ST

Preventive Maintenance Handbook

Standard

Corporate Cement Industrial Performance

Version 4.0 December 21st, 2016

LafargeHolcim

Abstract: The preventive maintenance handbook is a standard for preventive maintenance engineer. It contains the most common technical information, guide lines, guide values, mainly in the form of tables and graphs, which is needed to ensure sustainable operation of equipment through proper preventive maintenance.

Content

1. Health and Safety

As in every aspect of maintenance, safety comes first. Preventive maintenance involves tasks done while the equipment is in operation, as well as during scheduled stops. Make sure you are prepared accordingly and never compromise anyone's Safety for the sake of performing an inspection. All health and safety related documents must be applied without compromise and zero tolerance. The most important documents comprise:

1. H&S Policy
2. The 5 H&S rules
3. The 13 Fatality Prevention Elements
4. Rules on PPE

For more detailed information contact your H&S officer.

2. Introduction and Objectives

This manual is a compilation of different charts, tables, graphs and other useful tools for a preventive maintenance engineer. The handbook does not pretend to be a training document and to cover all necessary aspects of preventive maintenance.

It gathers the most important information that will allow preliminary decision taking while in the field or, at the very least, to decide whether an encountered issue needs a more in-depth follow-up. In case more details are required on any particular subject, reference must be made to the LafargeHolcim maintenance manual. The preventive maintenance handbook strives to reach a balance between the most relevant information and being easy to carry in the pocket.

The objectives can be summarized as follows:

- To act as a refresher on preventive maintenance knowledge for the plant personnel working in this field
- To provide an overview on the most critical preventive maintenance routines (PMR's) to be carried out in a cement plant, the so called 'Key PMR's'
- To put at the fingertips of the preventive maintenance engineers the most relevant definitions and tables for analysis and decision making, such as alarm levels and acceptance criteria.
- To facilitate communication and knowledge transfer between the preventive maintenance engineer and his/her plant colleagues, supervisors and plant management.

3. Scope and Applicability

The preventive maintenance handbook has been conceived as a handy reference for the LafargeHolcim preventive maintenance engineer. The rules and recommendations in this handbook are universal and can be applied in most cases to both integrated cement plants and grinding units in all organizations belonging to the LafargeHolcim group irrespective of the process being used.

4. LafargeHolcim maintenance basics

Proper maintenance of plant equipment significantly contributes to the overall plant performance and its relevant key performance indicators. Although maintenance is often seen as an expense, a more positive approach is looking at it to view maintenance works as a profit center. The key to this approach lies in a proactive maintenance approach.

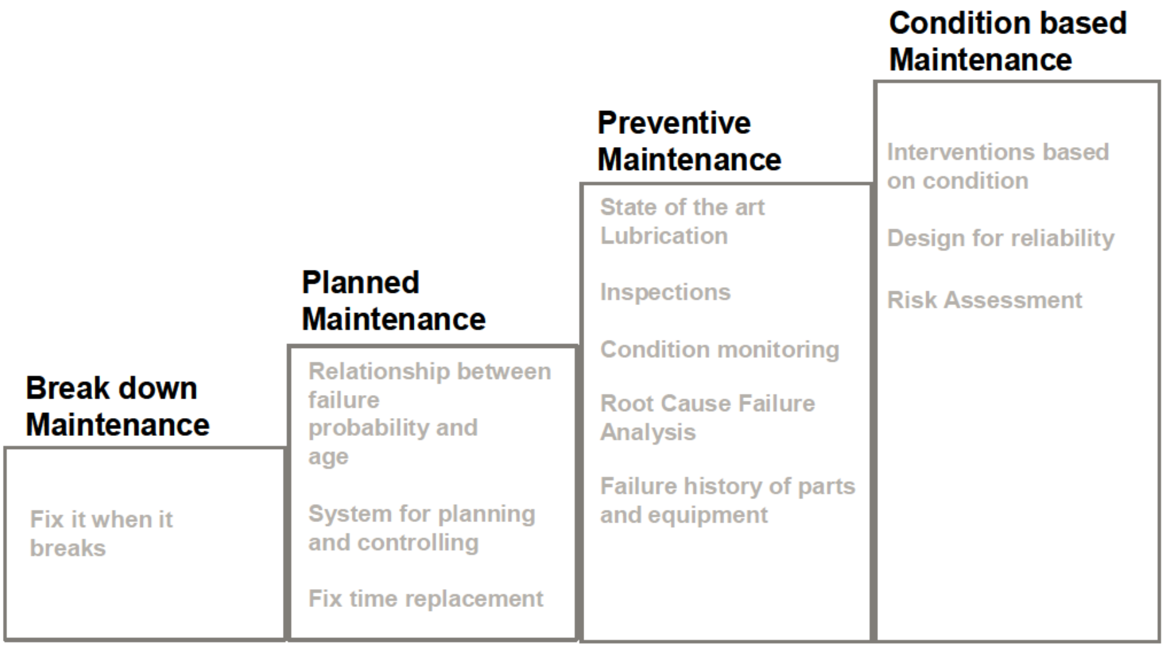


Figure 1: Evolution of maintenance. The ultimate goal is to find the right mix between all four strategies

4.1 Maintenance Management System (MAC)

MAC stands for Maintenance Cement

Objective: Achieve required asset availability and high reliability at an optimized sustainable maintenance cost, CAPEX to sustain and spare parts inventory level, in compliance with customer, environmental and safety requirements

Mission: To implement, sustain and consistently practice a standardized core of systems, techniques, tools and practices.

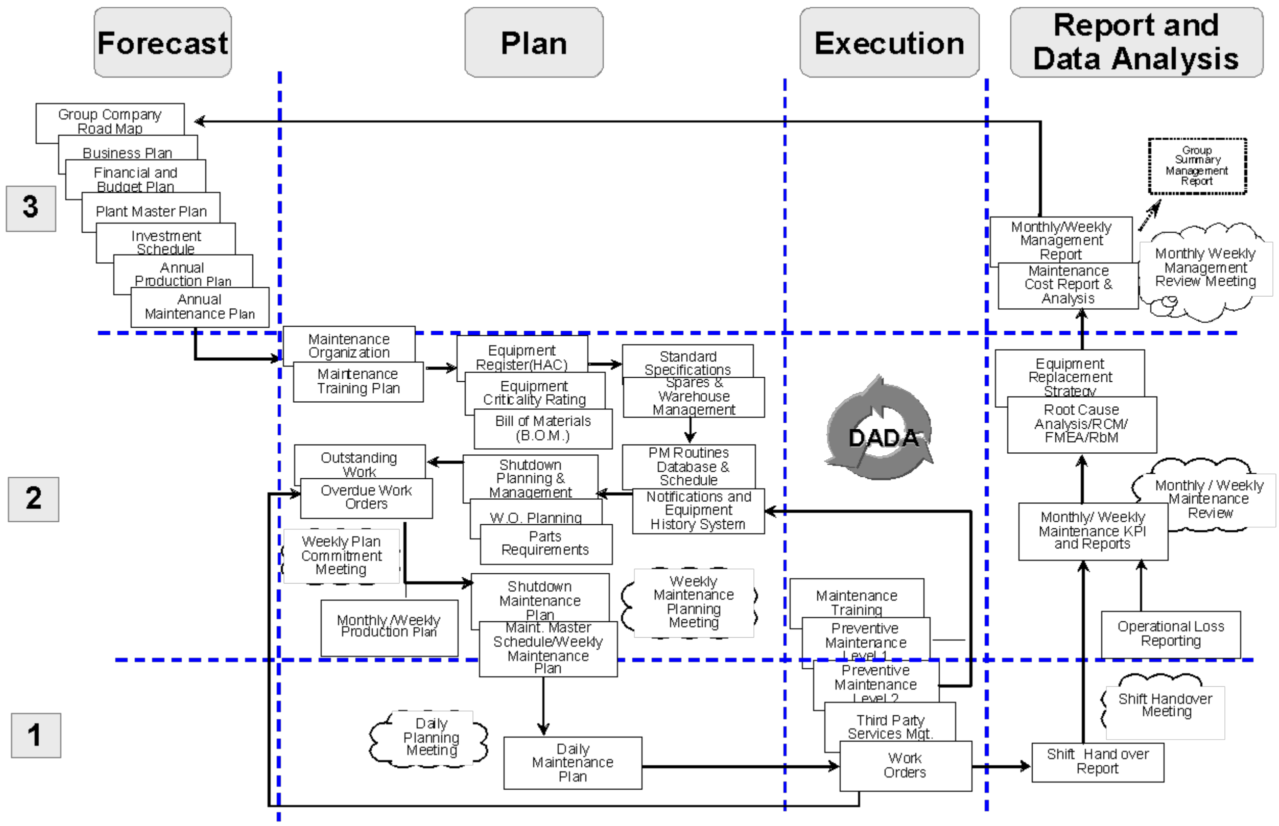


Figure 2: MAC process (system view)

The MAC system strongly supports preventive maintenance through:

- Preventive Maintenance Level 1, on the **foundation elements**, dealing with the basics, before proceeding to the next level (Level #2)
- Preventive Maintenance Level 2, on the **advanced elements**

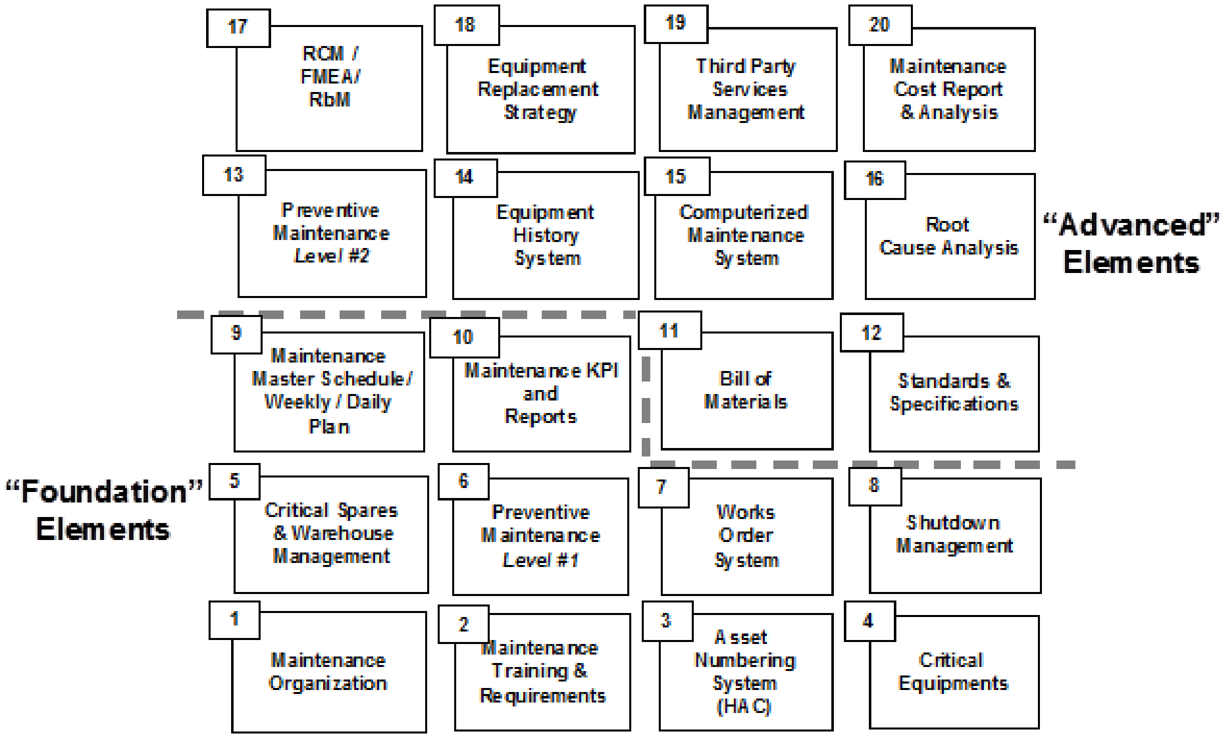


Figure 3: MAC elements (foundation and advanced)

It is crucial that preventive maintenance level #1 is firmly in place (lubrication, walk-by inspections, and preventive maintenance routines) before moving onto the preventive maintenance level 2. Experience has shown that for plants it is relatively easy to buy the measuring equipment required for advanced inspections, while neglecting the basics. This situation leads to an inadequate Maintenance performance.

For more detailed information on all the elements which are not related to preventive maintenance please refer to the Maintenance Manual.

4.2 Maintenance Organization

Based on the experience with different forms of organization the most efficient and powerful organization form is the functional organization. Clear structure, short lines of command and clear roles and responsibilities make this organization the best manageable.

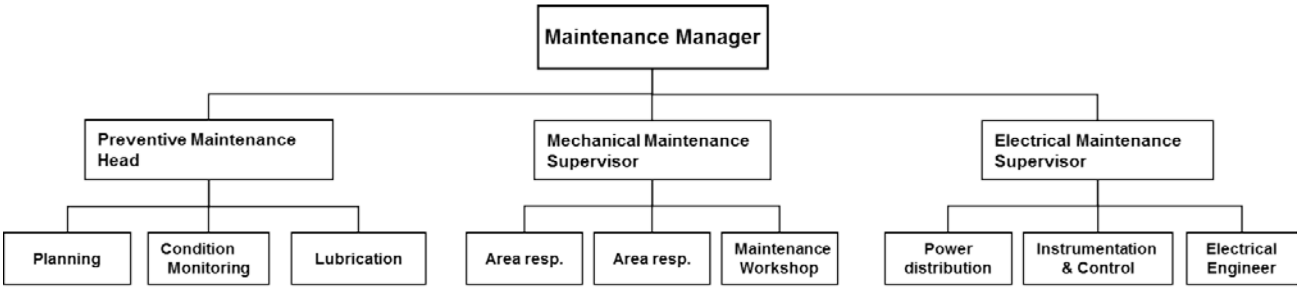


Figure 4: Maintenance organigram

For job descriptions please refer to the Annex 2: Job descriptions.

4.3 Preventive Maintenance

Preventive maintenance is one part of the overall equipment reliability process and is defined as follows:

Cost-effective maintenance tasks carried out at predetermined intervals to check the current physical condition, to reduce probability and/or impact of a failure in operation, or to maintain a desired level of performance of an equipment.

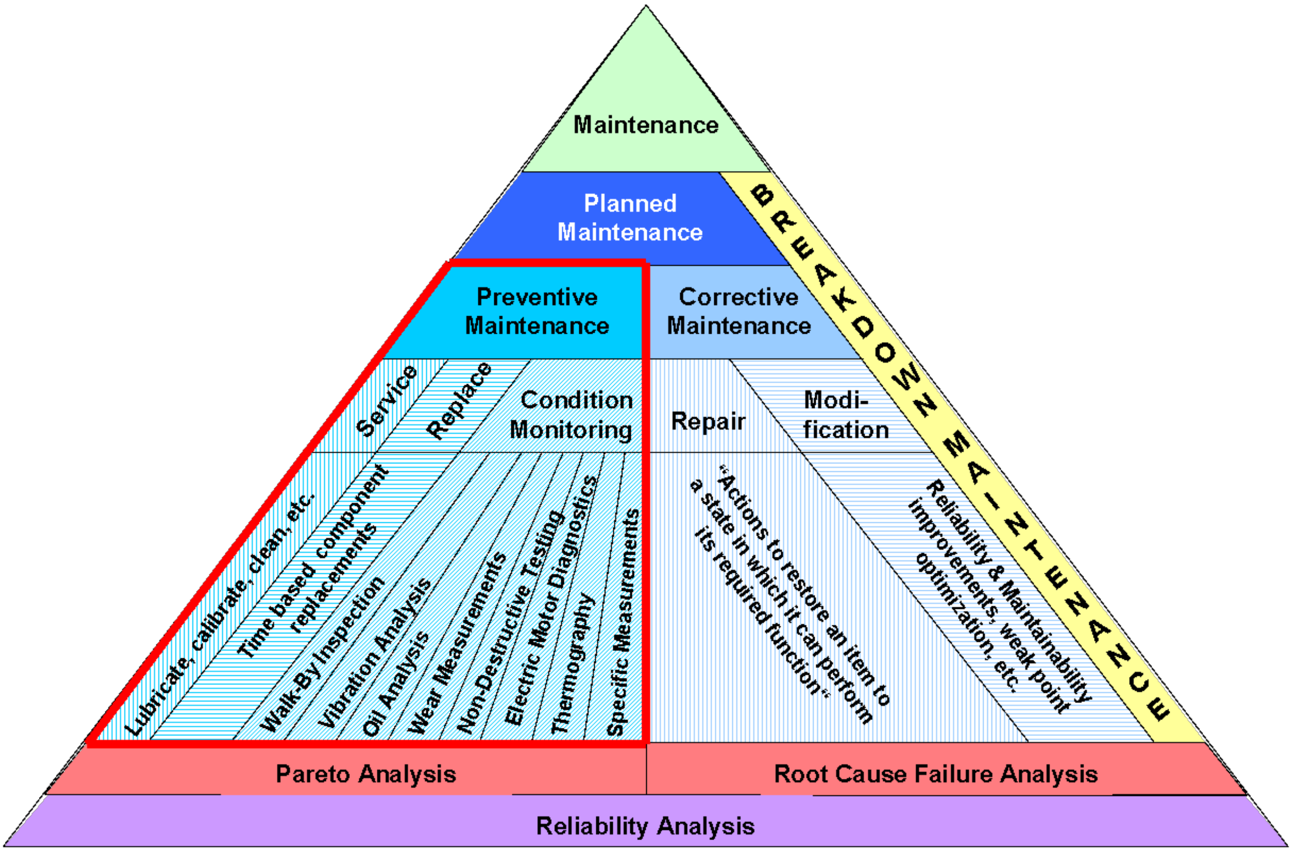


Figure 5: Preventive Maintenance elements within the overall Maintenance structure

4.4 Planning and Scheduling

Planning and scheduling is the core of maintenance activities coordination. Both represent the “work preparation” in maintenance and tackle the following aspects:

- Planning
  - → **What** is the scope of the work?
  - → **How** to do the work?
  - → **What** is required (materials, tools, people, etc.)?
- Scheduling
  - → **Who** does the work?
  - → **When** to do the work?

Both planning and scheduling are elements of the work order system.

