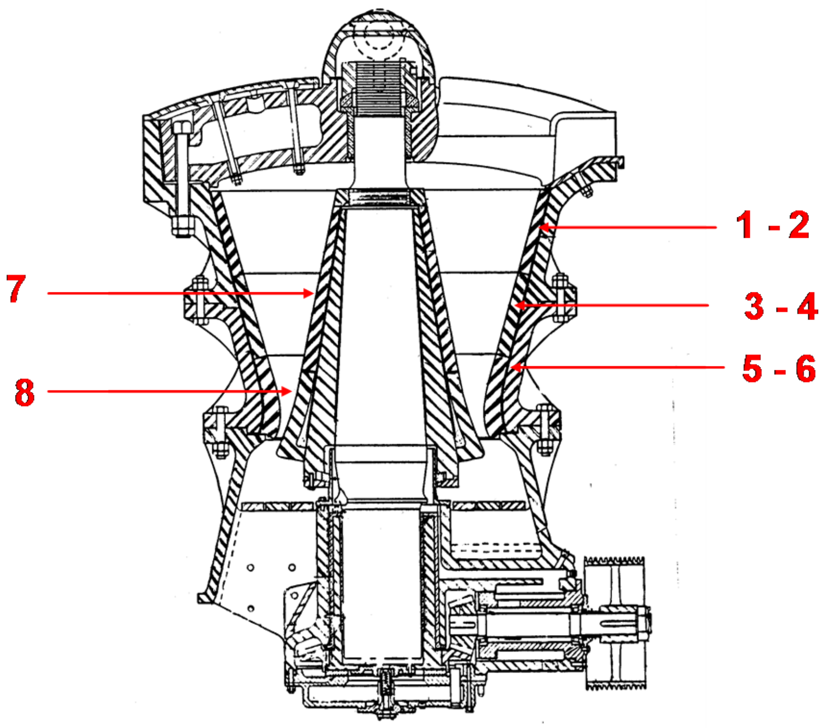


Figure 62 Wear points identification in drawings

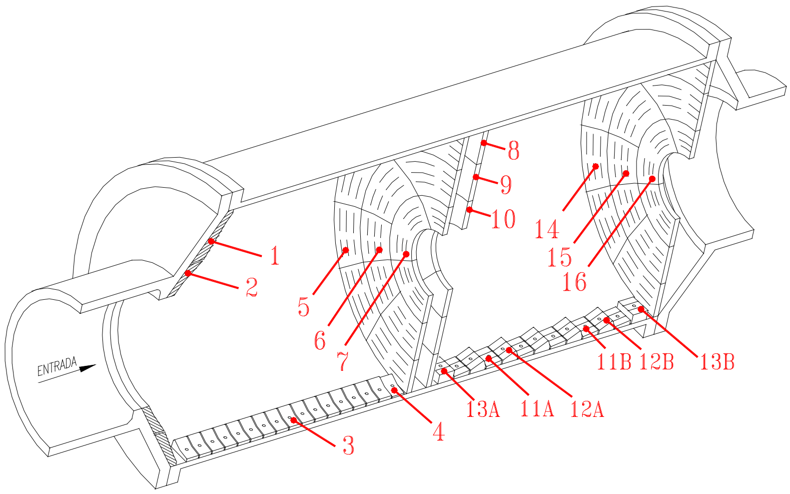
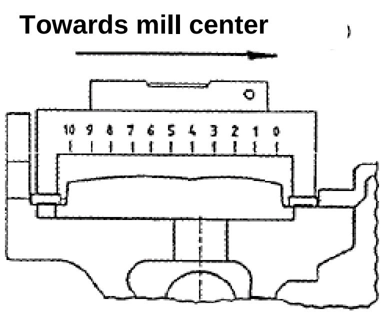


Figure 63 Wear points identification in drawings (3D)

4. Use standard template to register the measurements

VRM-ATOX-PETCOKE
WEAR TEMPLATE GRINDING TABLE SEGMENTS

HAC L23-MR1



DATE	OPERATING HOURS	HORAS	PRODUCTION	LAST PRODUCTION RATE

	0	1	2	3	4	5	6	7	8	9	10
MEASURING POINT NÚM. 1											
MEASURING POINT NÚM. 2											
MEASURING POINT NÚM. 3											
AVERAGE											

COMMENTS: ______________________________

Figure 64 Example of wear template

5. Train personnel for measurements execution

This task is extremely important to assure accurate measurements, in many cases measurements can be done during major shutdowns only. Documentation and training are key steps to achieve sustainability of a wear management program.

Figure 65 Measurements can be done easier and accurately with the proper tools and templates.

10.4 Alarm limits and trending

Target of a wear management program is determine the condition of the components and its remaining life time to predict and plan in advance the required actions to restore and maintain the equipment's performance and availability with the optimum cost, minimum intervention and maximize the useful life of the components. Under that sentence the following question show up:

When should I take action (replacement, refurbishment, adjustment, calibration, etc.)?