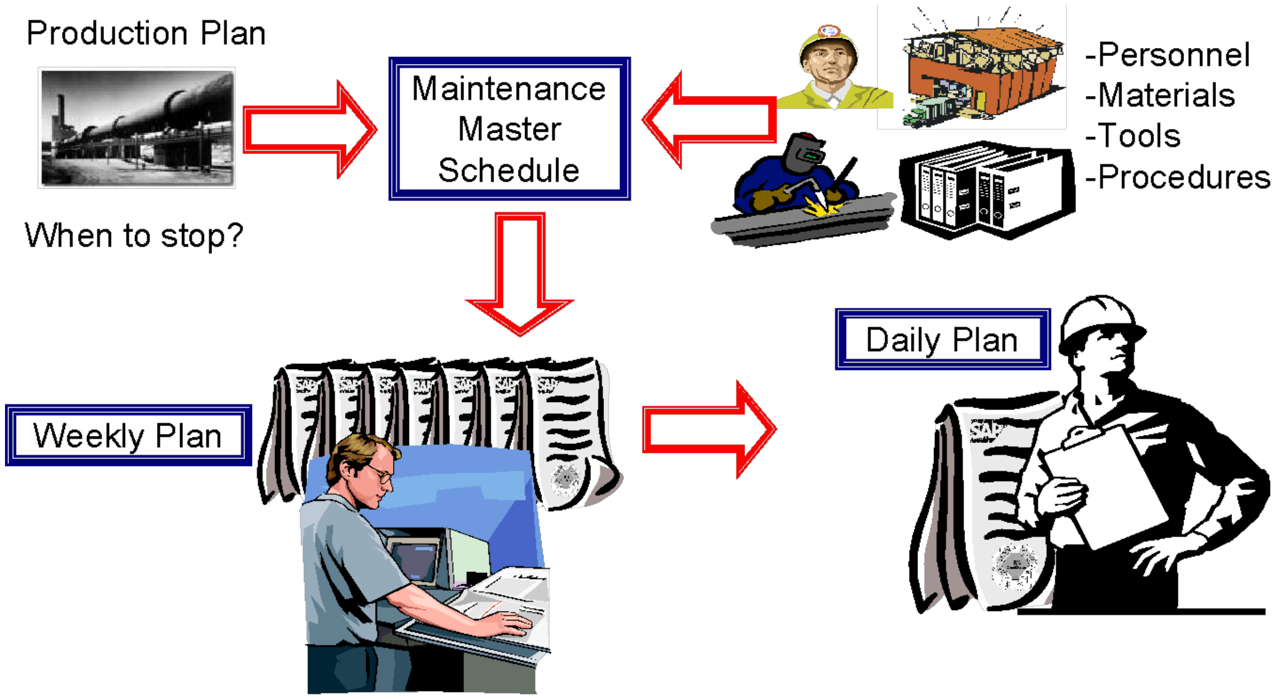


Figure 6: Planning and Scheduling process

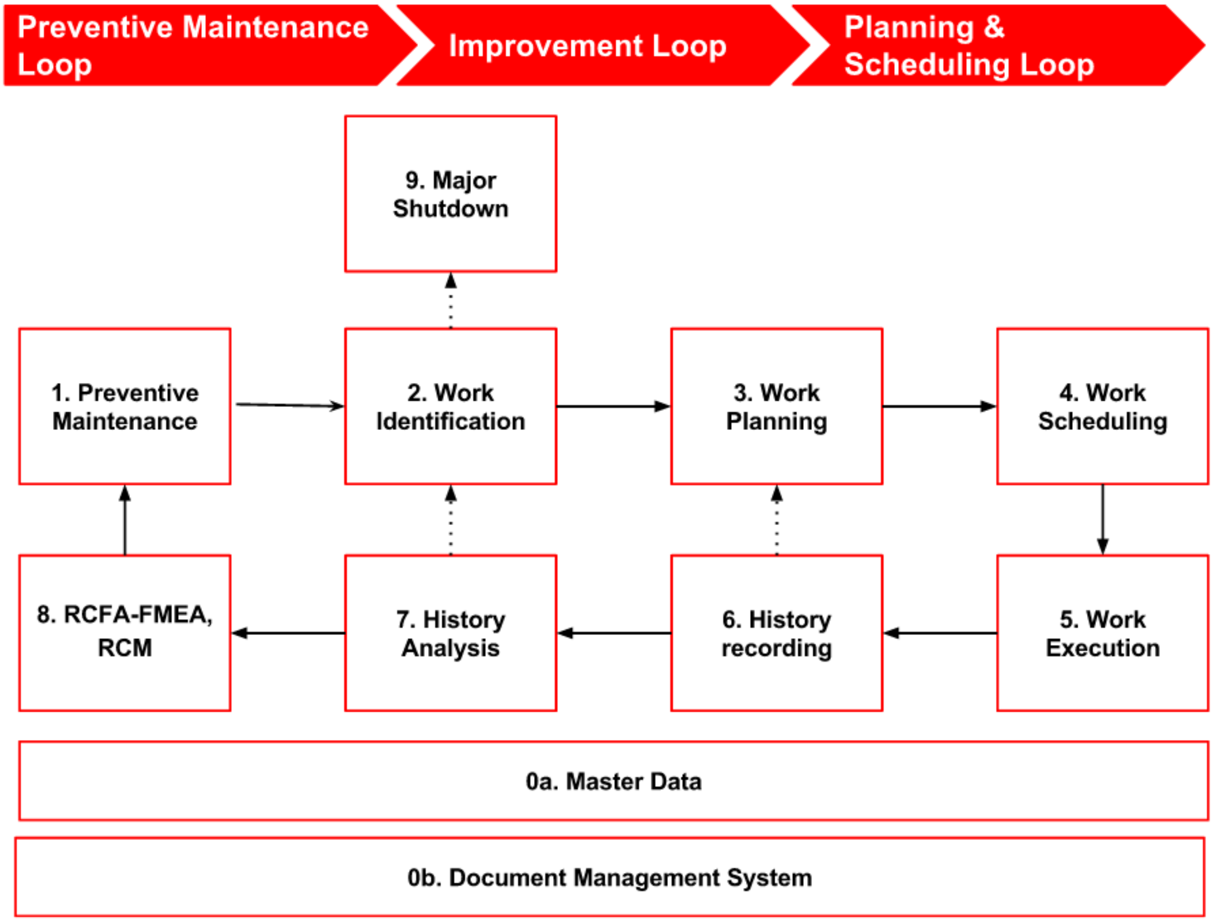


Figure 7: Work Order flow, triggered by the notification

4.5 Major Shutdown

It is a **plant** event and not a maintenance-only one!

In sold out markets the strategy is to optimize downtime, increasing availability and volume produced.

In non-sold out markets however, the strategy shall aim on cost optimization through increasing the number of shutdowns per year or to extend the shutdown duration (minimize third party services). Doing that, the following shall be achieved:

- Extension of the equipment lifetime (e.g. refractory, chains, belts, etc.)
- Reduction of avoidance of overtime and night work
- Internalization of costs (do it yourself instead of hiring third parties)

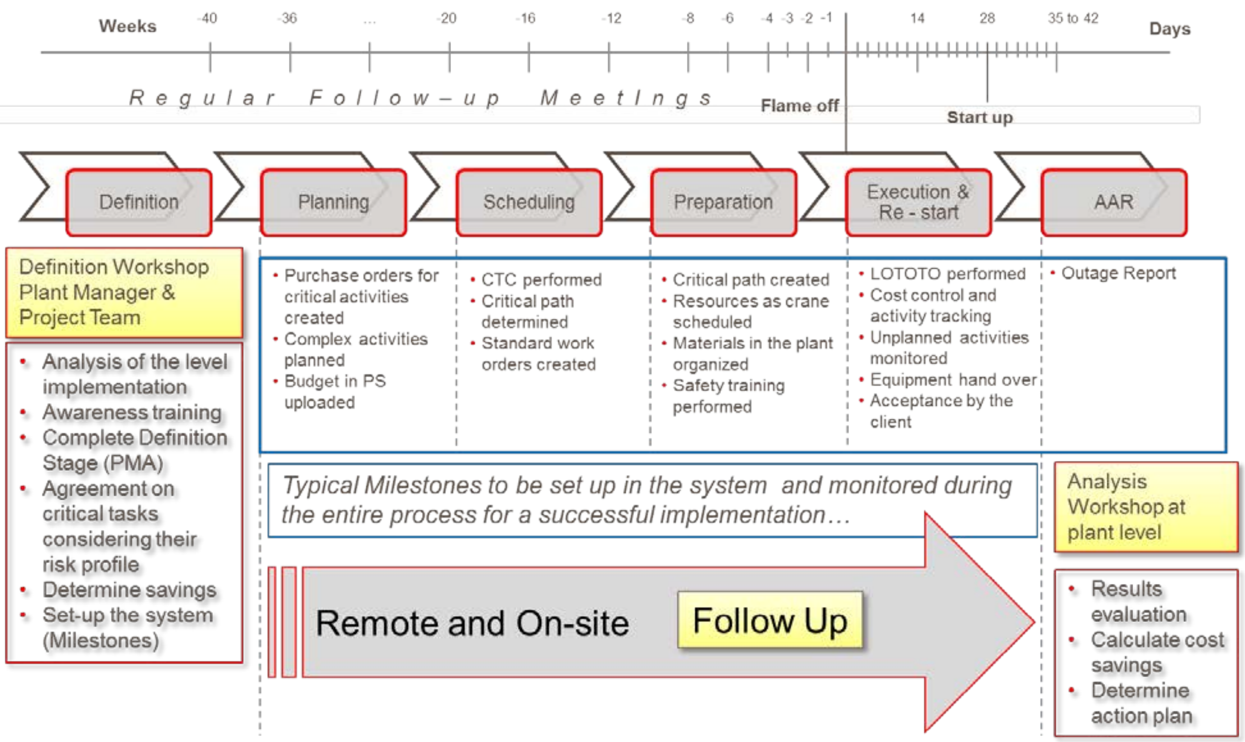


Figure 8: Major shutdown management cycle and success factors

4.6 Preventive Maintenance Routines (PMR's)

A preventive maintenance routine is a task performed at predetermined intervals, in order to check the current physical condition, to reduce probability and/or impact of a failure in operation, or to maintain a desired level of performance of an equipment. It is defined as PM02 in SAP PM.

This definition includes all periodic measurements performed as condition monitoring, whereas the resulting actions (e.g. alignment, fan balancing) would be considered as planned corrective maintenance (PM01 in SAP).

4.6.1 Workload balancing

Workload balancing aims on listing and distributing all PMR's within a certain period (one year as minimum) and adjust the sequence of them in order to balance the workforce requirements. Outsourced PMR's should also be listed but not included in the balancing of workforce requirement, unless own personnel is required. The Figure 9 shows the basic steps of workload balancing. An excel based tool is available.

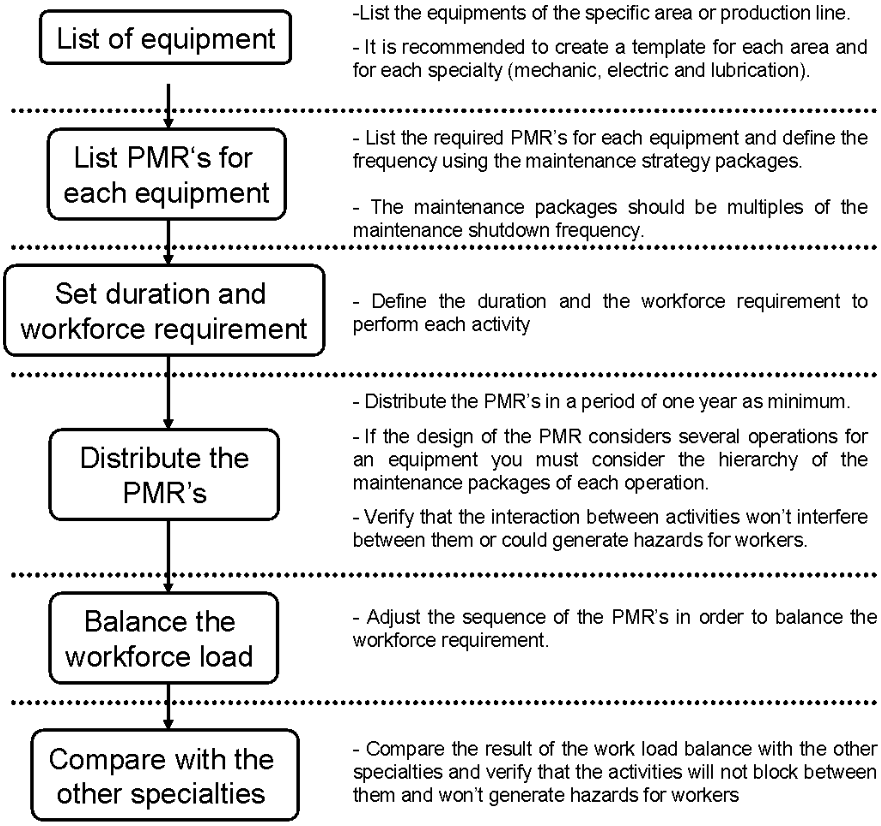


Figure 9: General & simplified workload balancing process

4.6.2 PMR management in SAP PM

The purpose of loading and scheduling PMR’s in SAP PM is the automatic generation of work orders for preventive maintenance activities at specific dates. This is a key input for the maintenance master plan. Workload balancing must be done before defining PMR’s in SAP PM.

Note that SAP PM uses the following terminology:

SAP PM	Purpose
Maintenance strategy	To define PM on time or counter basis or a process area or per plant To define packages (frequencies)
Tasks	Description of resources for PM activities (labour and material)
Maintenance item	Information for work order header (functional location, equipment, work center, cost center, order type and activity type)
Maintenance plan scheduling	To provide scheduling information

Table 1: SAP terminology regarding PMR management

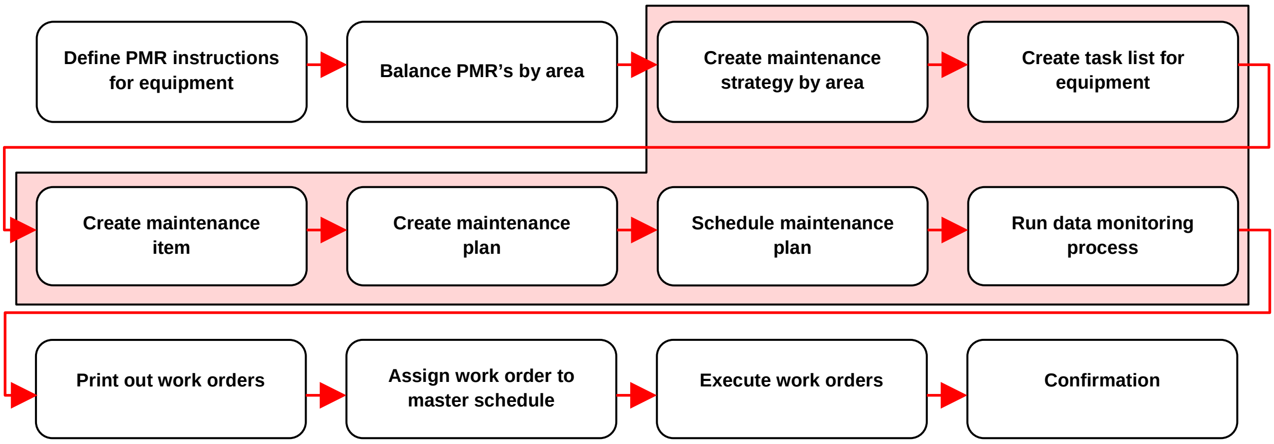


Figure 10: Preventive maintenance process (PM02) in SAP PM

The shaded area in the Figure 11 above represents the steps needed in SAP PM to set up the routines.

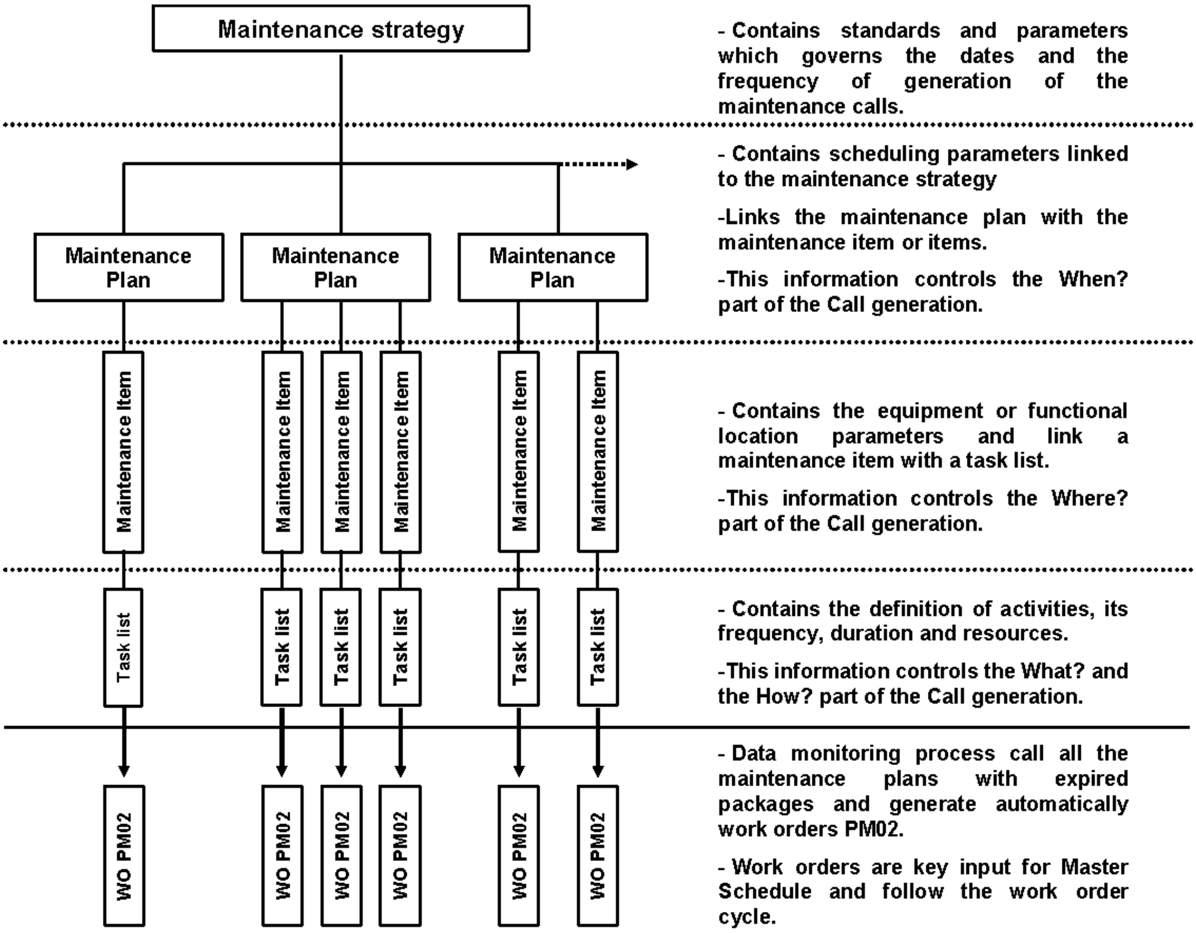


Figure 11: Preventive Maintenance database definitions in SAP PM

4.7 Maintenance Performance Indicators

Performance indicators are mainly used to understand the opportunities for improvement. Comparing performance indicators - along the time axis or between organizations - creates a learning challenge and gives management a tool to follow up on the progress of ongoing as well as on the sustainability of completed projects.

Note that the definitions in this chapter are in accordance with the "Maintenance Indicator Guide V6.1" and hence may not be up to date. Check on the latest version if used.