Alarm limits definition should consider wear rate, delivery time of the component/service, execution duration of the maintenance activity and planned maintenance shutdown frequency.

An empirical proposal is the following:

1. Determine the maximum allowed wear in the critical zones without compromise the equipment's performance and availability. This will define the maximum operating limit for the specific component.

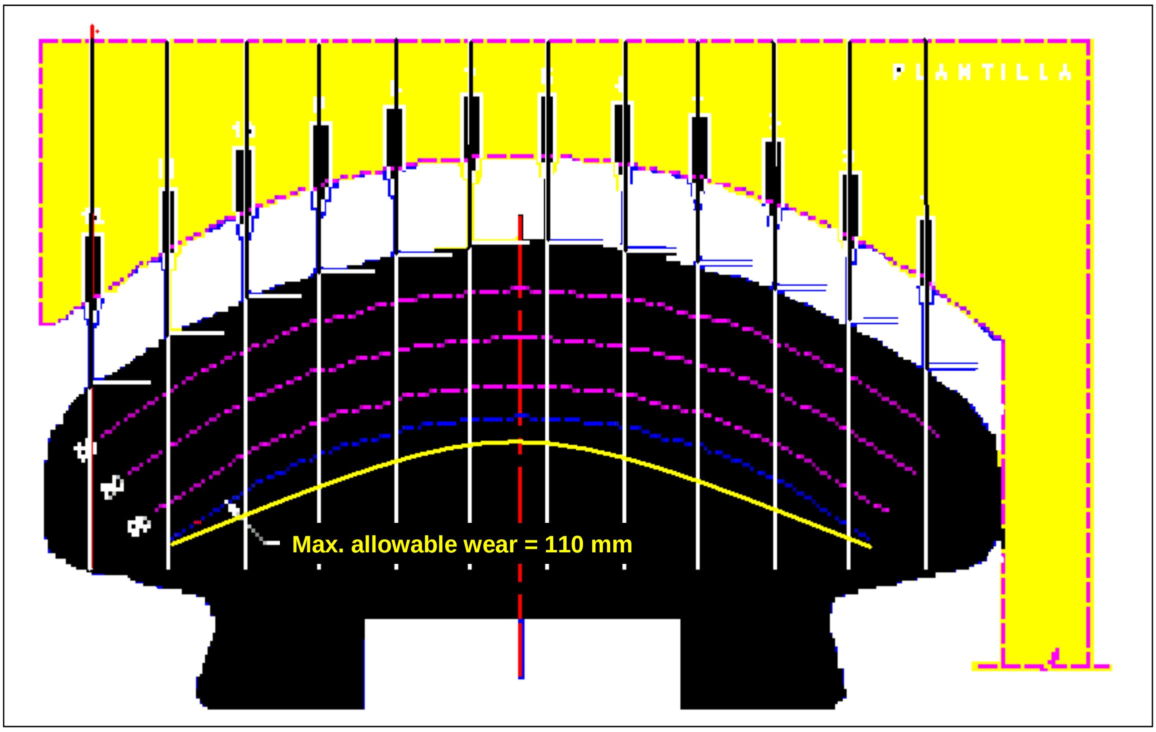


Figure 66 Wear profile follow-up and limits definition.

2. Determine the wear rate and then useful life time of the component in normal conditions.

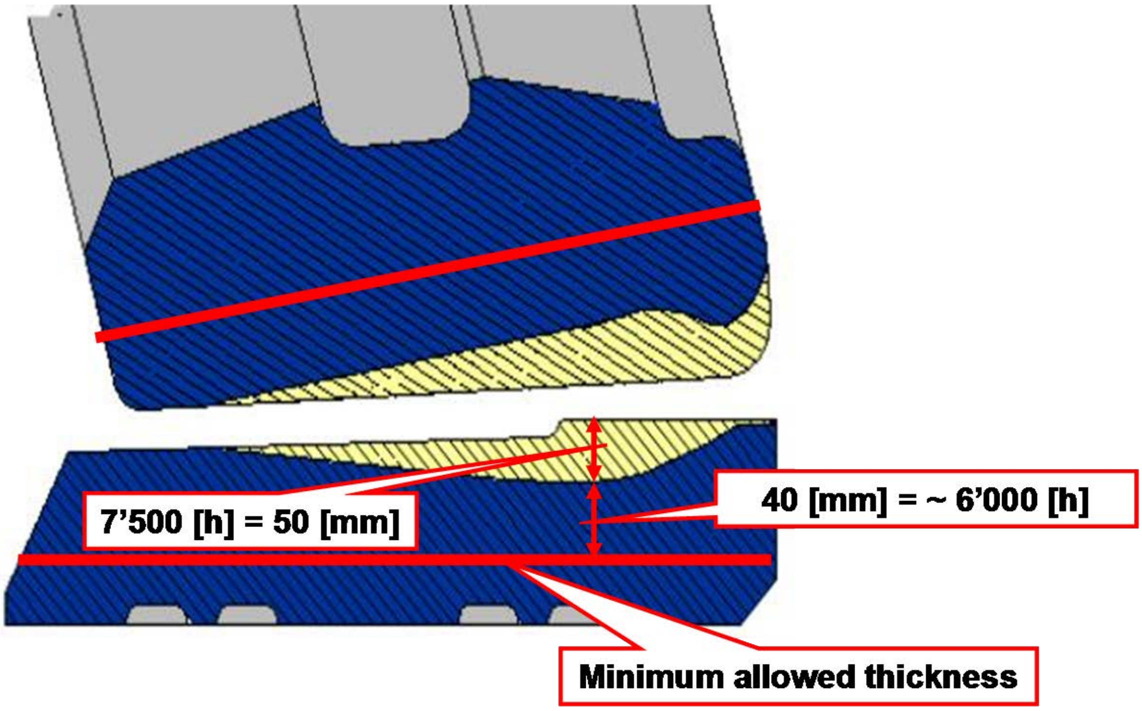


Figure 67 Limits definition based on wear rate

3. Determining alarm limit is an estimation which should consider at least delivery time, inspection frequency and in some cases the frequency of major stops.

With the higher amount of measurements, dates prognostication are easier defined because wear rate is more accurate and as a consequence the alarms limit definition.

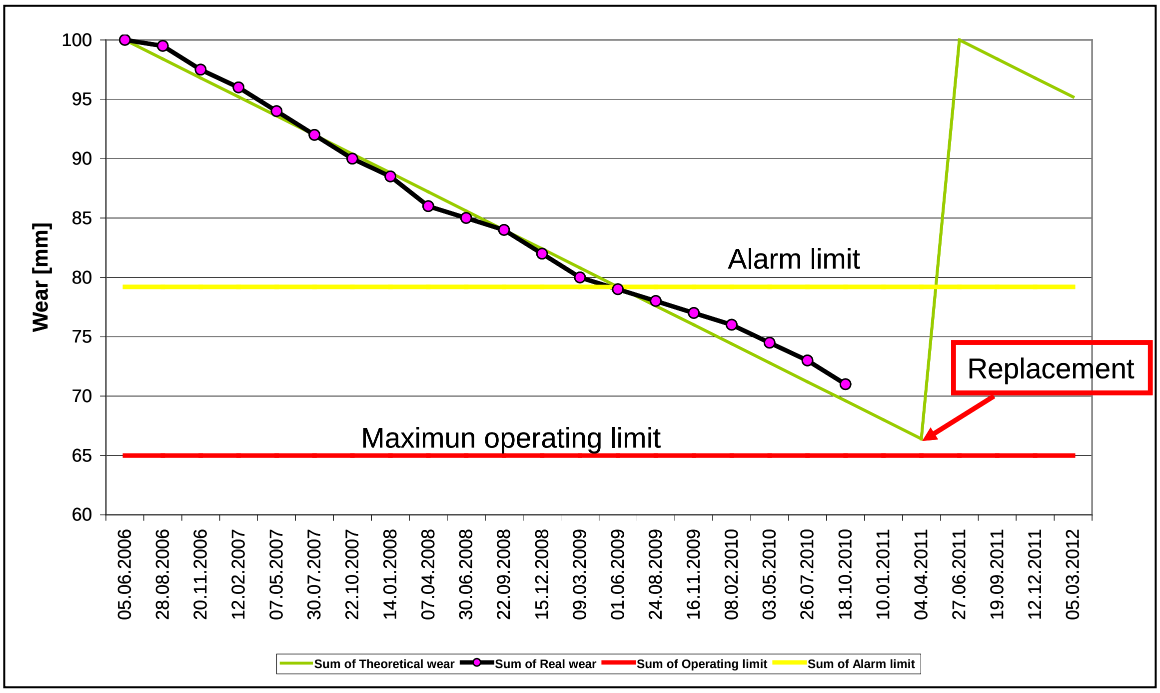


Figure 68 Wear follow up and trending

11.electric motor diagnostics (EMD)

Traditionally, the only Condition Monitoring (CM) for motors is Vibration analysis and simple Insulation test (Mega Ohmmeter). Although the use or online motor current to detect faults has been studied and used in some extent since 1980's, only recently is being considered by many industries to complement their existing CM program. The cement industry in general did not jump on the bandwagon right away.

One of the reasons is perhaps the unawareness of the Preventive Maintenance personnel in the plant since many of them have little background in the field of Electrical engineering. The advancement of computer technology, microelectronics and Computer software have made the testing concept practical in most (maybe not all) situations. Another reason would probably is the cost of the equipment

Because of numerous suppliers, the names of the test equipment and concept tend to get mixed up. To generalize and simplify we will refer to the complete motor diagnostic as Electric Motor Diagnostics or EMD. EMD will refer to the test methods and instruments designed for electric motor, electrical and mechanical non-destructive analysis.