4.7.1 Key Performance indicator (KPI)

(**K1**) **Mean Time Between Failures MTBF** (different targets for Kiln/Mill)

$$Mean\ Time\ Between\ Failure\ [h] = \frac{Actual\ operating\ time\ [h]}{Failures\ [\#]}$$

- MTBF target (h)
  - → ≥ 500h for kilns
  - → ≥ 225h for ball mills and
  - → ≥ 125h for other mills

(**K2**) **Net Availability Index** (NAI)

$$Net\ Availability\ Index\ [\%] = \frac{Operating\ time\ [h]\ +\ Idle\ time\ [h]}{Calendar\ time\ [h]} \times 100$$

- Net Availability Index target (%)
  - → ≥ 90% for all relevant assets

(**K3**) **Maintenance Cost** (Δ% to Reference Value)

$$Maintenance\ Cost\ [\%] = \frac{Actual\ specific\ maint.\ cost\ -\ Reference\ value}{Reference\ value} \times 100$$

- Maintenance Cost target [%]
  - → ≤ 0%

(K4) PMR %

$$PMR\ [\%] = \frac{actual\ labor\ hours\ on\ final\ confirmed\ \ operation\ from\ PM02\ \ WO}{Total\ maintenance\ work\ performed} \times 100$$

- PMR % target
  - → Between 15% and 30%

(**K5**) **PMR efficiency** [%] – Update target based on usage from country

$$PMR\ Efficiency\ [\%] = \frac{\#\ Maintenance\ request\ generated\ from\ PM02\ WO}{\#\ of\ Maintenance\ request} \times 100$$

- PMR Efficiency (%)
  → > 35%

(**K6**) **Scheduling compliance** [%]

$$Scheduling\ compliance\ [\%] = \frac{Number\ of\ operation\ performed\ as\ scheduled}{Total\ number\ of\ scheduled\ operation} \times 100$$

- Scheduling compliance [%]
  → > 85%

(K7) Planning accuracy [%]

$$Planning\ acc.\ [\%] = 100 \times (1 - \frac{\sum ABS(\ Est. -\ Actual)\ \ Labor\ h\ all\ confirmed\ \ scheduled\ ops}{Actual\ labor\ h\ on\ all\ completed\ scheduled\ ops})$$

- Planning accuracy [%]
  → > 90%

4.7.2 System and process performance indicators (SPI)

(**S1**) **Call out** [#]

$$Call\ out\ [\#] = \#\ of\ call\ out\ work\ orders$$

- Call out target [#]
  → < 5 per week in average during a year

(**S2**) **Outstanding work** [week]

$$Outstanding\ work\ [W] = \frac{\sum Estimated\ hours}{Weekly\ average\ available\ capacity}$$

(**S3**) **Overdue** [h]

$$Overdue\ (h) = \sum Estimated\ labor\ hours\ on\ all\ overdue\ work\ orders$$

(**S4**) **Schedule Ratio** [%]

$$Schedule\ Ratio\ (\%) = \frac{Total\ estimated\ hours\ on\ scheduled\ work\ orders}{Total\ estimated\ available\ own\ labor\ hours} \times 100$$

- Schedule Ratio target (#)
  → > 95%

(**S5**) **PMR not performed** [%]

$$PMR\ not\ performed\ (\%) = \frac{PMR\ not\ performed}{Total\ PMR} \times 100$$

- PMR not performed target [#]
  → < 5%

(**S6**) **BOM Material PR ratio** [%]

$$BOM\ \ PR\ ratio\ [\%] = \frac{\#\ PO\ item\ on\ maintenance\ material\ \ not\ attached\ to\ BOM}{Total\ \#\ PO\ item\ on\ maintenance\ \ material} \times 100$$

- BOM Material PR ratio target [#]
  → < 15%

(**S7**) **Aging Maintenance Request** [#]

$$Aging\ Maint.Request\ [\#] = \#\ Maint.request\ older\ than\ 10d\ not\ in\ process$$

- Aging Maintenance Request target [#]
  → < 5

(**S8**) **PM01 without Maintenance request** [%]

$$PM01\ without\ MR\ [\%] = \frac{\#\ of\ PM01\ WO\ without\ maintenance\ \ request}{Total\ \#PM01\ WO} \times 100$$

- PM01 without Maintenance request target [%]
  → < 1%

(**S9**) **Material reservation usage** [%]

$$Material\ reservation\ usage\ [\%] = \frac{\#\ of\ maintenance\ material\ reserved}{Total\ \#of\ maintenance\ material\ \ issued} \times 100$$

- Material reservation usage target [%]
  → > 50%

(**S10**) **Aging Work Order** [#]

$$Aging\ Work\ Order\ [\#] = \#\ Work\ Order\ not\ technically\ completed$$

- Aging Work Order target [#]
  → < 30

(**S11**) **PM02 manual call ratio** [%]

$$PM02\ manual\ call\ ratio\ [\%] = \frac{\#\ of\ PM\ work\ orders\ \ manually\ generated}{Total\ \#of\ preventive\ maintenance\ \ work\ order} \times 100$$

- PM02 manual call ratio target [%]
  → < 5%

(**S12**) **Unplanned** [%]

$$Unplanned\ [\%] = \frac{Actual\ work\ confirmed\ on\ unplanned\ operations}{Total\ maintenance\ work\ performed} \times 100$$

- Unplanned target [%]
  → < 10%

5. Preventive Maintenance Level 1

In the following an overview on the basic preventive maintenance philosophy and structure, application and practices are given.

5.1 Walk-by inspections

Walk-by inspection is defined as an inspection carried out with the equipment in running condition, using simple tools and human senses. Such inspections are supported by check sheets which show the points and criteria to be checked.

Do not confuse walk-by inspection with 'visual inspection'. The visual inspection is part of the non-destructive testing (NDT) techniques and is performed with the equipment stopped.

Responsible	Production	Maintenance
Objective	Symptom detection, e.g. spillages	Cause detection, e.g. belt scrapers complete and in proper position
Frequency	High (shift/daily)	Medium (Daily/Weekly)
Tools	Flashlight	Flashlight, Heat gun, vibrometer

Table 2: Walk by responsibility

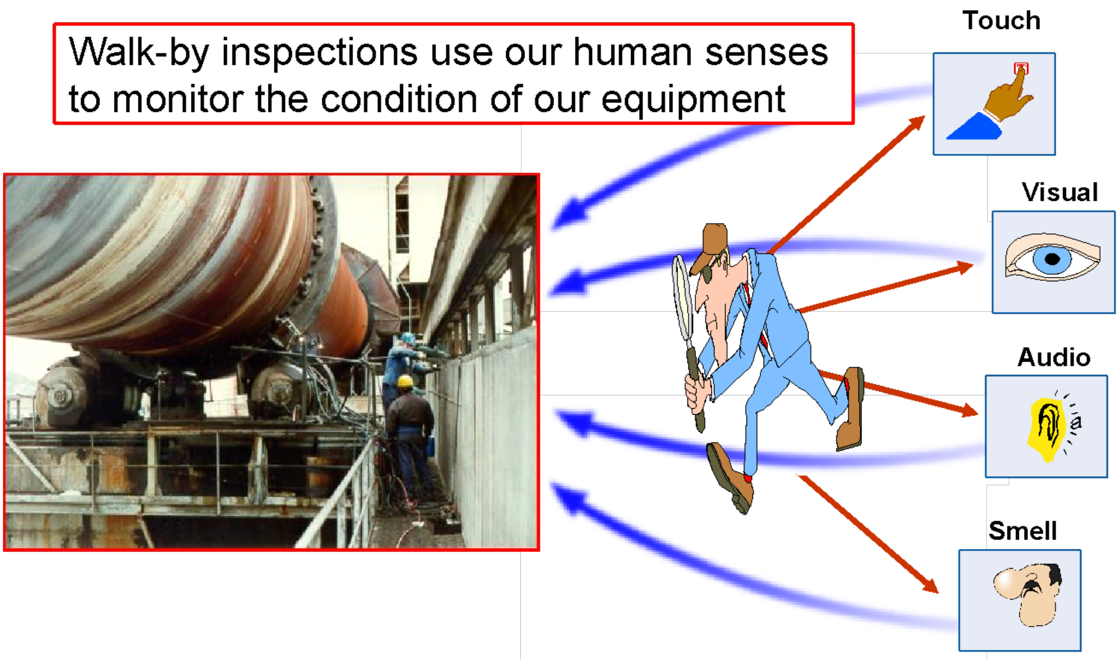


Figure 12: Definition of walk-by inspections

Visual aids (or marking of gauges) are an easy and simple way to boost the effectiveness of any walk-by inspection. If every important gauge in the plant is already showing the acceptable range of operation, even unskilled workers can immediately recognize if the range is exceeded and give warning to the responsible individuals for further action to be taken.

Figure 13: Visual aids for gauges

Plan category	Responsible	ACS code	Equipment	Activity SAP-PM	Task	Normal range	frequency (w)	equipment condition	task priority (legal - normal)
wbi	prod	xxx.BMx	Ball Mill	insp	safety protections and guards correctly installed	.	d	r	.
wbi	prod	xxx.BMx	Ball Mill	insp	leakages, spillages feed & discharge end, cilinder, manhole,	.	d	r	.
wbi	prod	xxx.BMx	Ball Mill	insp	Bolts loose or missing, mill feed/discharge end, shell, manhole, bearings	.	d	r	.
wbi	prod	xxx.BMx	Ball Mill	insp	check noices & vibration	.	d	r	.
wbi	prod	xxx.BMx	Ball Mill	insp	check mill sound	.	d	r	.
wbi	prod	xxx.BMx	Ball Mill	insp	check oil pres & temp of mill bearings (trunion or sliding shoes)	specify	d	r	.
wbi	prod	xxx.BMx	Ball Mill	insp	check oil level on feed and disch end (trunions or sliding shoes)	specify	d	r	.
wbi	prod	xxx.BMx	Ball Mill	insp	check for water leakages (water injection system, rotary seal,..)	specify	d	r	.
wbi	meci	xxx.BMx	Ball Mill	insp	check feed-end mill bearing pressure	specify	1	r	.
wbi	meci	xxx.BMx	Ball Mill	insp	check feed-end mill bearing temperature (trunion or sliding shoes)	specify	1	r	.
wbi	meci	xxx.BMx	Ball Mill	insp	check feed-end mill bearing oil level	specify	1	r	.
wbi	meci	xxx.BMx	Ball Mill	insp	check feed-end mill bearing water flow	.	1	r	.

Figure 14: Sample check sheet that can be integrated into SAP PM using the document management system (DMS).

The purpose of the inspection is to discover and report anomalies through **notifications**!

5.2 Lubrication

Note that a lot of useful information is available online under www.machinerylubrication.com

In the following the basic aspects of lubrication are shown. Note that oil analysis is handled in a separate chapter (preventive maintenance level 2).

5.2.1 Oil

Selecting oil is primarily based on the viscosity required to provide adequate lubrication for rotating elements at operating temperature. The viscosity of oil is depending on temperature. The respective relationship is characterized by the viscosity index. For rolling bearing lubrication, oils having a high viscosity index (little change with temperature) are recommended (95 and higher).

Viscosities and selection

Figure 15 shows the different viscosity scales commonly used and the conversion into other scales.

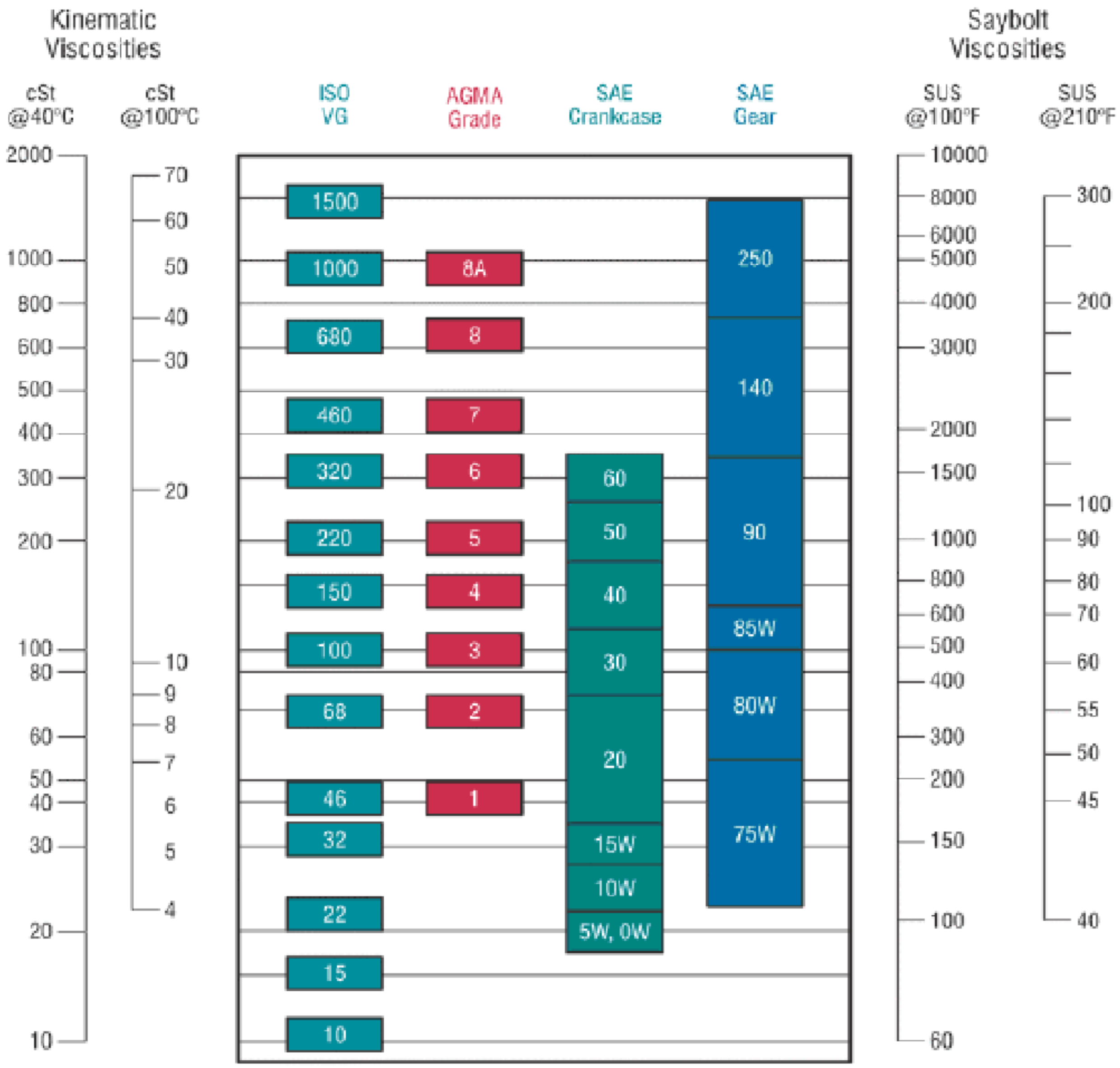


Figure 15: Equivalence chart for oil viscosities

The following figures allow the calculation of the required viscosity to assure proper lubrication at operating temperature of the machine.

Maximum Viscosities cSt	
22,000	Probably maximum pouring viscosity
Optimum Viscosities cSt	**At Operating Temperature**
25	Hydraulic Systems
30	Plain Bearings
40	Spur & Helical Gears (e.g. ISO-VG 220 @ 65°C)
75	Worm Gears (e.g. 460 @ 75°C)
Minimum Viscosities cSt	**At Operating Temperature**
13	Hydraulic Systems
13	Plain Bearings
21	Spherical Roller Bearings
33	Spur & Helical Gears
4	Minimum Viscosity to support a dynamic load

Table 3: Viscosity Guide Table

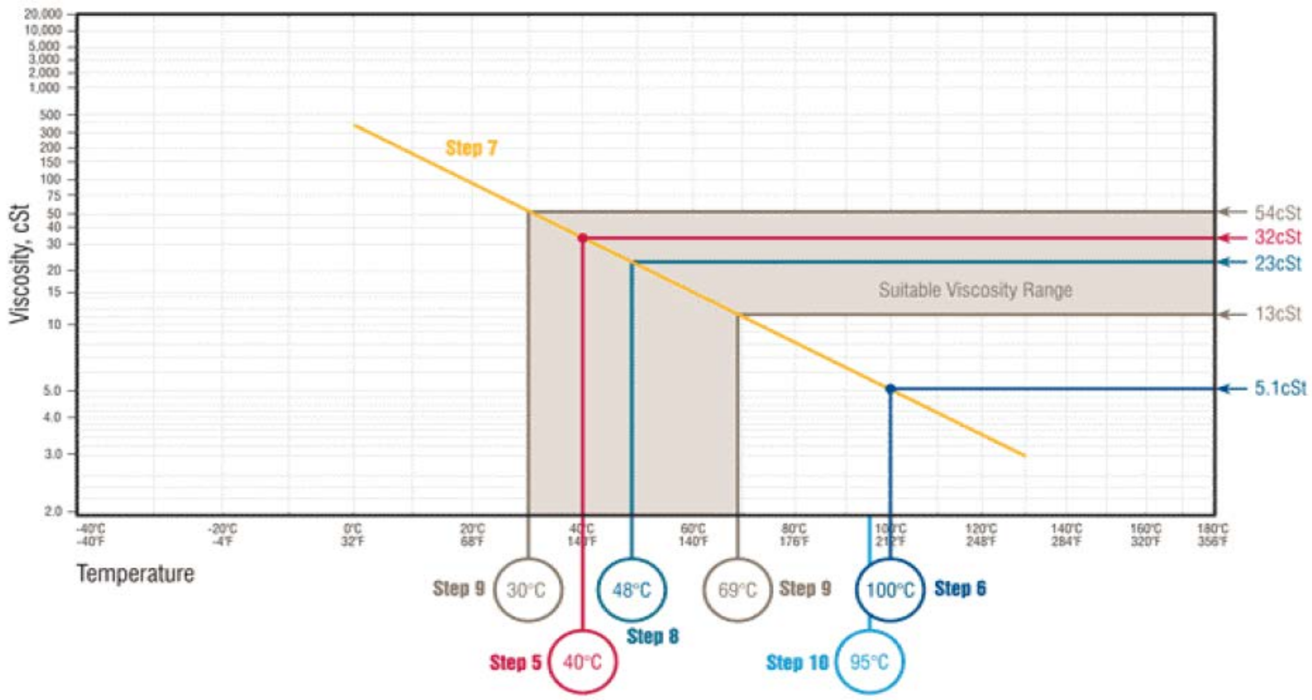


Figure 16: Example of oil viscosity selection for hydraulic systems

Based on the Figure 16, optimum viscosity is of 25cSt and minimum of 13cSt (at operating temperature). Choosing an ISO VG 32 grade, the line can be plotted between the respective viscosity values at 40°C and 100°C. Depending on the operating temperature, the viscosity will change along the green line. In this example, with an ISO VG 32 oil the minimum required viscosity would be reached at 69°C.

Additives

ADDITIVE	Engine Oils	ATF	General Purpose Oil	Hydraulic Oil	Industrial Gear Oil	Automotive Gear Oil	Grease
Detergents	✓	✓					
Dispersants	✓	✓					
Anti-Oxidants	✓	✓	✓	✓	✓	✓	✓
Rust Inhibitors	✓	✓	✓	✓	✓	✓	✓
Anti-Wear	✓	✓		✓	✓	✓	✓
E.P. Agents					✓	✓	✓
VI Improvers	✓	✓			Some	Some	
Pour Point Depressants	✓	✓	✓	✓	✓	✓	
Anti-Foam	✓	✓	✓	✓	✓	✓	
Dyes		✓					✓
Friction Modifiers	✓	✓					

ATF – Automatic Transmission Fluid

Table 4: Application of different additives

5.2.2 Grease

Grease lubrication is used wherever oil lubrication is not possible or not necessary and in particular when the lubricant must remain localized in a mechanism (e.g. re-lubrication not possible or not economic). Greases adhere well to sliding surfaces and provide efficient protection from ingress of dust, dirt and water. Their major disadvantage is increased internal friction.

Properties and application of thickeners and solid lubricants

Grease consists of: thickener (5-20%), lubricating oil (75-95%), additives (0-15%)

The majority of greases are used for roller bearings and sometimes for plain bearings, transmissions and open gears.

Thickeners	**Main Advantage(s)**
Metal Soaps (Ba, Li, Ca)	*multipurpose*
Bentonite (Clay) / Silica	*high temperature*
Aluminum Complex	*high temperature*
Plastic (PE, PTFE, FEP)	*high temperature*
Polyurea	*vibration, sealed for life*
Barium Complex	*extreme pressure*
Calcium Complex	*water resistance, corrosion protection*
Solid Lubricants	**Reason for Use**
Graphite	*anti-wear*
Zinc Oxide	*white colour*
Calcium Carbonate	*anti-rust, EP*
Molybdenum Disulphide (“Moly”)	*anti-wear, load-carrying*

Table 5: Application of grease thickeners and solid lubricants

NLGI Grade	Walk penetration DIN 51804 / 1 (0.1 mm)	Structure	Application Generally
000 00 0	445...475 400...430 355...385	fluid almost fluid extremely soft	Mainly for gear reducer lubrication
1 2 3	310...340 265...295 220...250	very soft soft moderate	Roller and plain bearing lubrication
4 5 6	175...205 130...160 85...115	stiff very stiff extremely stiff	Grease for labyrinth seals and fittings

Table 6: Grease consistency and general application

Bearing regreasing

Regreasing frequency

Regreasing frequencies can be estimated using the Figure 17. This simple approach ignores the bearing load ratio (stress on the bearing). However, for most applications this approach is still accurate enough. Regarding more accurate methods for determination of the re-greasing interval, please contact the manual owner.

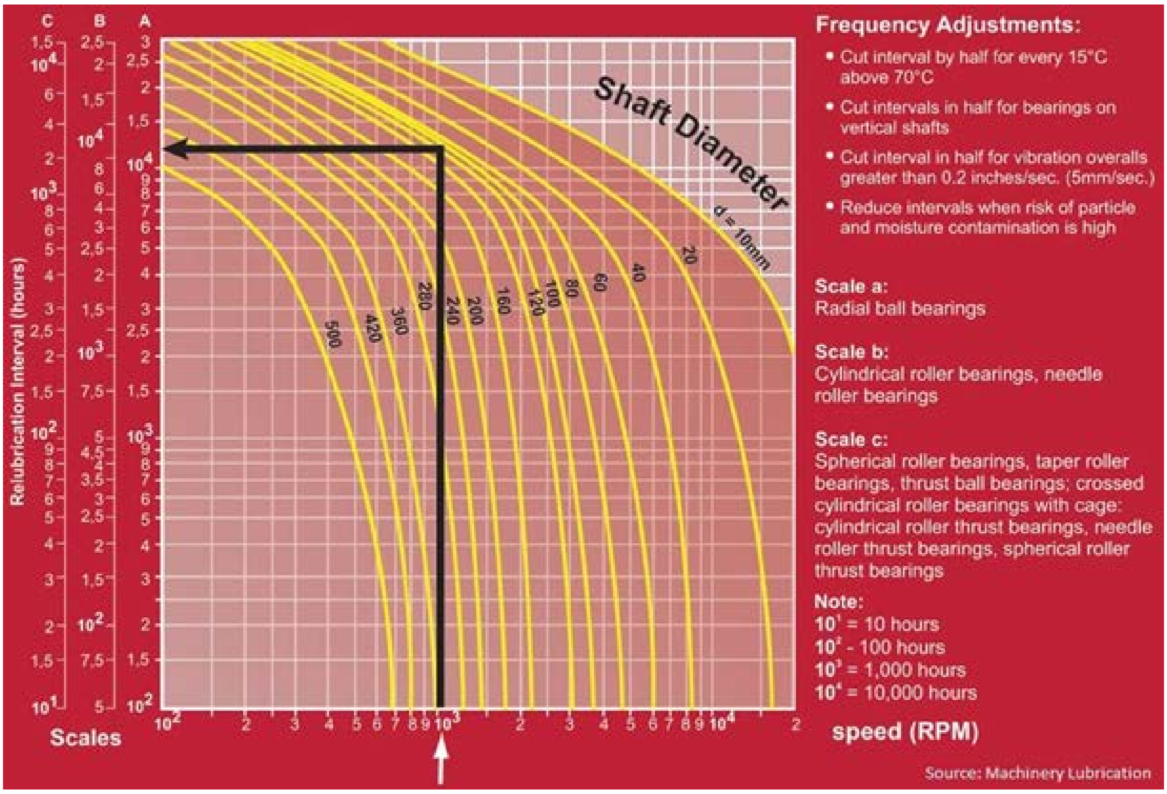


Figure 17: Determination of the regreasing frequency as a function of speed, shaft diameter and bearing type

An alternative to time based re-greasing is condition based re-greasing (ultrasound detection).

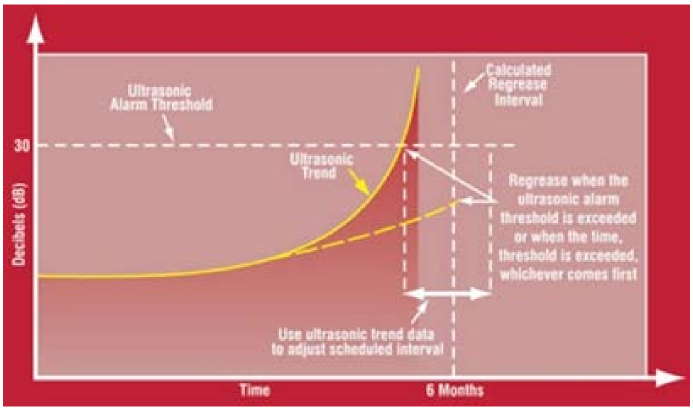


Figure 18: Condition based regreasing

Regreasing quantity

Suitable quantities for regreasing from the side of a bearing can be obtained from formula:

Gp = **0,005 D** x **B**

and for regreasing through the bearing outer or inner ring from formula:

Gp = **0,002 D** x **B**

Where:

Gp - grease quantity in grams

D - bearing outside diameter in mm

B - total bearing width in mm (the corresponding dimension for thrust bearings is H)

Grease compatibility matrix

	Aluminum Complex	Barium	Calcium	Calcium 12 Hydroxy	Calcium Complex	Clay	Lithium	Lithium 12 Hydroxy	Lithium Complex	Polyurea	Sodium	Calcium Sulfonate
Aluminum Complex	-	■	■	●	■	■	■	■	●	■	■	■
Barium	■	-	■	●	■	■	■	■	■	■	■	▼
Calcium	■	■	-	●	■	●	●	▼	●	■	■	N/A
Calcium 12-Hydroxy	●	●	●	-	▼	●	●	●	●	■	■	N/A
Calcium Complex	■	■	■	▼	-	■	■	■	●	●	■	●
Bentone (Clay)	■	■	●	●	■	-	■	■	■	■	■	■
Lithium	■	■	●	●	■	■	-	●	●	■	■	●
Lithium 12-Hydroxy	■	■	▼	●	■	■	●	-	●	■	■	●
Lithium Complex	●	■	●	●	●	■	●	●	-	■	■	●
Polyurea	■	■	■	■	●	■	■	■	■	-	■	■
Sodium (Soda Base)	■	■	■	■	■	■	■	■	■	■	-	■
Calcuim Sulfonate	■	▼	N/A	N/A	●	■	●	●	●	■	■	-

▼ Borderline Compatibility ● Compatible ■ Incompatible N/A - Not Available

Table 7: Grease compatibility (Source: Noria)

5.2.3 Lubrication chart

The lubrication chart is the main source of information regarding lubrication activities required at the plant.

This is a **MUST** for every plant, since based on this data the lubrication routes will be developed.

LafargeHolcim **Lubrication Chart** Plant: ____________ Revision Date: ____________

			Lubricant					Application Method	Lubricating Points		ACTIVITY TYPE FREQUENCY											
											Inspection Points				Grease		Oil					
ACS	Equipment Description	Element to Lubricate	Type of Lubricant	Comercial Designation	Technical Designation	Quantity	Unit of Measurement	Application Method	No. of Lube pt	Fitting	Oil Level	Grease Level	Oil Filter	Breather	Regreasing	Regreasing [g]	Oil Sampling	Oil Analysing Company	Oil Change	Oil Filteration	Comments	ROUTE

Figure 19: Lubrication chart template layout example

			Lubricant				Application Method
ACS	Equipment Description	Element to Lubricate	Type of Lubricant	Designation	Quantity	Unit of Measurement	Application Method

Figure 20: Lubrication chart template layout example Zoom

Lubricating Points		ACTIVITY TYPE FREQUENCY													
		Inspection Points				Grease		Oil							
No. of Lube pt	Fitting	Oil Level	Grease Level	Oil Filter	Breather	Regreasing	Regreasing [g]	Oil Sampling	Oil Analysing Company	Oil Change	Oil Filteration	Comments	ROUTE		

Figure 21: Lubrication chart template layout example Zoom

5.2.4 Lubrication storage and handling practices

Lubricant should always be kept cool, dry and clean. This applies also for the storage facility.

A storage temperature increase of 10 °C doubles the oxidation rate!

Assuming a clean environment within the lube workshop, filter rating of 25µm is required for the breather. Filtering oil upon arrival and storing it in dedicated containers is best practice, since possible contaminations are removed.

Figure 22: Battery of drums connected to a single desiccant breather filter

Figure 23: Fresh oil is filtered and transferred to a bulk storage (tote), fitted with desiccant breather filters

Figure 24: General health and safety related information signs shall be displayed in the lubrication workshop

Figure 25: Labelling of containers should include information on the lubricant type as well as health and safety related aspects

The following labelling system from Noria Corporation is a good example what kind of information should be displayed on a lubricant containing container. Such kind of labeling systems may also be used directly on the equipment for a fast identification of the correct lubricant.

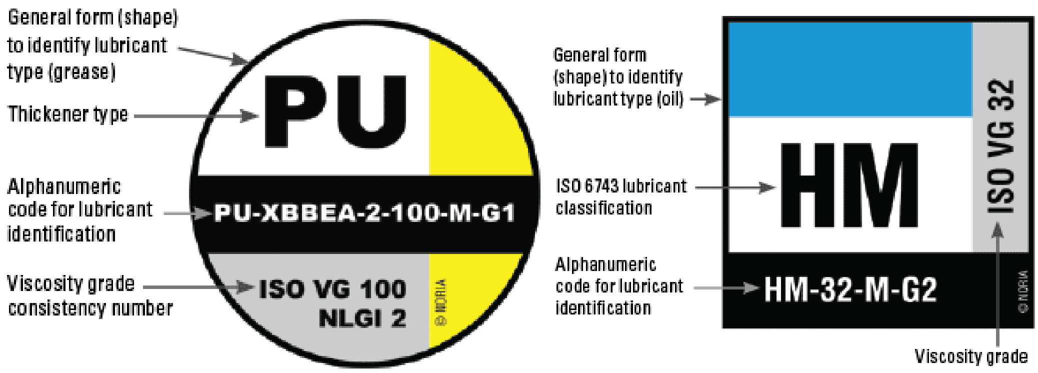


Figure 26: Example for labeling of a grease and oil drums

Drums should always be stored such that the bung of the drum is located at the 3 or 9 o'clock positions to avoid drying out of the seal and hence ingress moisture.

Preventive maintenance on lubrication storage rooms:

	Task description	Visual Check	Frequency [weeks]
Lubricants	Ensure lubricant drums are stored horizontally	X	24
	Ensure drip trays are available	X	24
	Ensure that tools are kept very clean	X	24
	Ensure proper housekeeping is in place and the storage location is free of dust	X	24

Table 8: Preventive maintenance on lubrication storage rooms

Product	Maximum Recommended Storage Time
Lithium Greases	12 months
Calcium Complex Greases	6 months
Lubricating Oils	12 months
Emulsion Type Fire-Resistant Fluids	6 months
Soluble Oils	6 months
Custom Blended Soluble Oils	3 months
Wax Emulsions	6 months
Source: Wills' Recommended Shelf Life for Select Lubricants	

Table 9: Recommended shelf life for lubricants

6. Preventive Maintenance Level 2

This is more of an in depth and advanced application of the preventive maintenance philosophy and refers to the different technical methods and tests. In the handbook the focus is on:

- Oil analysis (electrical and non-electrical)
- Vibration analysis
- Thermography
- Non-destructive testing
- Wear measurement
- Electric motor diagnosis
- PMR's on Emission monitoring systems

The purpose is determining the condition of an equipment and its main components. By detecting anomalies at an earlier stage, more time will be left to plan an adequate corrective measure. More training and skills are required in order to succeed with this MAC element, although some of the techniques will be outsourced to specialized companies.

6.1 Condition monitoring (CM): P-F curve and condition monitoring matrix

"The continuous or periodic measurement, recording and interpretation of data to indicate the condition of an item to determine the need for maintenance"

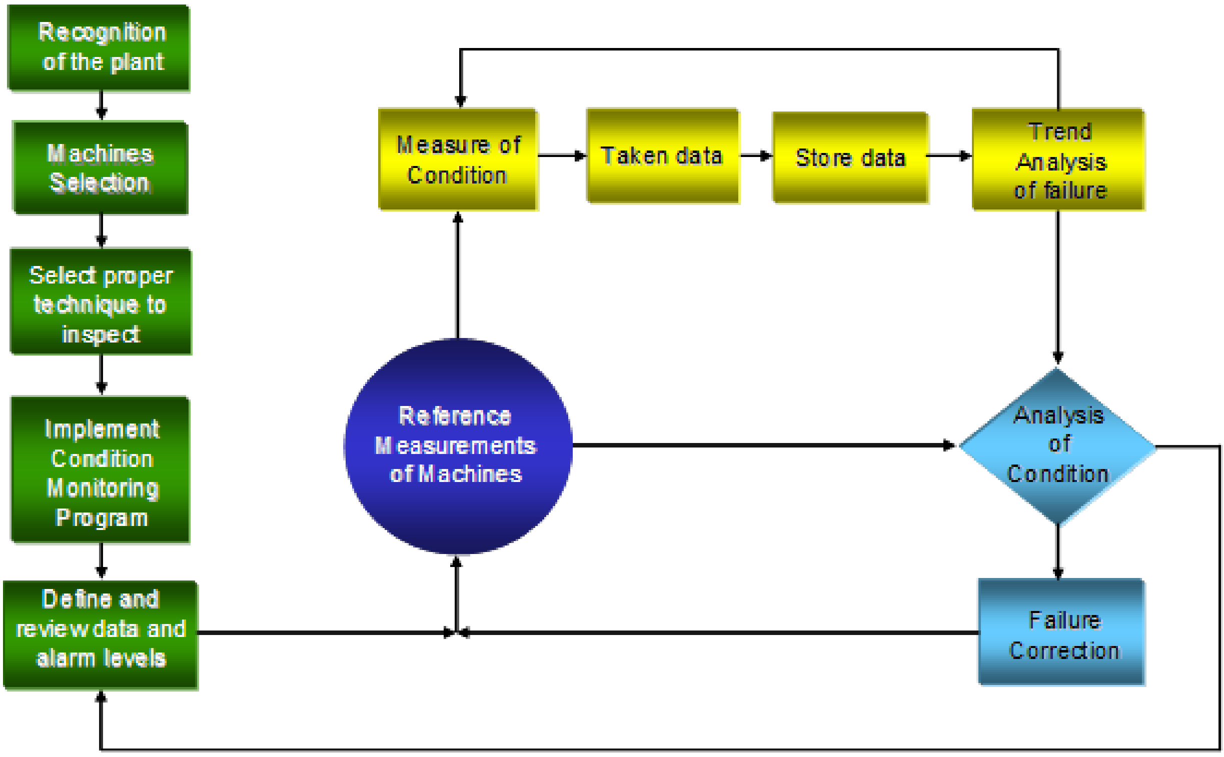


Figure 27: Condition monitoring program implementation

Condition Monitoring relies on the fact that most failures do not occur instantaneous, but rather over time (see Figure 28):

A: At the beginning of a failure, the deviation is so small that it is un-detectable

P (Potential Failure): At some point, however, the deviation reaches a level in which it is measureable

F (Functional Failure): If not corrected, the component will fail completely

T = P-F interval: Time between the occurrence of a potential failure (detection possible) and its decay into the failure itself. In reality P-F-Intervals are not necessarily consistent. In fact they can vary over a considerable range of values.

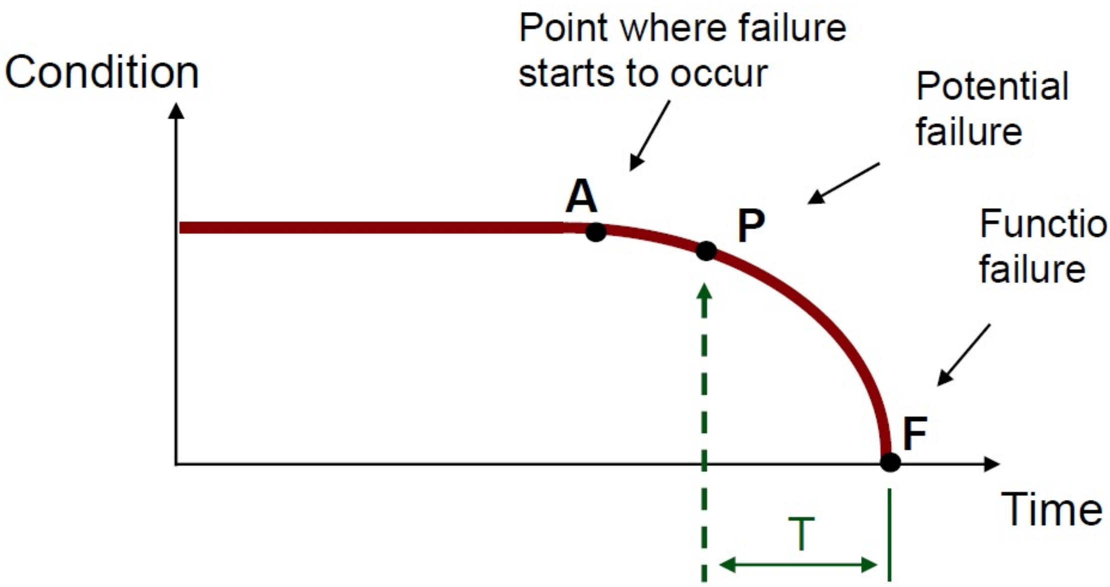


Figure 28: P-F Curve

Condition monitoring techniques are not necessarily cheap, however, if the concept is correctly applied, it can save a lot of money by detecting a failure at an early stage and thus preventing unplanned equipment downtime.

The techniques should be selected upon mode of failure and its consequences. Information about the applied techniques and frequencies for each equipment should be kept in a condition monitoring matrix, as shown in the Figure 29.

	NDT				Thermo	Oil Analysis	Vibration Analysis	Wear Measurement	Walk-By Inspection	Other	
	VT	UT	MT	DP						Freq	Description
ELECTRICAL INSTALLATIONS											
GROUNDING SYSTEMS										48	CHECK THE RESISTANCE OF THE GROUNDING SYSTEMS
MCC					12						
SWITCHGEAR					12						
TRANSFORMER					12	48					
AIR LIFT,PNEUMATIC ELEVATOR											
FABRIC	SPS										
TANK	SPS										
BELT CONVEYOR											
BELT									0,14 TO 2		
DRIVE									0,14 TO 2		
DRIVE SHAFT	24 TO 48										
MOTOR							2 TO 4		0,14 TO 2		
PULLEY	24 TO 48			24 TO 48							
REDUCER						12	2 TO 4		0,14 TO 2		
BUCKET ELEVATOR											
BELT	SPS									48	MEASURE SHOREA HARDNESS
CHAIN	6			96						48	MEASUREMENT OF CHAIN
DRIVE	24								0,14 TO 2		
DRIVE SHAFT		96		96							
MOTOR							2		0,14 TO 2		
REDUCER						12	2		0,14 TO 2		

Figure 29: Condition monitoring matrix

6.2 Oil analysis

Note that a lot of useful information is available online under www.machinerylubrication.com/

Oil analysis is performed to monitor the condition of both, the equipment and the oil. The criteria for selection of equipment for oil analysis is not only the installed oil quantity, but also the equipment criticality. 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.

There are three main categories of oil analysis:

1. Fluid properties: Current physical and chemical state of the oil and remaining useful life
2. Contamination: Detection of destructive contaminants and narrowing down their probable sources (internal or external)
3. Wear debris: Determination and identification of particles produced as a result of mechanical wear, corrosion or other machine surface degradation.

6.2.1 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.

The recommended point for sampling is in the return line before filtering.

- **Ingression Points**. Where possible, sampling ports should be located downstream of the components that wear, and away from areas where particles and moisture ingress. Return lines and drain lines heading back to the tank offer the most representative levels of wear debris and contaminants.
- **Filtration**. Filters and separators are contaminant removers. Sampling valves should be located upstream of filters, separators, dehydrators and settling tanks unless the performance of the filter is being specifically evaluated.