Under EMD there are two major test procedures or conditions, Static and Dynamic Testing.

11.1 Static Testing

This group of test is being done while the motor is not running and is completely isolated from the power supply. Various manufacturers refer to this Test as the following:

MCA - Motor Circuit Analysis (MCA sometimes is referred to as Motor Current Analysis, an on-line motor test)

MCE- Motor Circuit Evaluation

Parameter	Description	Unit	Problem/condition detected
Coil resistance	Low resistance	Milliohm / µohm	Loose connection / imbalance
Insulation resistance	High resistance	Megaohm / Gigaohm	Insulation condition
Inductance	Low inductance	Milihenry / µhenry	Imbalance, turn-short, eccentricity
Capacitance	Low capacitance	µfarad, nanofarad	Dirt build-up

Figure 69 Parameters measured during a static test and possible faults

11.2 Dynamic testing

This group of test is performed while the motor is running and with load. The test may, during start up, measure and capture the in-rush current or during steady state to measure and capture the current and voltage.

Terms: Which of the following term is appropriate?

- ESA - Electrical Signature Analysis.
- MCA - Motor Current Analysis
- MCSA - Motor Current Signature Analysis
- CSA - Current Signature Analysis
- CSA - Current Spectrum Analysis

All of them are. The only problem is that sometimes they get mixed up, especially the term MCA, which can mean motor circuit analysis or Motor Current Analysis. At this point it is important to emphasize the meaning of the abbreviation rather than just to say the letters.

A comparison of motor current and mechanical vibration signatures obtained simultaneously from a motor operated valve provide similarities and distinctions. Both spectra contain frequency peaks corresponding to the motor speed, worm gear tooth meshing, and its harmonics; though the amplitude relationships are different.

One distinction is that there is a strong spectral component in the motor current signature that is defined as the slip frequency. This signal is a general characteristic of AC induction motors and reflects the rate at which the spinning armature continually falls behind the rotating electrical field generated by the motor's field windings (no such peak appear on DC motor signatures.) Since this motor slip frequency component is electrical rather than mechanical in origin, it has no vibration counterpart and it is not present in the vibration spectrum.

Tests on motor operated valves indicate the dynamic testing is capable of detecting and tracking the progress of: stem packing degradation, incorrect torque switch settings and/or varying switch trip points, degraded stem or gear case lubrication, gear tooth wear, restricted valve stem travel, obstructions in the valve seat area, and disengagement of the motor pinion gear.

The following table summarizes the outcome of dynamic testing:

Measurement	Faults
Voltage: phase to phase, phase to neutral	Power Quality
Current: phase	Low voltage, excessive loading
Imbalances (current & voltage)	High resistance connection
Harmonic distortions (current & voltage)	Non Linear Loads
Crest Factor (voltage & current spikes)	Switching devices, Variable Speed Drives, load transients
Impedance (data with calculated unbalance)	Stator Winding defects
Power & Efficiency (kW, kVA, kVAR, cos phi, eta)	

Figure 70 Power analysis (dynamic test) parameters and possible faults

11.3 Recommended inspection frequencies

Spot checking a point less frequently than once a year is of significant value only after a plant has developed its own baseline of application data.Once historical files have been developed, spot checking can be cost effective for critical or expensive machines, as well as less critical or balance of plant equipment. It could also be used effectively as a troubleshooting tool.

On a predictive basis, both dynamic and statis testing should performed on a yearly basis. Periodic dynamic testing can provide a more subtle indication of bearing, packing, coupling or gear wear; allowing personnel to project acceptable machine performance into the future. This advance notice of developing problems means that they can be repaired during normal machine shutdowns, rather than allowing a serious machine failure to cause unscheduled down time. Since problems are detected when they are relatively minor, they are usually less expensive to repair.

On a similar basis, periodic static testing can determine the actual need of a motor to undergo cleaning of the windings or when to be sent to an electric workshop for overhaul of the insulation (instead of using a time-based frequency to do this). In addition, new or refurbished motors can be measured upon receipt at the plant, in order to assure they are fit for service.

Long term dynamic testing can be used to identify improper maintenance or repair practices. These can include improper seal/packing installation, improper bearing or gear installation, inaccurate shaft alignment or imprecise rotor balancing. This information can be of particular importance in reducing recurring machine problems.

Long term trends can also be used to identify improper operating conditions, such as continually running equipment beyond design specifications (i.e. at higher temperatures, speeds, or loads.) They can be used to compare similar equipment from different manufacturers to determine if there ear any inherent design flaws of benefits that can be reflected in increased service life.

11.4 Advantages/limitations

Both static and dynamic testing are one of the moderately complex but 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.

The dynamic testing is particularly useful due to its non-intrusive nature. Measurements can be taken without the need to make or break electrical connections, and shut down or open up machinery. This eliminates equipment downtime for inspection, and improves personnel safety. In addition, since readings can be taken remotely, the technique can be more conveniently and safely performed on large, high speed, or otherwise hazardous machines.

11.5 Associated costs

In general terms, it is recommended to outsource the EMD to specialized companies, due to the complexity of interpreting the data. This is mostly true in the case of single cement plants, where the technician doing the analysis will be doing this only once or twice a year.

For bigger Group Companies the testing equipment for EMD can be purchased and used on a regional basis. On one of these successful applications, a region bought the equipment and appointed 2 to 3 dedicated technicians, who are responsible for all measurements and their interpretation.

There are on the market separate devices for dynamic and static testing or all inclusive. For single plants, the investment on a static testing device only can be justified.

It is not only knowledge, but practice and experience what counts for a proper analysis of results!

12.Environment

The linkage of maintenance to environment has been recognized by industry for a number of years. In fact, many activities associated with maintenance, such as good housekeeping, tank cleaning, inventory control and waste segregation, and are among the first areas addressed in a pollution prevention program. In fact, maintenance is one of t he most crucial areas for pollution prevention.

While producing cement, a cement industry releases a large amount of dirty effluents. By implementing new technologically advanced facilities, some of them can be lowered (e.g. NOx by SNCR), and some even stopped (e.g. dust by bag filters). However, as man-made devices are never perfect, these devices would have a short time life without a proper maintenance program, thereby causing a dramatic environmental impact. Plant housekeeping plays also a role. It is important, for instance, to promptly eliminate rust from pipes in order to avoid ducts weakening and breakages, leakages of explosives gas, and fugitive dust, thus strongly affecting the surrounding environment. All this might strongly affect our public image, and thereby, might give a negative influence on our business.

This chapter deals with the importance of maintenance on environmental performance, and, as a part of the Maintenance Manual gives indication on how to correctly implement a good EMR-CEM maintenance system.

12.1 LafargeHolcim Environmental Performance and EMR

At LafargeHolcim, our goal is to continuously demonstrate our commitment to sustainable environmental performance, actively working to improve our performance and to increase our understanding of the challenges that we - and our industries - face in this area. Our aim is then understand our current environmental performance by consistent measurement and reporting techniques. To promote continuous improvement, we have set a global emission reduction target (ERT), that is, to reduce global specific nitrogen oxides (NOx), Sulfur dioxide (SO2), and dust emission (g pollutant/ton cementitious materials) by 20%, compared to 2004 levels. Of particular importance is thus given to the emission concentration measurement from the stacks of the cement plants, and continuous investment are required to implement our emissions monitoring and reporting (EMR) standard that sets all the criteria for assuring high quality emissions monitoring and reporting at all continuously emission monitoring device (CEM). Within the EMR standards, directives are set to implements an effective plant CEM-maintenance system, in order to reach a high CEM availability and data reliability.

12.1.1 EMR Performance Targets

In December 2007, LafargeHolcim EXCO has approved that within 2008, all the LafargeHolcim plants have to comply the following EMR Performance Targets:

EMR Availability*	>90% as a standard >95% as a target
EMR Reliability	“Extended gas bottle calibrations”* executed by the supplier in the framework of the yearly maintenance Yearly “test house calibrations”* for comparison of CEM* measurements with reference methods
EMR Transparency and Auditability	EMR roles and responsibilities Standard continuous EMR equipment* EMR equipment: service, maintenance and maintenance training contract signed Automated handling and conversion of data from EMR equipment CEM* equipment calibration EMR once-per-year*, base line* and trial burn* emission measurements EMR documents management

The EMR performance targets as well as the whole EMR standards are implemented according to 13 EMR directives (formerly called guidelines) and a LafargeHolcim EMR Manual for Good Practices.

12.2 Environmental Roles and Responsibilities

Being committed to Sustainable Development, the LafargeHolcim OpCos are encouraged to implement an Environmental Management System EMS (ISO 14001). The correct implementation of this system, involves a number of responsibilities at both company and plant level. Below is a list of the main environmental roles and responsibilities of LafargeHolcim environmental functions:

Company Manager for the Environmental affairs: Elaborates together with the Environmental Coordinator policies, strategies and guidelines as well as (the yearly) environmental Capex budgets and proposes them to the management for approval.

Company Environmental Coordinator: Covers and coordinates the environmental issues in all company activity sectors (cement, aggregates, ready mixed concrete, alternative fuels and raw materials, mineral components, concrete products, etc.), keep the company environmental management system (ISO 14‘001) in perfect working condition and organizes the recertification audits. Moreover, he assures that the EMR Performance Targets are in place and comply with the”LafargeHolcim EMR Manual for Good Practices”.