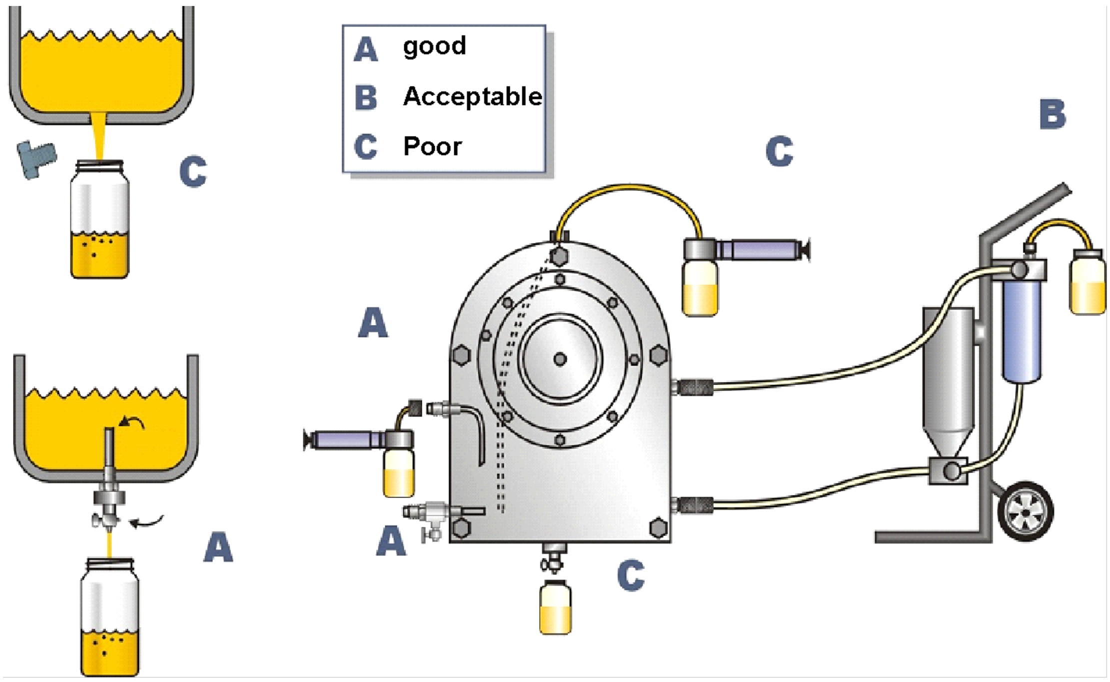


Figure 30: Location of sampling points

The Figure 30 above shows location of sampling points for systems without oil circulation. Do not use position C (directly from the drain), since accumulated sludge will falsify the analysis results.

For systems with oil circulation, install a minimess valve on the return line.

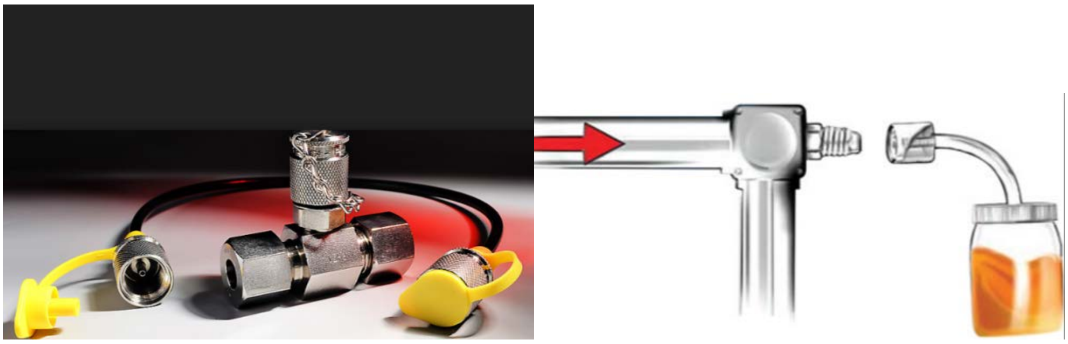


Figure 31: Minimess valve and its working principle

6.2.2 Oil Degradation

The main causes for oil degradation are oxidation, thermal breakdown, micro-dieseling, additive depletion and contamination.

One of the most important parameters of oils is the viscosity, since it has a great influence on its ability to lubricate. If the viscosity changes, also the oils ability to lubricate changes. As a consequence surfaces are not optimally protected anymore.

Oxidation

Oxidation is the reaction of oil and oxygen contained in ambient air. The oxidation rate depends on the temperature and increases with increasing temperatures. The effects of oxidation comprise viscosity increase, buildup of varnish, sludge and sediments. Also the acidity of the oil is likely to increase and as a consequence, formation of rust and corrosion can occur.

Thermal breakdown

The purpose of a lubricant is not only to separate different surfaces from each other, but also the dissipation of heat. If not sufficiently cooled, oil will heat above its recommended stable temperature and the chemical reactions, which lead to oil degradation, occur at increased speed.

Every 10°C rise in temperature above 70°C halves the life expectancy of the oil

Micro-dieseling

Micro dieseling, also known as pressure induced thermal breakdown, occurs when an air bubble is compressed as it travels from a low pressure area to a high pressure area. Since this process happens almost adiabatically, the surrounding oil molecules heat up to very high temperatures, causing instant oxidation of those molecules.

Additive depletion

Most oil additives are designed to be sacrificial and as a consequence, are consumed as oil ages. It can be distinguished between additive decomposition and mass transfer. In the first case the consumed additive is still dispensed in the oil, however in an altered state, in which it is not able anymore to perform its task. In case of mass transfer, the additive precipitates when consumed. The respective particles tend to settle e.g. at the ground of reservoirs and can be captured by filters.

Contamination

Contaminants in solid, liquid or gaseous form have a great influence on oil degradation. The following table gives an overview on how different contaminants affect oil degradation and attack equipment components.

Contaminant	Changes in oil chemistry	Changes in physical properties of oil	Chemical attacks of equipment surfaces	Mechanical destruction of equipment surfaces
Solids (dirt. metal particles, soot)	Oxidation, Additive depletion	Effect on viscosity	Adherent varnish	Abrasion, Surface fatigue
Water	Oxidation, Additive depletion	Effect on viscosity	Acidity destruction, Rust/corrosion	Cavitation, Scuffing
Air (oxygen)	Oxidation (micro-dieseling)	Oxidation, Viscosity increase	Rust/corrosion	Cavitation
Fuel (combustion engines)	Additive depletion, Aromatics, Sulfur	Flashpoint decrease, Viscosity decrease, Vapor pressure increase	Corrosion (sulfuric acid)	Film strength loss
Glycol (antifreeze in combustion engines)	Oxidation, Sludge formation	Viscosity increase	Acidity increase	Film strength loss

Table 10: Effects of contamination

6.2.3 *Test methods and limits*

There is a large variety of different test methods which can be applied to an oil sample. The following table gives an overview of the most common ones and what they primarily aim on:

Test method	**Fluid properties (aging process)**	**Contamination**	**Wear**
Viscosity	Primary benefit	Minor benefit	No benefit
Patch test	No benefit	Primary benefit	Minor benefit
Particle counting	No benefit	Primary benefit	Minor benefit
PQ index	No benefit	No benefit	Primary benefit
Analytical ferrography	No benefit	Minor benefit	Primary benefit
ICP & RDE Spectrometry	Primary benefit	Minor benefit	Primary benefit
Moisture analysis	No benefit	Primary benefit	No benefit
Acid number	Primary benefit	Minor benefit	Minor benefit
IR spectroscopy	Primary benefit	Minor benefit	No benefit

Table 11: Test methods overview and benefits

Viscosity

The viscosity of industrial oils is measured at 40°C using a viscometer or rheometer. The limits for viscosity changes are ±10% (caution) and ±15% (critical). The viscosity decreases if (by mistake) a more fluid oi is added, or as a result of high water content, or by shearing of the VI-improver. The viscosity increases if (by mistake) a more viscous oil is added, and by oil oxidation (e.g. as a result of overheating).

In case of engine oils, the viscosity is measured at 100°C and can drop for reasons of dilution by fuel, 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.

Patch test

The patch test, also patch microscopy, is a low cost test which can be done on-site and which allows identification of particles in an oil sample. It is typically used as a decision base for to performance of continuative and more accurate tests.

Using a vacuum pump to which a bottle is attached at the bottom and a funnel at the top, a mixture of oil and solvent (e.g. mineral spirit) is drawn through a filter paper. Thereby the task of the solvent is to clean the particles making it easier to identify them. The filter paper is then placed under a microscope (at least 100x) and the particles can be analyzed in terms of quantity and size, shape and color - similar to an analytical ferrography (see also section "analytical ferrography").

Although quite simple, the patch test (together with analytical ferrography) has the unique capability of detecting large non-magnetic and non-metallic particles. Routine laboratory methods like spectrometry and PQ index fail in this respect.

Particle counting

Particle counting aims on determination of the total number of particles in an oil sample and is hence a measure of the oil cleanliness. Most widely used underlying standard is the ISO 4406 which indicates the absolute number of particles in the three different size categories >4µm, >6µm and >14µm in a 1ml sample (sometimes also in a 100ml sample). In case of two digit code, only particles >6µm and >14µm are counted. Another common and similar standard is AS4059 which replaced NAS 1638 in 2005.

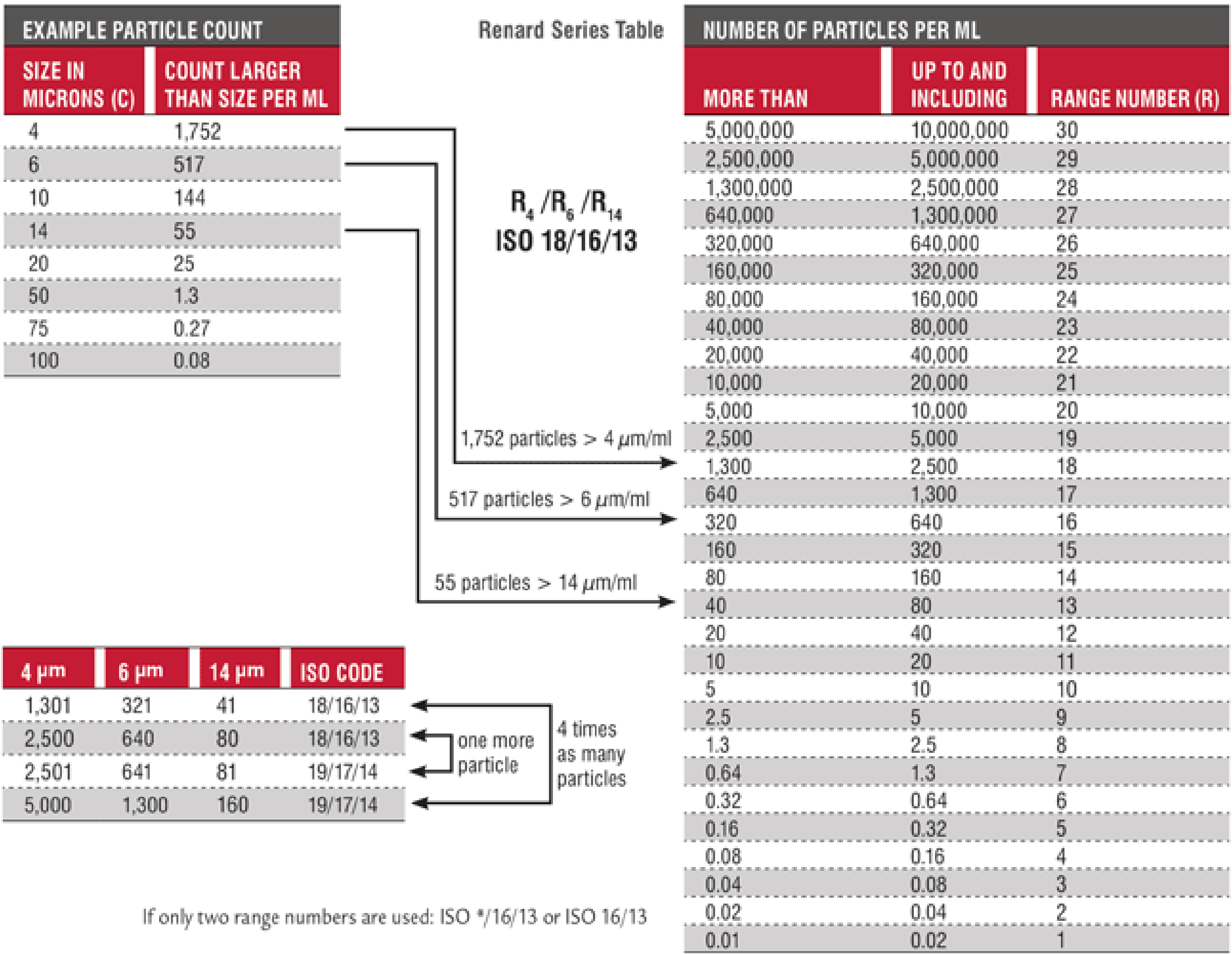


Figure 32: Example of a particle count coding according to ISO 4406 (Source: Noria)

There are three basic methods that can be used to determine the absolute number of particles in any given sample:

1. Optical microscopy: A representative portion of the sample is examined under an optical microscope. The particles are counted manually.
2. Automatic optical particle counting (most widely used): Individual particles are identified in an analyzer (portable, stationary or even online) using the light scattering principle. Determines the equivalent spherical diameter.
3. Pore blockage particle counting: Oil passes through a mesh screen of 10µm. Clogging of the screen allows a conclusion on the particle size distribution.

Recommended limits for oil cleanliness in typical systems are shown in the Table 12. Note that before defining any cleanliness targets the basics (lubricants management, tightness of the equipment, etc.) must be in place.

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

Table 12: Limits for oil cleanliness expressed as per ISO 4406:99

Remark: The above values are valid for critical 'A' equipment. For less critical equipment, cleanliness targets can be reduced.

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

Table 13: Specific cleanliness limits for circulation system components

Particle quantification index (PQ index)

The PQ index test belongs together with direct read ferrography to the ferrous density analysis. In this handbook, the focus lies on the PQ index test since it is much simpler and cheaper.

The PQ index is a measure for the total magnetizable iron content in an oil sample, whereby iron is the main wear element in virtually all components. Magnetizable particles other than iron are also detected, however, are negligible. On analysis reports, the PQ index is shown as "ok" if smaller than 25. If higher, the actual number is given which can be an indicator for increased wear. Very high numbers (several thousands) may indicate wrong sampling, e.g. sample taken from a filter bowl.

Iron is also detectable by spectrometry, however, only in case of particle size <3-10µm, depending on the type of spectrometer. As a consequence, the PQ index test gives most valuable information if applied in conjunction with spectrometry. The Table 14 shows the relationship between the two methods, whereby “high”, “medium” and “low” are qualitative terms and should be interpreted in context of other historic analysis of the same equipment.

Spectrometry	**PQ index**	**Conclusion**	**Wear profile**
Low	Low	Few wear particles	Normal wear profile
High	Low to medium	Lots of small particles, few or no large ones	Corrosion, Accelerated wear, Dirt entry (abnormal)
Low	High	Few small particles, many large ones	Fatigue, Pitting
High	High	Lots of particles of all different sizes	Serious wear likely, catastrophic failure possible

Table 14: Relationship between iron detection with spectrometry and PQ index

Analytical ferrography

Analytical ferrography is a relatively expensive test method which is applied when other tests indicate abnormal wear conditions. Using a bichromatic microscope, particles are investigated in terms of size, concentration, composition, shape and surface structure in a very wide range (0.1 to 500µm).

The suspended solid particles are separated and systematically deposited onto an inclined glass slide (ferrogram) using a magnet positioned underneath. Thereby the magnetic iron particles act as a dyke for non-magnetic particles which deposit randomly across the length of the glass slide. Particles can be broken down into six categories:

- White non-ferrous: aluminum and chromium
- Copper
- Babbitt: tin and lead
- Contaminants: dust (silica)
- Fibers: typically from filters or contamination
- Ferrous wear: high and low alloy steel, dark metallic oxides, cast iron and red oxides (rust).

Investigation is done before and after heat treatment of the ferrogram at 316°C. By doing this, certain particles change color and shape, which facilitates identification.

Besides classification of the composition, also particle size and shape (rough, curved, spherical, etc.) are rated. The particle shape gives information about the type of wear (e.g. cutting, sliding, fatigue, etc). The particle size gives information on the severity of the wear. Particles with a size of >30µm are of particular interest since their presence indicate abnormal wear.

Figure 33: Hydraulic unit, normal wear

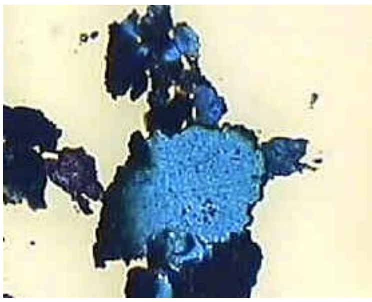


Figure 34: Hydraulic unit, bearing wear, low alloy steel

Figure 35: Hydraulic unit, cutting wear, white non-ferrous

Spectrometry

Spectrometry, also referred to as atomic emission spectrometry (AES), optical emission spectrometry (OES), elemental analysis or wear metal analysis is a quantitative method to determine a multitude of different elements in an oil sample ranging from wear metals and contaminants to oil additives. Measurements are expressed in parts per million (ppm). Some elements can belong to more than one category. For example, silicon can be a component of wear debris (piston crown material in case of combustion engines), of the additive package (antifoaming agents), and of contaminants (dust). Only by looking at a complete set of results it is possible to predict the source of the particular element.

There are many different types of spectrometers, however nearly all oil analysis labs use either inductively coupled plasma (ICP) or rotating disc electrode (RDE) spectrometers. The difference between the two methods is the way oil is vaporized in the analyzer and the limitations in terms of particle size that can be vaporized (ICP up to 3µm, RDE up to 10µm). As a consequence, contributions from larger wear particles (>10µm) originating from e.g. fatigue, are not detectable by spectrometry. For a more complete picture on wear particles it is therefore necessary to combine spectrometry with the PQ index test and/or analytical ferrography.

Spectrometry is in general not suitable for detection of additive depletion, which are subject to decomposition. Since the elements are detected (and not the compounds), the concentration of the respective elements will remain unchanged, even if the chemical composition changes. In case of additives which precipitate as they are consumed, the situation is different. The concentration of such elements will decrease as they are consumed (e.g. boron from extreme pressure additives).

The Table 15 shows a selection of elements detected by spectrometry. For more elements consult the maintenance manual.

Metal	Centrifugal Pumps and Compressors	Reciprocating Pumps and Compressors	Gear Pumps and Screw Compressors	Gear Boxes	Electric Motors	Diesel and Gasoline Engines
Iron	Case Corrosion, Roller Elements, Roller Bearing Races, Sleeve Bearing Backing, Shafts	Case Corrosion, Cylinders and Cylinder Walls, Valves, Valve Guides, Springs, Cams, Shafts, Rods, Bearing Backing.	Case Corrosion, Screws or Gears, Roller Bearing Elements and Races, Sleeve Bearing Backing.	Case Corrosion, Gears, Roller Bearing Elements and Races.	Roller Bearing Elements and Cages.	Block Corrosion, Pistons, Cylinders and Cylinder Walls, Shafts, Cams, Valves, Valve Guides, Springs, Rods, Gear Sets.
Copper	Roller Bearing Cages, Sleeve Bearing Backings, Cooler Tubes, Slinger Rings	Bushings, Bearing Backings, Roller Bearing Cages, Valve Guides, Thrust Plates	Roller Bearing Cages, Some Gear Pump Gear Sets	Roller Bearing Cages, Worm Gears, Slinger rings	Roller Bearing Cages, Sleeve Bearing Backing.	Main and Rod Bearings, Bushings, and Backings, Some Cylinder Inserts, Some Engine Gear Sets.
Tin	Sleeve Bearings, Tubing Solder Joints	Sleeve Bearings, Tubing Solder Joints	Sleeve Bearings, Tubing Solder Joints	Sleeve Bearings, Tubing Solder Joints	Sleeve Bearings	Tubing Solder Joints,
Lead	With Tin: Sleeve Bearings Without Tin: Sealing Compounds	With Tin: Sleeve Bearings Without Tin: Sealing Compounds, Corrosion Resistant Paint	With Tin, Sleeve Bearings Without Tin: Sealing Compounds, Corrosion Resistant Paint	With Tin, Sleeve Bearings Without Tin: Sealing Compounds, Corrosion Resistant Paint	Sleeve Bearings	Bearings, Sealing Compounds, Leaded Gasoline.
Chromium	With Iron: Shaft metal	With Iron: Shaft Metal, Cams, Rods, Springs, Valves, Valve Guides	With Iron: Shafts	With Iron: Shafts	With Iron: Shafts	With Iron: Shafts, Cams, Rods, Springs, Valve, Valve Guides. Without Iron: Rings
Nickel	With Iron: Shaft Metal	With Iron: Shaft Metal, Cams, Rods, Springs, Valves, Valve Guides	With Iron: Shaft Metal	With Iron: Shaft Metal	With Iron: Shaft Metal	With Iron, Shafts, Cams, Rods, Springs, Valve, Valve Guides.
Titanium	With Iron: Shaft Metal	With Iron: Shaft Metal, Cams, Rods, Springs, Valves, Valve Guides	With Iron: Shaft Metal	With Iron: Shaft Metal	With Iron: Shaft Metal	With Iron: Shafts, Cams, Rods, Springs, Valve, Valve Guides. Without Iron: Turbo-Charger.
Antimony	With High Tin: Sleeve Bearing Wear	With High Tin: Sleeve Bearing Wear	With High Tin: Sleeve Bearing Wear	With High Tin: Sleeve Bearing Wear	With High Lead or Tin: Sleeve Bearing Wear	With High Lead: Main Bearing Wear
Zinc	With High Copper: Severe Roller Bearing Cage Wear or Slinger Ring Wear. Without Copper: Galvanize piping Corrosion, Sealing Compound	With High Copper: Severe Roller Bearing Cage Wear or Slinger Ring Wear. Without Copper: Galvanize piping Corrosion, Sealing Compound	With High Copper: Severe Roller Bearing Cage Wear or Slinger Ring Wear. Without Copper: Galvanize piping Corrosion, Sealing Compound	With High Copper: Severe Roller Bearing Cage Wear or Slinger Ring Wear. Without Copper: Galvanize piping Corrosion, Sealing Compound	Sealing Compound	With High Copper: Severe Bushing Wear With High Lead: Severe Main Bearing Wear, Possible Gear Set Wear Alone: Sealing Compound
Aluminum	Thrust Collars and Rings.	Thrust Collars and Rings, Shims and Spacers	Sleeve Bearing Overlay	Case Corrosion	Seldom Seen	Pistons, Block Corrosion, Sealing Compounds
Silver	Seldom Seen	Seldom Seen	Seldom Seen	Seldom Seen	Seldom Seen	EMD Bearings

Table 15: Elements and their potential sources

The Table 16 shows typical wears metal limits for different applications and elements. Note that these values are generic. Whenever possible use values defined by the equipment manufacturer or based on equipment history. Take 50% of these values as caution level.

	Hydraulic systems	**Transmission**	**Circulating systems**	**Miscellaneous**	**Engine**
Iron	40	50	50	100	60
Copper	30	100	50	200	40
Silicone	20	25	20	25	15
Lead	20	30	30	40	15
Chromium	10	15	15		10
Aluminum	10	30	30		15
Tin	10	20	15	20	15
Sodium		50			50

Table 16: Generic wear limits by metal type in ppm and application

Moisture analysis

The main causes for water ingress into equipment are defects on cooling systems, condensation and rain. Water in oil can occur in dissolved, emulsified and free states, whereby emulsified water is most destructive for equipment parts. Caution level is reached if the water concentration exceeds 500ppm (0.5%). For gear oil the critical level is reached at 2000ppm (0.2%) and for hydraulic oil at 1000ppm (0.1%).

In the following, a selection of tests to detect and quantify the presence of water in oil is shown.

<ins>Visual check</ins>

For a rough estimation of the amount of free water in oil, a visual check can be done.

Figure 36: Oil samples with moisture content 0.01%, 0.03%, 0.06%, 0.1%, 0.5% and 1%

Visual crackle test

The visual crackle test is a simple and reliable indicator for free and emulsified water down to approximately 500ppm, which can be done on-site. Is is typically used as a decision base for the performance of continuative and more accurate tests.

The procedure is as follows: A plate is heated and kept at a temperature 160°C. The oil sample is violently agitated to achieve a homogenous suspension of water in oil. A drop of oil is placed on the hot plate using a clean dropper. Depending on the amount of water, bubbles will be visible and a crackling sound audible.

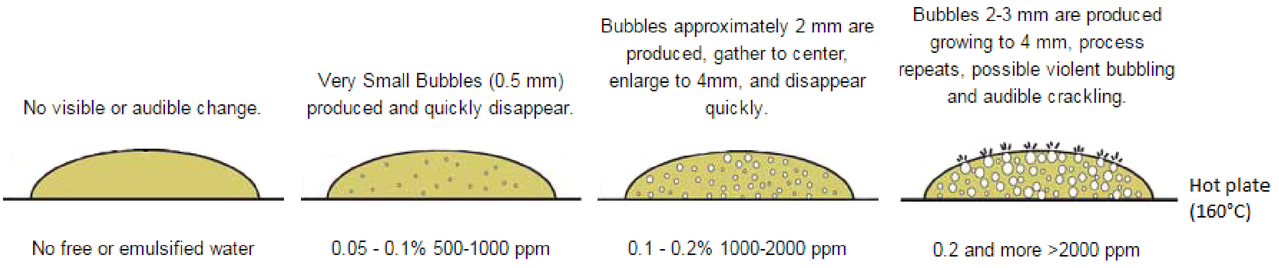


Figure 37: Crackle test for determining the presence of free and emulsified water (Source: Noria)

IR spectroscopy

IR spectroscopy allows determining the presence of different components in the oil. Amongst other also water, if concentrations exceed 1000ppm. For more details consult the respective section.

Calcium hydride test

This simple test, which can be done on-site employs the known reaction of free and emulsified water with calcium hydride (CaH_2) to produce hydrogen gas. Because the amount of hydrogen gas liberated is directly proportional to the amount of water present in the sample, the water content can be determined by measuring the rise in pressure in a sealed container. Applied correctly the test is accurate down to 50ppm water.

Karl Fischer titration

The most accurate method to detect and quantify water in oil is the Karl Fischer titration. It is typically used if other tests indicate an increased water concentration. The test considers water in all three states.

Acid and base number (AN & BN)

The acidity of oil is measured by titration through a base and expressed in mg KOH that is needed to neutralize the acids in 1g of oil. A change in the acid concentration of an oil can originate from multiple sources such as acidic contaminants, wrong oil, alkaline-reserve depletion and oxidation. Critical limits are reached when the number is >1 compared to the new oil.

The counterpart of the AN is the BN, which is a measure for the basicity of the oil and which is expressed in terms of the equivalent number of mg KOH per 1g of oil. It indicates the level of the alkalinity reserve which is used to neutralize formed acids.

Note that the terms total acid number (TAN) and total base number (TBN) are being replaced by AN & BN. The reason is that the respective tests cannot detect extremely weak acid and hence, the total acidity of the sample is not exactly known.

Infrared (IR) spectroscopy

IR spectroscopy also referred to as Fourier Transform Infrared Spectroscopy (FTIR) identifies chemical compounds by using the principle of IR absorption by the covalent bonds between atoms. The spectrum of the oil sample is compared to the new oil reference spectrum which makes the aging process visible.

IR spectroscopy is used to determine oil degradation products like oxides, nitrates and sulfates, as well as additive depletion and water ingress (if >1000ppm). In addition In case of combustion engines, contamination from fuel, glycol and soot can be determined.

Many of the observed parameters may however not be conclusive. So often the results are coupled with other tests and used more as supporting evidence.

Table 17 shows the absorption wavenumbers for different oil parameters.

Parameter	**Wavenumber [cm^{-1}]**	**Precision***	**Interferences**
Oxidation	mineral oil: 1750 organic ester: 3540 phosphate ester: 815	±25%	VI improvers, dispersants, heavy moisture contamination
Sulfation	1150	±25%	sulfurous additives (ZDDP, sulfur/phosphorous EP, some rust inhibitors)
Water	mineral oil: 3400 organic ester: 3625	±25%	excessive soot, detergent additives, glycol, antioxidant, ester basestocks, severe oxidation, free vs. dissolved water
Phenol (antioxidant)	3650	±50%	moisture, glycol
ZDDP (anti-wear)	980	±35%	aromatic impurities, fuel, dust (silica)
In addition for combustion engines			
Soot	2000	±10%	particle size/density, engine type
Nitration	1630	±25%	VI improvers, dispersants
Glycol	880, 1040, 1080, 3400	±50%	water, antioxidants, oxidation by-products
Fuel	diesel: 800 gasoline: 750 jet fuel: 795, 815	±50%	varying fuel aromatics, fuel evaporation
* Precision will vary based on condition and the availability of an accurate new oil reference			

Table 17: IR spectroscopy absorption wavenumbers for different oil parameters

Recommended tests and frequencies

The following table is a recommendation which routine tests should be carried out for which type of equipment, for the respective frequencies and for continuative tests, if required.

Note the following "coding":

A Critical hydraulic systems and reducers (exceptions are explicitly indicated)

B Non-critical hydraulic systems and reducers, critical bearings, compressors

	Test method	On-site	Lab - Routine	Lab - Exceptional triggered other method
1	Viscosity @40°C	A 2w B 1m	A 1m B 3m	
2	Patch test	A 2w B 1m		
3	Particle counting		A 1m	B 2
4	PQ Index		A 1m B 3m	
5	Analytical ferrography		VRM reducer & roller, Oil lubr. thrust rollers: 6m Crit. reducers general: 12m	Crit. hydraulic systems: 4 6 B 4 6
6	ICP/RDE spectrometry		A 1m B 3m	
7	Crackle or Calcium hydride	A 2w B 1m		
8	Karl Fischer			A 7 10 B 7 10
9	Acid number		A 1m B 3m	
10	IR spectroscopy		A 1m B 3m	

Table 18: Recommended tests and frequencies for various equipment

6.3 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 38: Three types of tests and their application

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

6.3.1 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:

6.3.1.1 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.

6.3.1.2 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.

6.3.1.3 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.

6.3.1.4 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.

6.3.1.5 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.

6.3.1.6 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.

6.3.2 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.

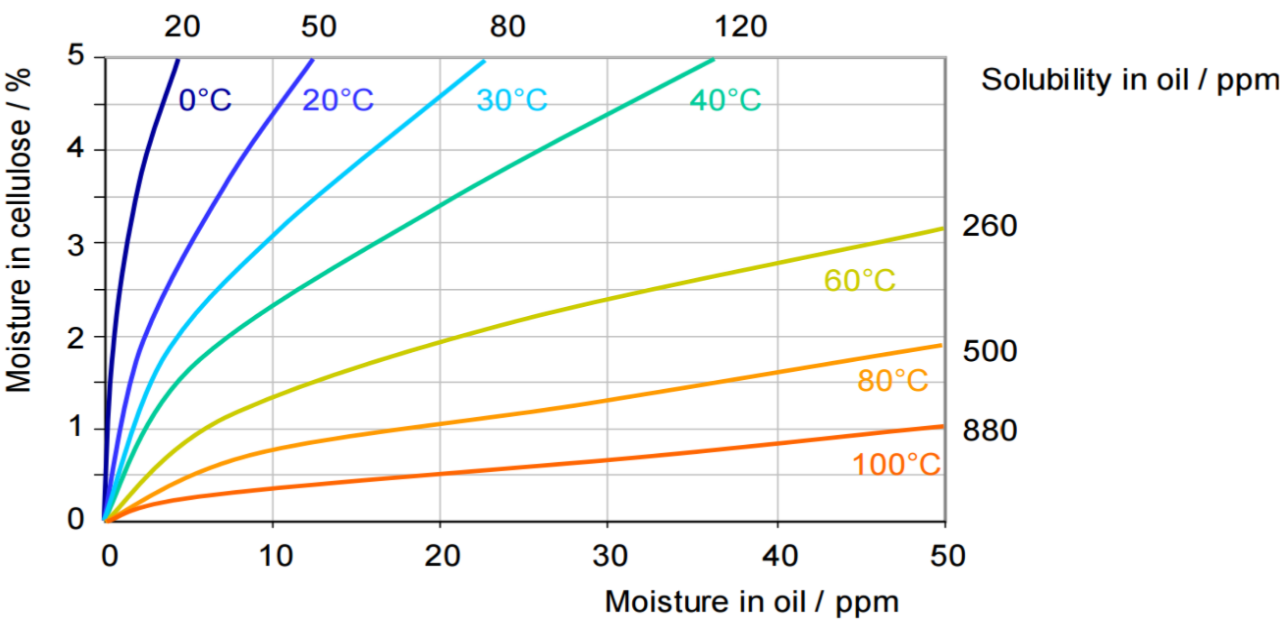


Figure 39: Ratio between moisture in oil and cellulose as a function of the temperature

		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 40: 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 41: 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 42: Recommended actions according to results of Basic 6 part test

6.3.3 *Dissolved Gas Analysis (DGA)*

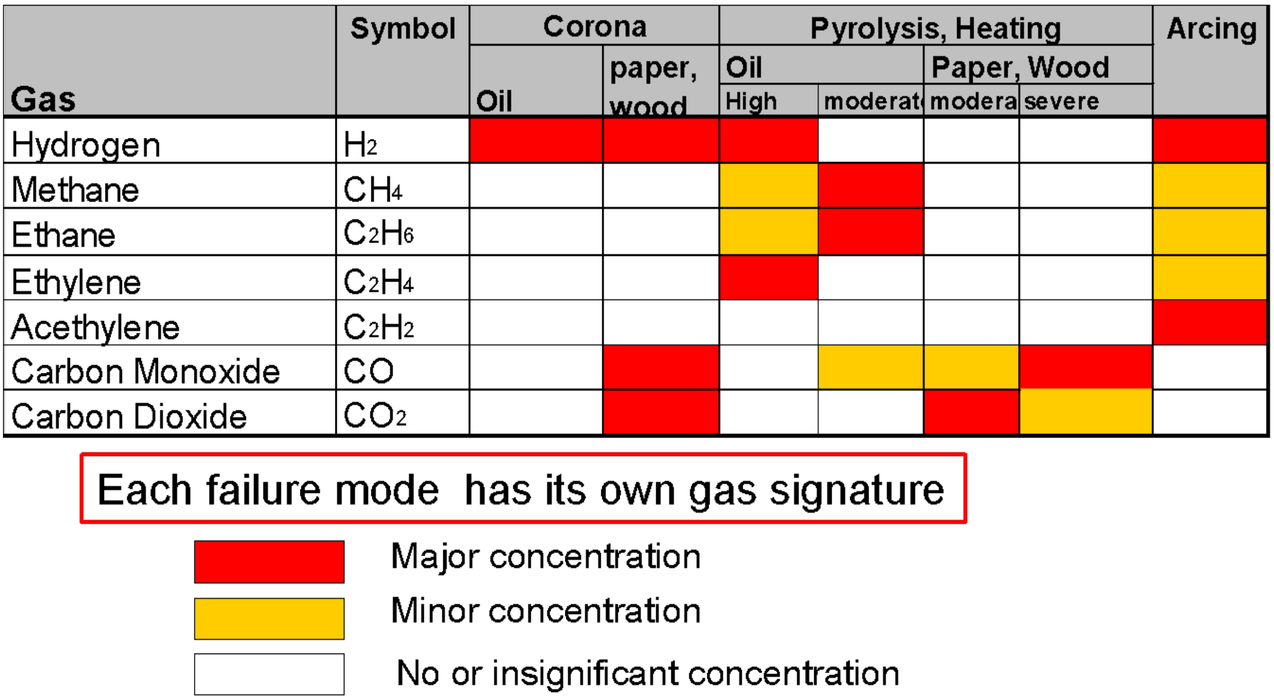
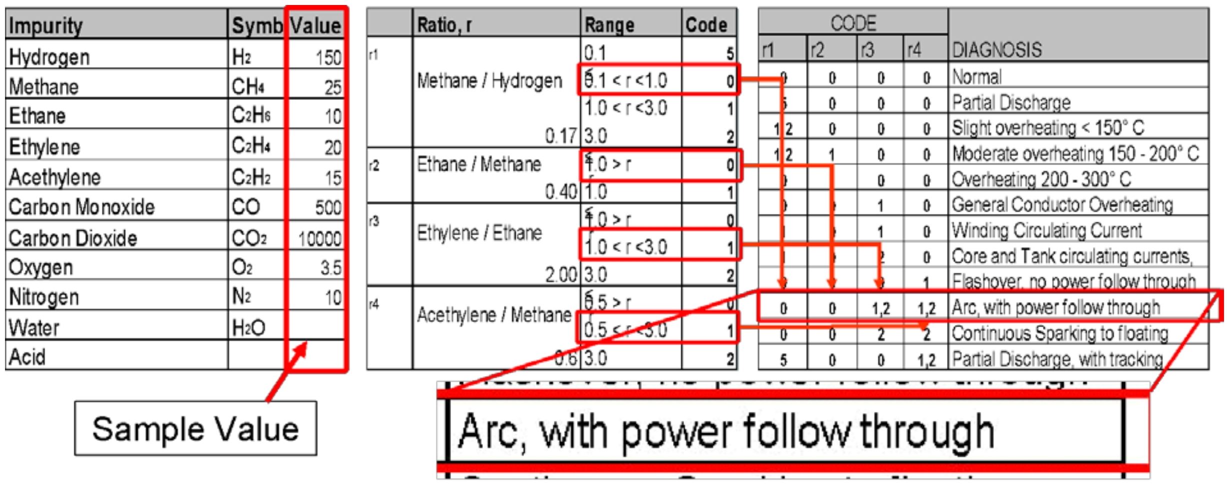


Figure 43: Simplified Gas Formation table

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



Impurity	Symb	Value
Hydrogen	H_2	150
Methane	CH_4	25
Ethane	C_2H_6	10
Ethylene	C_2H_4	20
Acethylene	C_2H_2	15
Carbon Monoxide	CO	500
Carbon Dioxide	CO_2	10000
Oxygen	O_2	3.5
Nitrogen	N_2	10
Water	H_2O	
Acid		

	Ratio, r		Range	Code
r1	Methane / Hydrogen		0.1	5
			0.1 < r <1.0	0
			1.0 < r <3.0	1
		0.17	3.0	2
r2	Ethane / Methane		1.0 > r	0
		0.40	1.0	1
r3	Ethylene / Ethane		1.0 > r	0
			1.0 < r <3.0	1
		2.00	3.0	2
r4	Acethylene / Methane		0.5 > r	0
			0.5 < r <3.0	1
		0.6	3.0	2

CODE				
r1	r2	r3	r4	DIAGNOSIS
0	0	0	0	Normal
5	0	0	0	Partial Discharge
1,2	0	0	0	Slight overheating < 150° C
1,2	1	0	0	Moderate overheating 150 - 200° C
0	[illegible]	0	0	Overheating 200 - 300° C
0	[illegible]	1	0	General Conductor Overheating
[illegible]	[illegible]	1	0	Winding Circulating Current
[illegible]	[illegible]	2	0	Core and Tank circulating currents,
[illegible]	[illegible]	[illegible]	1	Flashover, no power follow through
0	0	1,2	1,2	Arc, with power follow through
0	0	2	2	Continuous Sparking to floating
5	0	0	1,2	Partial Discharge, with tracking