Plant Environmental Officer: Keeps close contacts with the plant manager and with the company environmental coordinator. Keep them Informed on general environmental and compliance issues. Organizes environmental data collection and checks them for correctness. Moreover, organizes the plant EMR approach according to the requirements of the “EMR Performance Targets” (and the EMR Good Practices List).

Plant Maintenance Manager: Assurance of CEM equipments, routine and breakdown maintenance. Responsibility for work orders and procedures for preventive maintenance, and respective CEM maintenance log book

Plant Manager: Implements, together with the plant environmental officer, the company environmental visions and programs and cares for sustainability.

12.3 Recommended Continuous Emission Monitoring Equipments

2000 the ExCo had taken first decision on a LafargeHolcim Emission Monitoring and reporting (EMR) standards:

To install and operate continuous emissions monitoring (CEM) equipment for dust, nitrogen oxides (NOx), sulfur dioxide (SO2), volatile organic compounds (VOC) [,and for oxygen (O2) and water vapor (H2O), from the main stack of the clinker production lines.]
To measure hydrogen chloride (HCl), ammonia (NH3), benzene (C6H6), dioxins/furans (PCDD/PCDF) and heavy metals (HM) at least once per year [whereby - if equipment allows - HCl and NH3 can also be measured continuously]
To report in a standardized form once per year [01.02.20xy to HGRS-CIE-ETPS]
EMR to be implemented by all financially consolidated OpCo’s of the group

Note: Remarks in […] are interpretations added by CIE-ETPS.

Continuous emission measurements for dust, SO_2, NO_x and VOC [plus O_2, H_2O] and optional for HCl, NH_3, CO, CO_2 require a set of three measuring devices.

Measuring device for **dust** (in-situ)
Measuring device for **inorganic gases** (extractive or in-situ)
Measuring device for **volatile organic compounds** (VOC) (only extractive)

The EMR standards give the following directives on the recommended LafargeHolcim EMR-CEM system for the measurement of the above reported components (EMR GL 1)

12.3.1 Recommended measuring devices for dust:

SICK-Maihak RM 210/230: stray/scatter light measuring device, 17th BImSchV FW 100: forward-scattering light device, 17th BImSchV OMD 41: Transmission monitor for average dust concentration > 20 [mg/m3] only, 13th BImSchV
DURAG D-R 300: stray/scatter light measuring device, 17th BimSchV D-R 280-10 (or 290): Transmission monitor suitable for average dust concentration > 20 [mg/m3] only, 13th BImSchV
Other suppliers As an exception only. Need to apply optical measuring principles. Need to fulfill at least 13^{th}BimSchV (transmission), or better: 17^{th} BimSchV (stray/scatter light)

12.3.2 Recommended measuring devices for inorganic gases:

ABB (H&B) Multi-Component Analyzer, System ACF-NT (Advance Cemas-FTIR NT) with integrated oxygen measurement (ZrO_2-cell)	
OPSIS AR 600/650 with separate O2 measurement by ZrO2 analyzer (in-situ)	
SICK-Maihak MCS100 E HW, Multi-Component Analysis System with integrated oxygen measurement (ZrO_2-cell)	
Other suppliers	*None known for the time being to be able to offer equipment equivalent to the above.*

12.3.3 Recommended measuring devices for volatile organic gases:

ABB (H&B), SICK	ABB and SICK have integrated FID devices, i.e. the FID part is physically connected to the inorganic gas analyzer, has a common gas supply line and is under the same control scheme ABB: Multi-FID 14 SICK: EuroFID or FID model 3006
M+A **Mess- & Analysentechnik**	Thermo-FID MK Contractor of OPSIS Sales and maintenance by OPSIS
Other suppliers	Need to fulfill the 17th BimSchV requirements

12.4 Conditions for Proper Functioning of the CEM Equipments

Continuous Emission Monitoring systems require a certain number of peripheral equipments (provided by the cement plant, but in accordance with the CEM supplier specifications) for the proper functioning: air conditioned measuring station container, purge and instrument compressed air, an UPS system in case of power failure, and calibration and fuel gas cylinders. More details are written below:

<u>Instrument air:</u>

Instrument air has to be free of oil, water (dew point below -25° C), dust and dirt (according to supplier specifications). This is usually assured by a filter station (converting air from the plant network into instrument air), or by oil-free compressors and filter stations. The filter station should be designed and dimensioned according to supplier prescriptions and needs regular maintenance.

<u>Air conditioning of CEM equipment container:</u>

Assures appropriate temperature level in the CEM equipment container/room according to supplier prescriptions. Air conditioning equipment needs regular maintenance, too.

Calibration gas and hydrogen for FID:

Availability of calibration gases to be assured according to local requirements (and responsibilities to be assigned accordingly)

Fuel gas (hydrogen) needs to be at stock (open-air) for assuring high availability of FID equipment.