Figure 45: 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

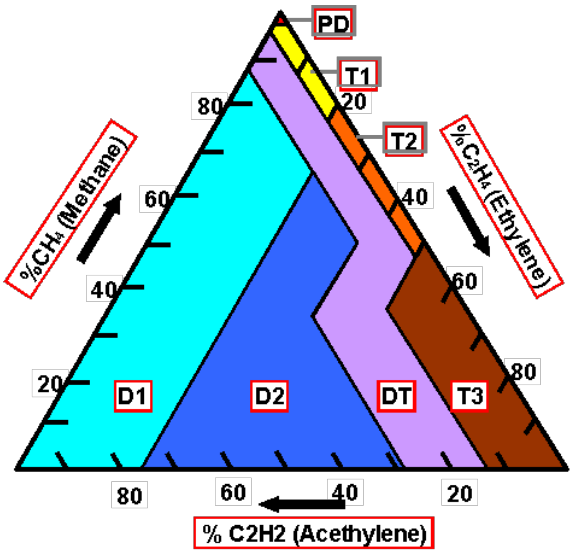
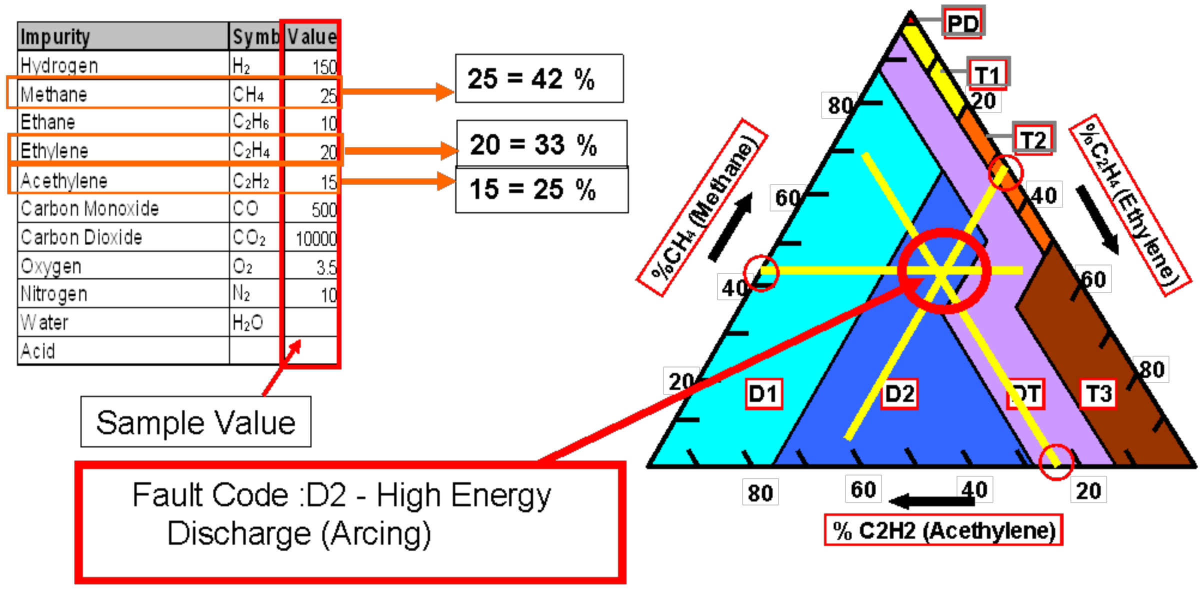


Figure 46: Fault Analysis by Duvall Triangle Method



Impurity	Symb	Value
Hydrogen	H_2	150
Methane	CH_4	25
Ethane	C_2H_6	10
Ethylene	C_2H_4	20
Acethylene	C_2H_2	15
Carbon Monoxide	CO	500
Carbon Dioxide	CO_2	10000
Oxygen	O_2	3.5
Nitrogen	N_2	10
Water	H_2O	
Acid		

Figure 47: Example of Duvall Triangle Method

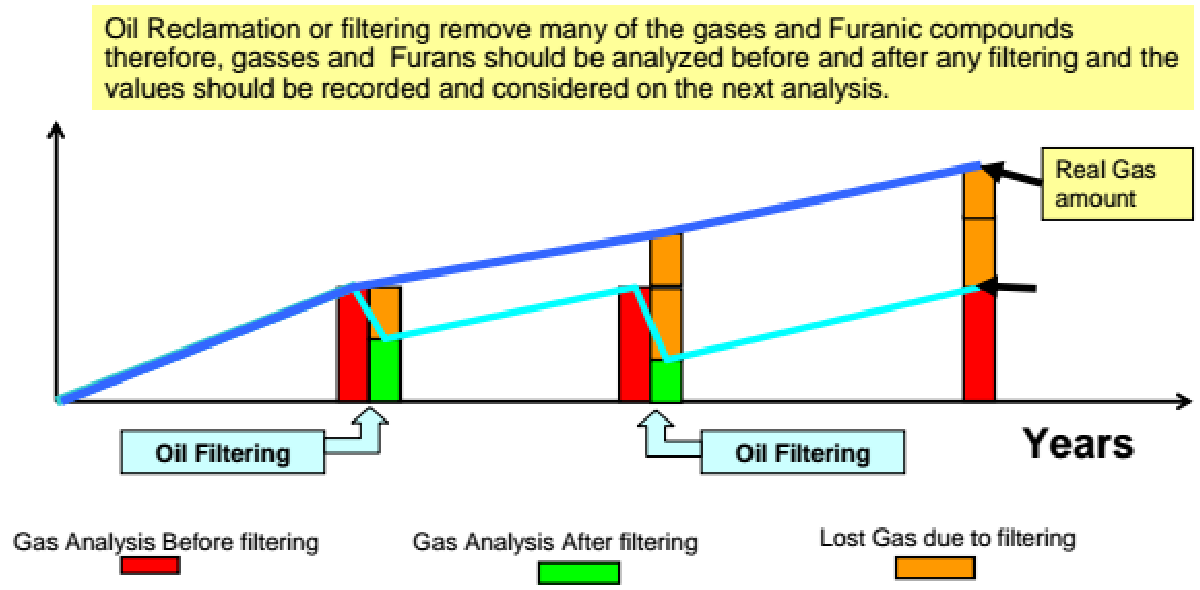


Figure 48: Effect of oil filtering on dissolved gases

6.4 Vibration analysis

Vibration analysis aims on the detection of vibrations due to

- mechanical defects: imbalance, bent shafts, misalignment, mechanical looseness etc. (forced vibration)
- resonance vicinities: i.e. a natural frequency of the system is close to an exciting frequency (free vibration)

All vibrations can be described as one or several overlapping oscillations around a zero-point and quantified by the frequency (reciprocal of time period) and amplitude as a function of time. For analysis, most important values are:

- Peak: Maximum amplitude
- Peak to peak: Minimum plus maximum amplitude
- Root mean square - RMS: Square root of the arithmetic mean of the squares of the values. In case of a pure sine wave: RMS = 0.707 x Peak

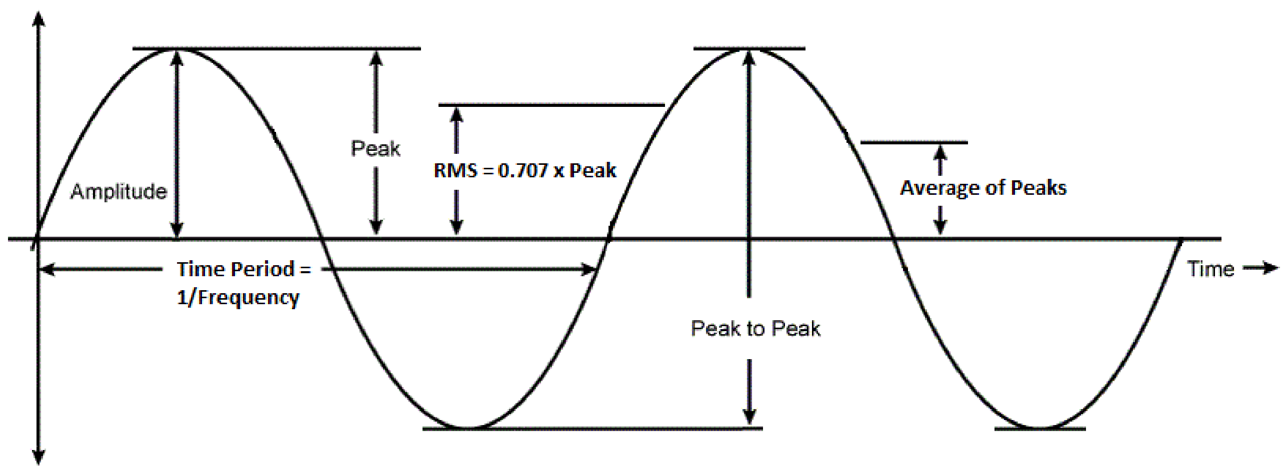


Figure 49: Sinusoidal oscillation and main characteristics

Performing vibration analysis, three parameters can be measured which are displacement, velocity and acceleration. In order to obtain useful results, the measuring principle must match the “nature” of the vibration. Note that nowadays almost all measurements are done with acceleration sensors whereby velocity and displacement values are obtained by integration of the signal.

Displacement is measured in peak to peak units of mm or µm and recorded in three directions (axial, horizontal and vertical). The respective amplitudes decrease typically to very small values above about 100Hz. For that reason, displacement measurements are rarely used for machine condition monitoring. They are more useful for monitoring structural vibration which are typically in the low frequency ranges (>5Hz).

Velocity tends to have a reasonably uniform response over a wide range of machine frequencies and is therefore most commonly used to identify various problems such as: unbalance, misalignment, looseness (machinery structural, foundations, or bearings). Values are recorded in mm/s RMS and in three directions (axial, horizontal and vertical).

Acceleration increases with increasing frequency and is therefore the logical choice for monitoring those components that generate high frequency (>2000Hz) vibration such as bearings and gearing. Acceleration is measured in units of g or mm/s^2 whereby $1g = 9.81mm/s^2$.

Shock pulse monitoring (SPM) is a patented technique for the detection of defects in antifriction bearings. Compared with other vibrations, shock pulses from anti-friction bearings are very weak signals that hardly affect the general vibration spectrum of a machine. Even strong shock pulses may not be easily differentiated by conventional vibration analysis from other sources of machine vibration. If detected by vibration analysis, shock pulses may be difficult to analyze or interpret accurately. Such defects generate typically high frequency signals and therefore special acceleration sensors are used. The severity is expressed in gSE (g Spike Energy) whereby $1g = 9.81mm/s^2$.

All three parameters can be displayed in a time waveform. It contains all the information about the vibration at the point where it is measured, however, the individual patterns of vibration caused by different effects in the machine are all overlapping. By analyzing a time waveform it is almost impossible to separate all the individual motions that are represented in the signal. Hence, for clarification and simplification the time waveform is converted into a frequency spectrum (using Fast Fourier Transformation - FFT), which reveals all the individual frequencies and amplitudes. The relation between time waveform and frequency spectrum is illustrated on the following Figure 50, where a geared motor produces vibrations due to imbalance, bearing and gear defect.

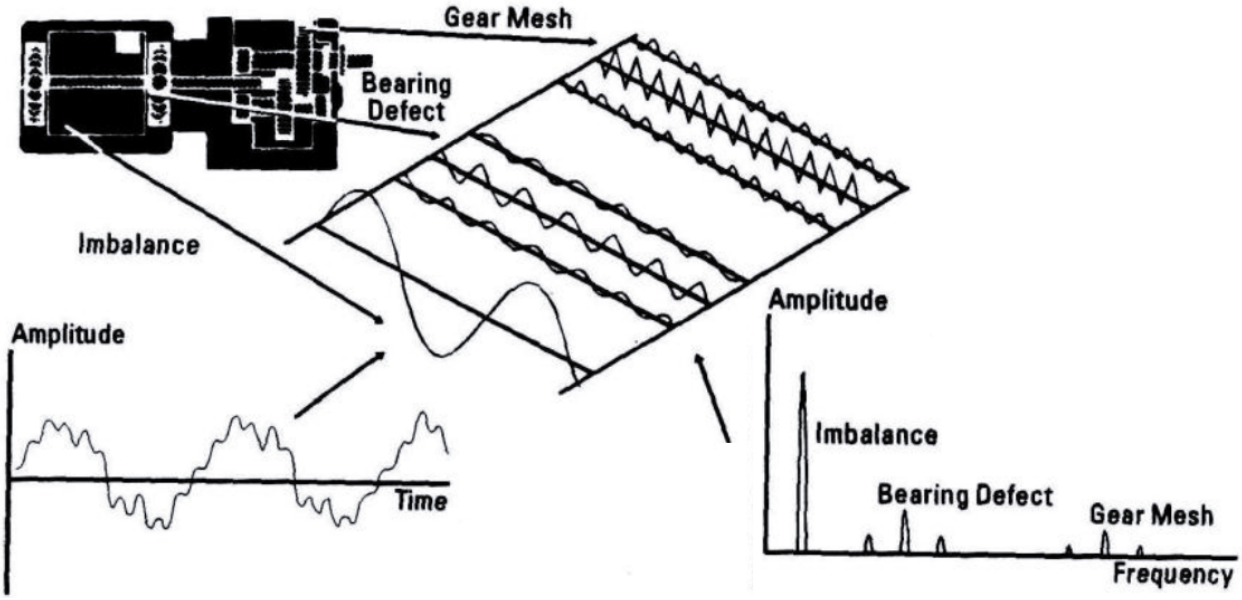


Figure 50: Geared motor with different defects. Looking at the sum of the individual vibrations from the front is like looking at the time waveform. Looking from the side is like looking at the frequency spectrum

6.4.1 Common detectable failure modes

- Imbalance: 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 2kHz and 5kHz depending on shaft speed and transducer resonance
- Electrical problems: synchronous frequency and sidebands
- 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

6.4.2 Measuring points for main equipment

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

Bucket elevator

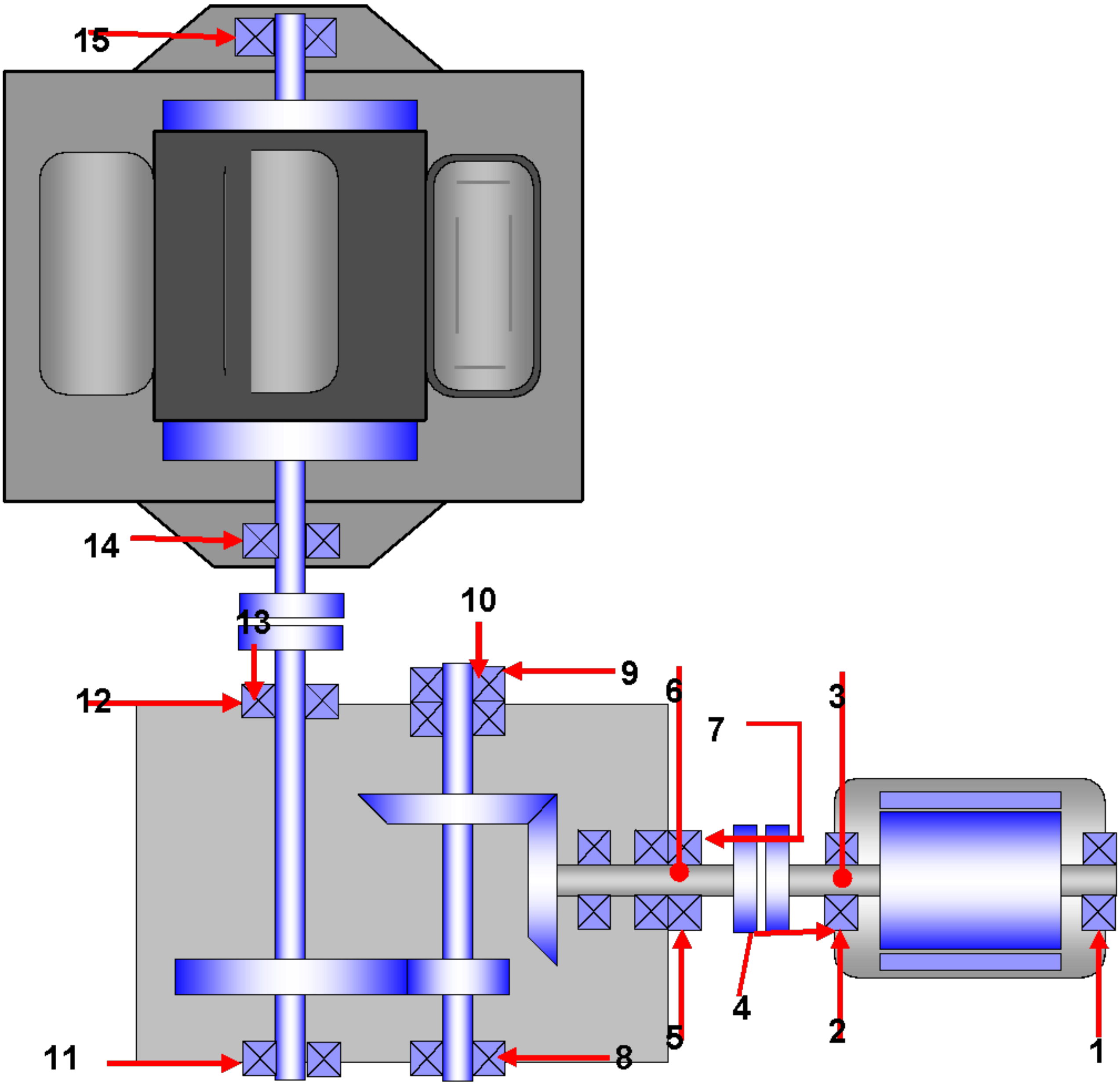


Figure 51: Bucket elevator drive unit measuring points

	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

Table 19: Bucket elevator drive measurement directions and parameter per measuring point

Belt conveyors

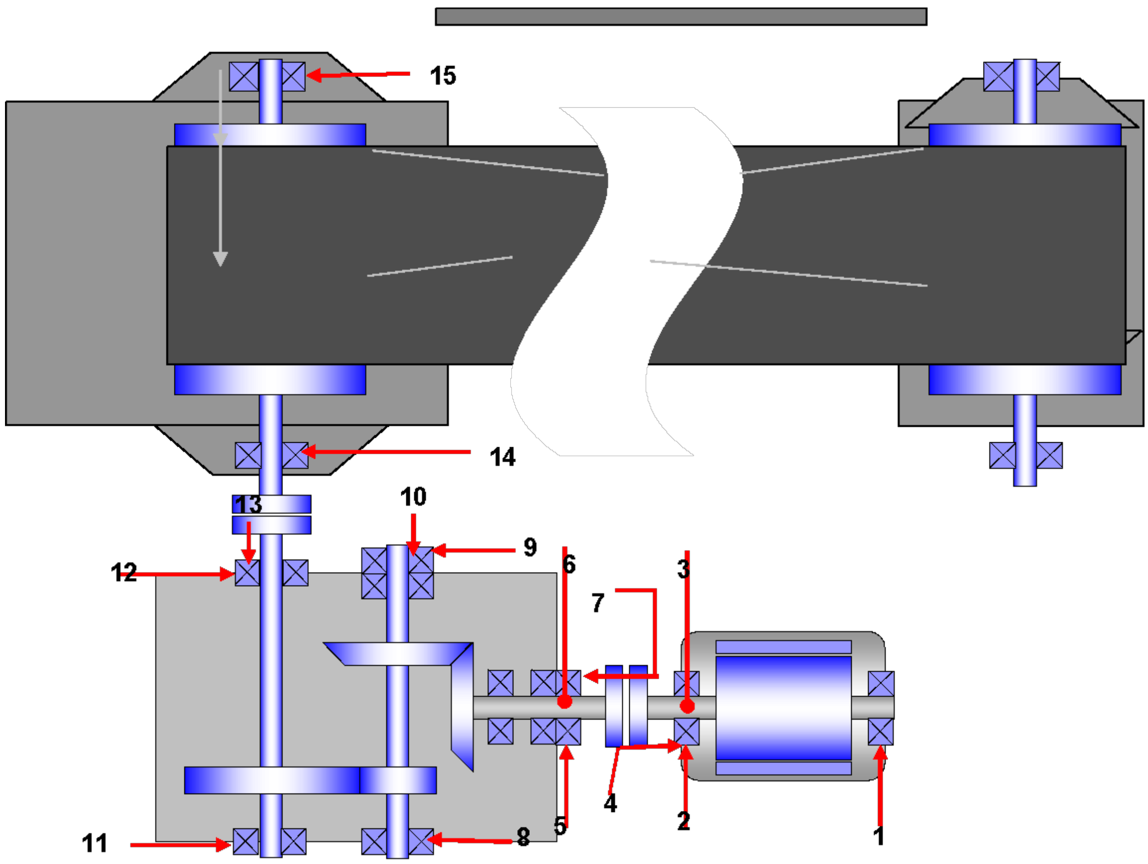


Figure 52: Belt conveyor measurement points location

	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

Table 20: Belt conveyor drive measurement directions and parameter per measuring point