12.5 EMR service and maintenance contract – Maintenance routines

There are a number of maintenance operations that have to be carried out in order to keep high instrument availability and, above all, high data reliability. Although the differences between the CEM systems from the three EMR vendors can vary substantial, the EMR directives set minimum requirements for CEM routine maintenance and responsibilities described in the EMR Service and Maintenance contract (EMR GL 13):

The EMR Service and Maintenance contract structures and defines the cooperation between the XY Cement OpCo (with plants A, B and C) and the CEM equipment supplier, aiming to ensure an EMR equipment availability of at least 90% referred to the yearly operating hours of the respective cement kiln. Following recommendation are defined therein

Recommendation No 1:

Thereby, daily/weekly/monthly maintenance as well as simple break-down maintenance is assured by appropriately trained plant personnel, whereas half-yearly/yearly maintenance and services as well as heavy breakdown maintenance is assured by the supplier.

Recommendation No 2:

The maintenance experts of the (main) supplier (e.g. ABB, SICK, OPSIS) should be well trained to assure the maintenance of sub-supplier components (dust and VOC measurement devices) and to assure adequate training of plant personnel.

Recommendation No 3:

It is recommended to keep maintenance materials/spare parts/consumables in stock centrally by the supplier or decentralized, i.e. at the cement plant on behalf of the supplier to assure the a.m. routine maintenance during 1.5 years. The stock has to be refilled once per year.

12.6 CEM Maintenance Manuals

LafargeHolcim HGRS has developed together with the LafargeHolcim CEM suppliers, a set of maintenance documents describing frequency for maintenance actions and maintenance procedures for the most used CEM at the LafargeHolcim plant.

SUPPLIER	MEASURING DEVICE	FILE-ID
ABB	Advance Cemas-FTIR NT incl. Multi-FID-14	01-ABB-FTIR-FID
SICK-Maihak	MCS100E HW	02A-SICK-MCS100EHW
	EuroFID – Integrated in MCS100E	02B-SICK-EuroFID
	FID-(M&A) – Integrated in MCS100E	02C-SICK-FID-M&A
	OMD 41 (Dust Monitor)	02D-SICK-OMD41
	RM210 (Dust Monitor)	02E-SICK-RM210
	FW101 (Dust Monitor)	02F-SICK-FW101
	Flowsic100 (Flow Monitor)	02G-SICK-FLOWSIC
	GM31 (In-Situ-Device for NO/SO2)	02H-SICK-GM31
	LT1 (In-Situ-Device for O2)	02I-SICK-LT1
OPSIS	(AR600/650, O2000, Thermo-FID)	03-OPSIS-AR-O2000-FID
DURAG	D-R 290 (Dust Monitor)	04A-DURAG-DR290
	D-R 300 (Dust Monitor)	04B-DURAG-DR300
	D-FL 200 (Flow Monitor)	04C-DURAG-FL200
BHA	CPM 5001/5003 (Dust Monitor)	05-BHA-CPM5003

These documents are available upon request and will be possible to download them on the EMR platform (from May 2008). It is recommended to implement the instructions described on EMR maintenance actions on the SAP of the plant maintenance technicians, for an easier organization of the maintenance operations.

12.6.1 Break-down Maintenance

In case of an equipment break-down the parties stick to the following routine approach for problem solving:

- Plant personnel to check if problem can be solved with own means. If yes, do it and inform supplier by e-mail.
- If not, plant personnel to contact supplier's expert by phone (hot line) with problem description (and later written confirmation by e-mail). Supplier's expert tries to solve problem via remote action (e.g. oral or written advice, modem connection) immediately.
- If not immediately successful: Supplier's expert to solve the problem on site (by on-site repair or by initiation of a removal/repair/re-installation process) within … days from notification.
- After action reporting

12.7 EMR Platform

The EMR platform is a web-based communication tool that will be created in the Knowledge sharing/community of the LafargeHolcim Portal (go live foreseen by May 2008). Objectives of the EMR platform are:

- Enhance the communication between LafargeHolcim HGRS and EMR expert/CEM maintenance personnel from the LafargeHolcim plants
- Create a more robust LafargeHolcim EMR scheme by sharing the knowledge/experience on the EMR scheme and CEM troubleshooting

Within the EMR platform information and documents on CEM maintenance will be also available:

- EMR Manual for Good Practices
- EMR directives
- CEM Maintenance Manuals
- Other Environmental information

An EMR forum will be also created in the platform, so that maintenance personnel can easily communicate and share their problems with other member of the community.

13. Elimination of failures

Condition monitoring will not eliminate problems and failures by itself; systematic data analysis and problems solving are key activities for success. Specific skills and training are required in order to interpret and analyze collected data and find effective solutions. There are several methods that can be used to find root causes and define which solutions are the most suitable for implementation. Some of these methods are:

- Pareto Analysis
- Root Cause Failure Analysis (e.g. Solve!)
- Failure Mode Effect Analysis (FMEA)
- Cause and effect diagram (Fish bone or Ishikawa)
- Fault Tree Analysis (FTA)

After execution of the solutions, a proper documentation and work order confirmation will provide valuable information to validate the effectiveness of the solution and to refer back in the future in case of reoccurring problems (with the same or equipment or a similar one).

14. Message

The clear goal of Preventive Maintenance within LafargeHolcim is to focus on Condition Monitoring activities, as long as it is economically feasible. Time based replacement activities must be limited to well justified cases, where their benefits outweigh performing Condition Monitoring.

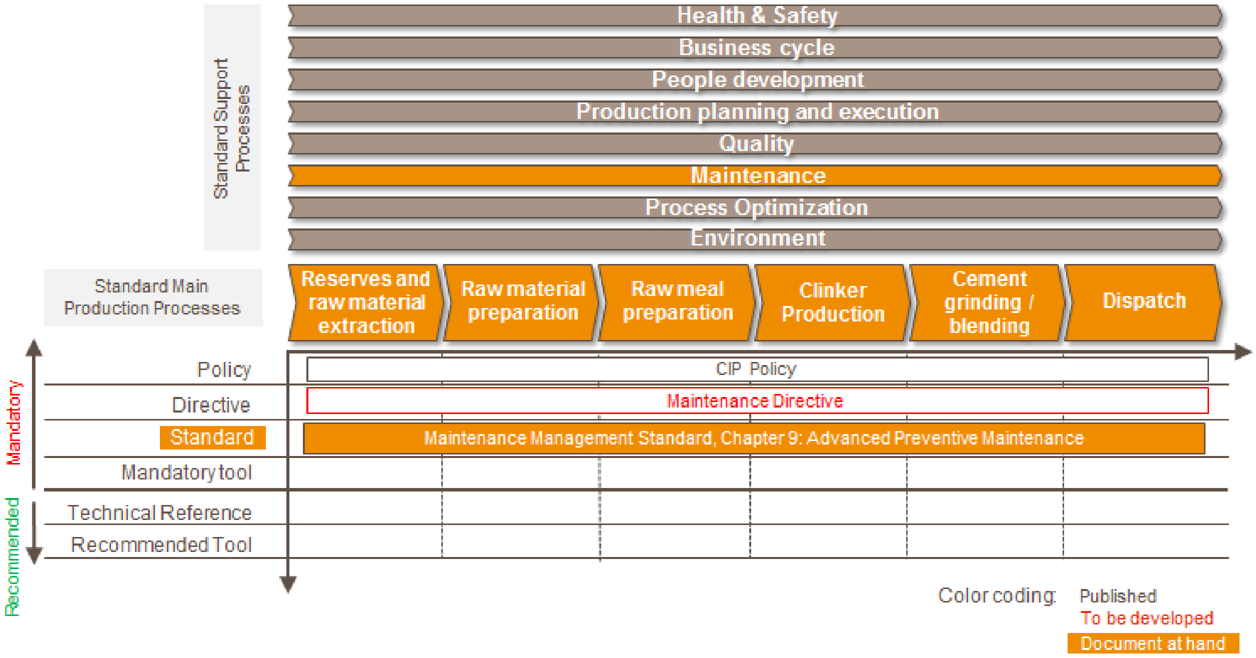
A strong foundation (walk-by inspections, lubrication management, PMR's) is a must for a successful roll-out of Condition Monitoring techniques

Condition monitoring is complement of preventive - predictive maintenance. Specific skills and training for systematic analysis and effective problem solution are required to get the expected results; knowledge and discipline are key factors for success of a condition monitoring program.

Condition monitoring techniques shall not substitute PMR's and services, in fact, the combination of all carried out are more effective on prevention and early detection of failures. Be aware of the approaches and limitations of each technique; remember that for a proper selection of a specific condition monitoring technique it is crucial to know the behavior of the failure mode and the correlation with the measuring variables or parameters.

15.Document management

15.1 Cement Industrial Framework



15.2 Document information & revisions

Content owner	Jorge Gamarra, Head of Maintenance & Equipment		
Author(s)	Fernando Cruz, Bruno Callais		
Reviewed by	Jorge Gamarra, Jean-Yves Marrel, Michael Schmid		
Validated by	CIP Standards and Tools		
Revisions	**Version**	**Date**	**Main changes**
	1.0	09 Jan 2017	First version

15.3 Related Document

	Type	Name
I	Policy	CIP policy
II	Directive	Maintenance Directive
III	Standard	Maintenance management standard, chapter 1 to 13
IV	Mandatory Tool	
VI	Technical Reference	
VI	Recommended Tool	

This document replaces:

Type	Name
Legacy Holcim	MER1MM_09v0_Advanced Preventive Maintenance.doc
Legacy Lafarge	