Fans

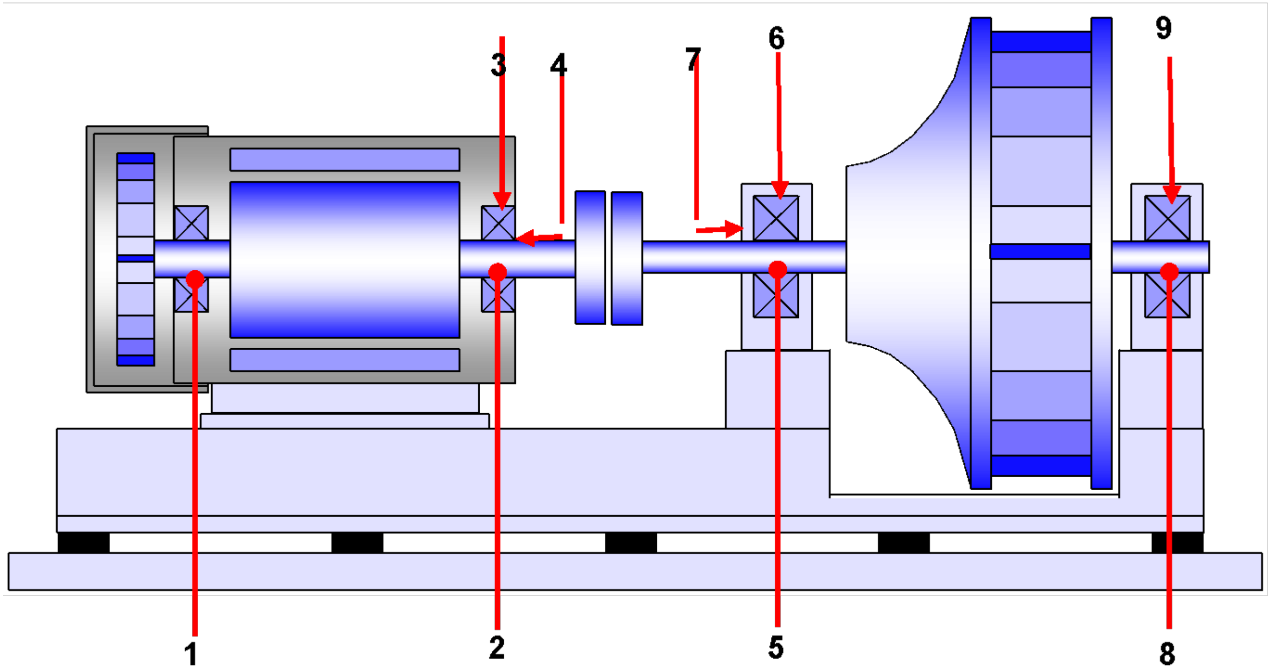


Figure 53: Fan measurement points location

	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

Table 21: Fan measurement directions and parameter per measuring point

Ball Mills - Central Drive

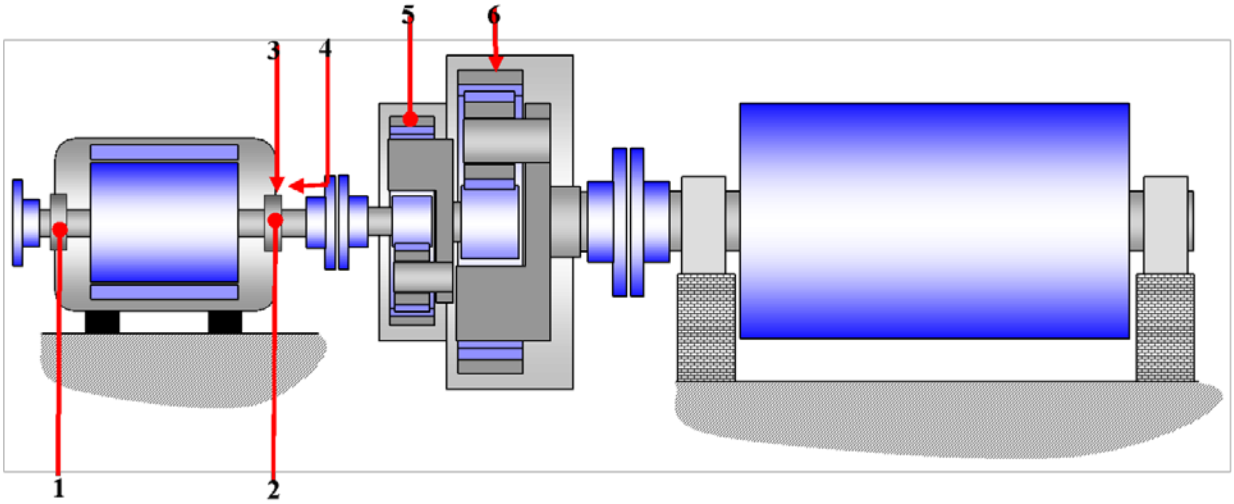


Figure 54: Ball Mills - Central Drive measurement points location

	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

Table 22: Ball Mills - Central Drive measurement directions and parameter per measuring point

Ball Mills and Kilns - Girth Gear drive

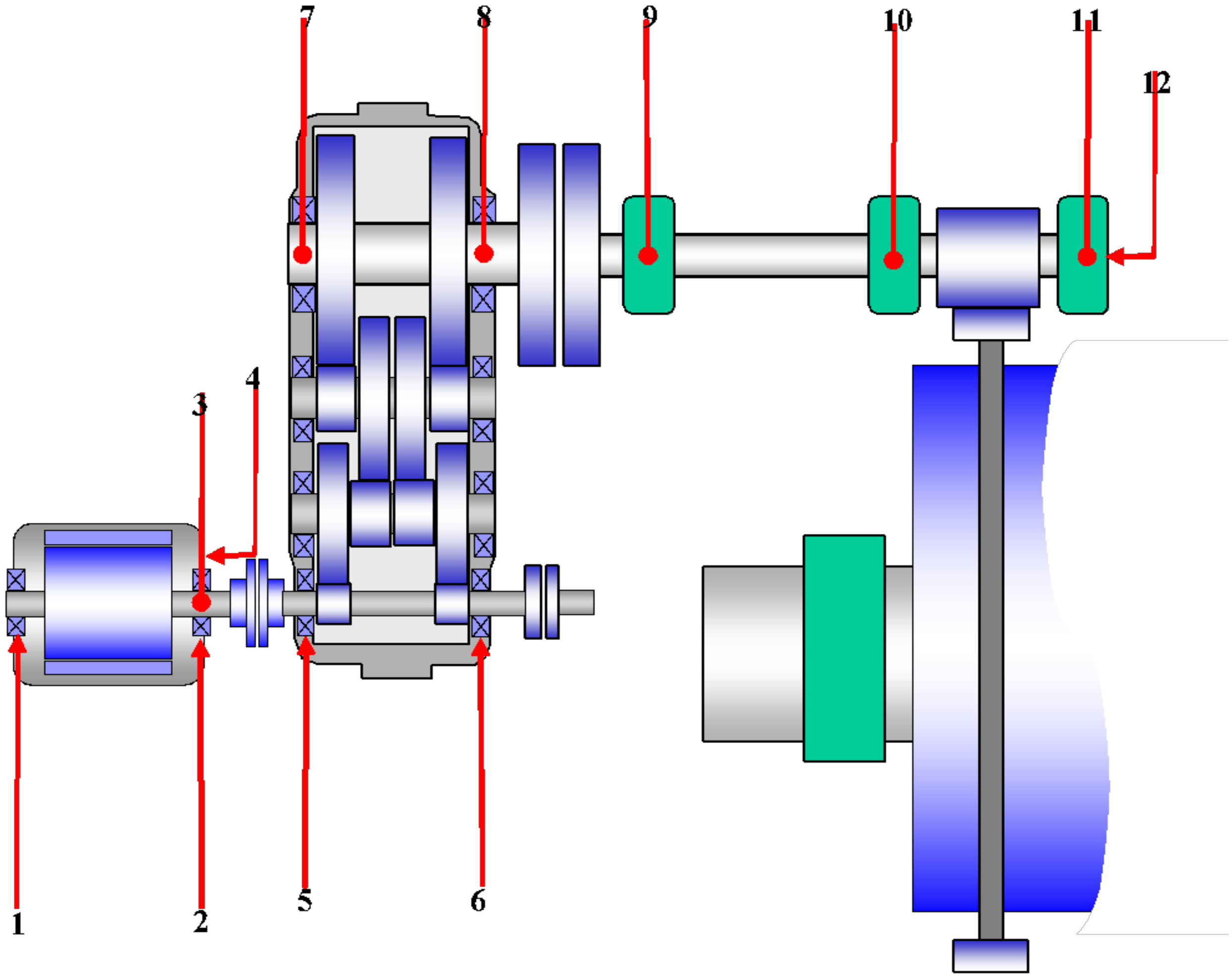


Figure 55: Ball Mills and Kilns - Girth Gear drive measurement point's location

	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
6	Reducer, inlet DE		X			X
7	Reducer, inlet DE			X		X
8	Reducer, inlet NDE	X			X	X
9	1st Intermediate shaft, NDE	X	(X)		X	X
10	1st Intermediate shaft, DE	X	(X)		X	X
11	1st Intermediate shaft, DE			X		X
12	2nd Intermediate shaft, NDE	X	(X)		X	X
13	2nd Intermediate shaft, DE	X	(X)		X	X
14	2nd Intermediate shaft, DE			X		X
15	Reducer, Outlet, NDE	X			X	X
16	Reducer, Outlet, DE	X			X	X
17	Drive shaft	X			X	X
18	Pinion, DE	X			X	X
19	Pinion, DE		X			X
20	Pinion, NDE	X			X	X
21	Pinion, NDE		X			X
22	Pinion, NDE			X		X

Table 23: Ball Mills and Kilns - Girth Gear drive measurement directions and parameter per measuring point

6.4.3 Vibration limits for main equipment

Gear reducers and fans

It is common engineering practice that the vibration severities of industrial gear drives are assessed in accordance with ISO 10816.

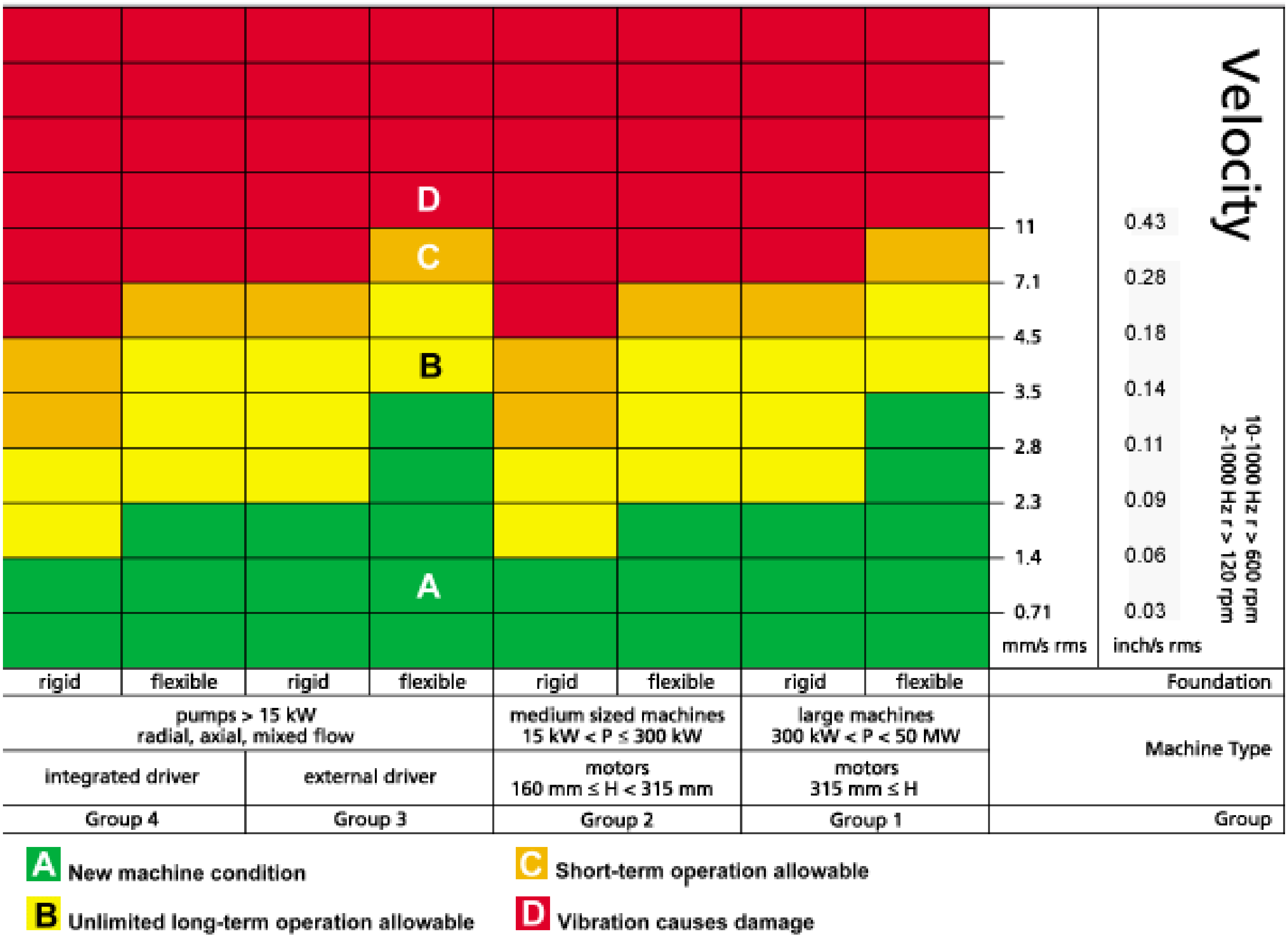


Figure 56: Vibration limits for gears and fans in accordance with ISO 10816

In general concrete foundations for **fans and blowers** are tuned to low frequency, i.e. the natural frequency (critical speed) is below the operating speed.

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.

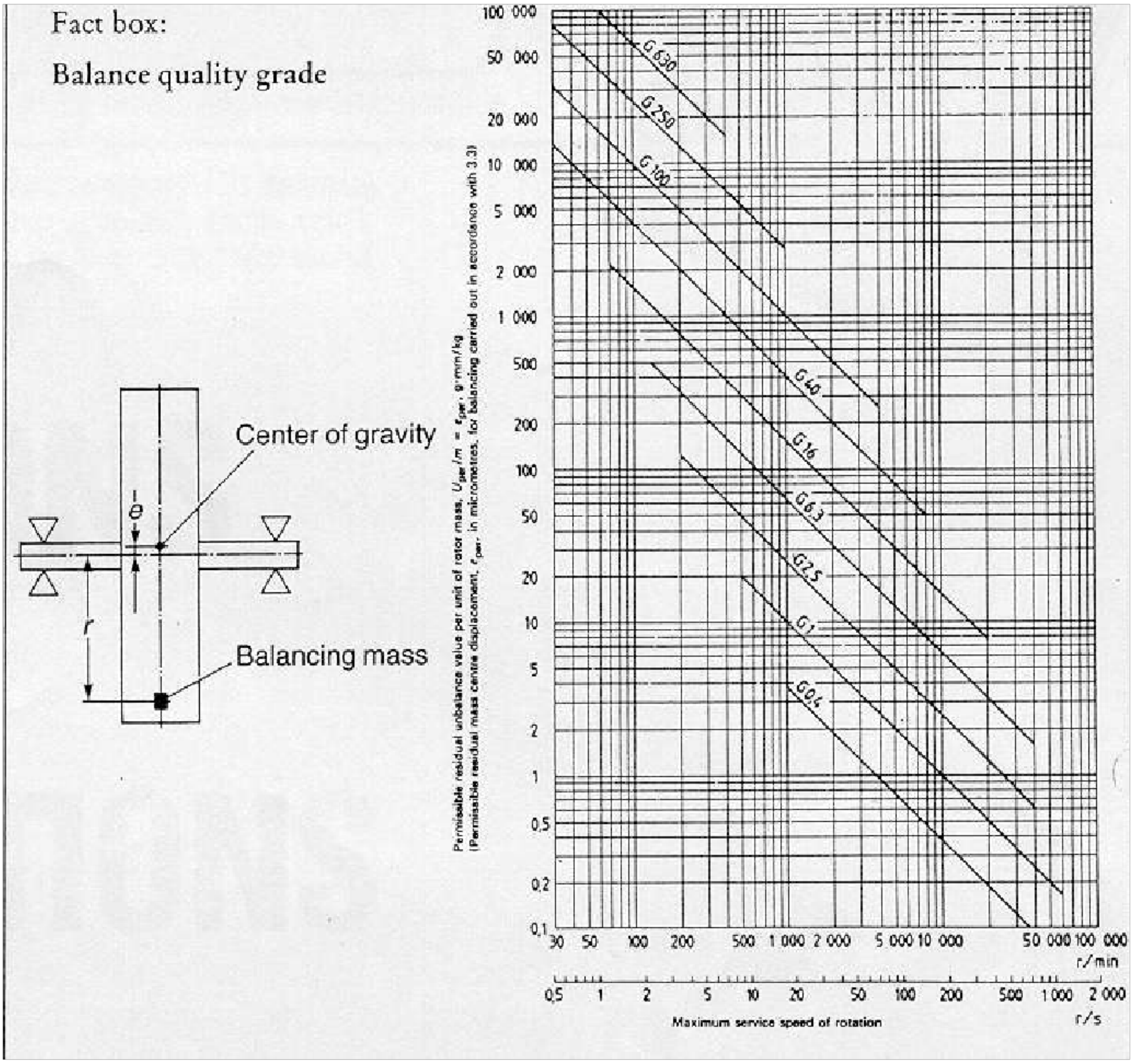


Figure 57: Guidance values for the permissible residual unbalance

Quality grade G 6.3 is generally used for big fans in the cement industry.

Girth gear drives

For open girth gear drives the above mentioned guidelines are definitely not applicable and are 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

Table 24: Vibration severity for girth gear drives

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.

Analysis Frequency

For equipment which is not equipped with a permanent vibration monitoring systems vibration measurement frequency should be in accordance with the table below.

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

Table 25: Recommended frequencies for vibration analysis

6.5 Thermography

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.

Note the thermographic analysis must be done which the equipment is operational.

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

Table 26: HTEC recommended equipment and frequencies for thermography

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

Table 27: Warning limits for thermography

6.6 Non Destructive Tests (NDT)

NDT aims on detection of fabrication, machining or operations-related material defects and is a general term for the condition monitoring techniques described in the following.

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. For info regarding equipment, applicable methods and frequencies consult the chapter "Key PMR's".

Visual Test (VT)

Visual testing are sight controls of the surfaces of parts or components, which are accomplished without or with the help of optical devices. Such inspections shall be carried out before all other NDT -tests. Applications include:

- Detection of cracks
- Dimension control: lengths, diameter or circumference, radius, missing or additional steps and grooves
- Verification of completeness: missing parts
- Test of coarse fabrication or machining defects: mechanical damages, cracks, scales, etc.
- Roughness comparison (Ra, Rz, Rmax)

Dye Penetrant Test (PT)

A strong colored liquid (penetrant) with a very high creeping capability is applied on the surface to be inspected. After a certain time the excess penetrant is removed by cleaning the surface again. A second substance (developer), draws the penetrant 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.

This method is the only possible surface examination for non-ferromagnetic materials as well as for parts with very complicated surface shapes. The only restriction is that the possible defects must be open to the surface. Applications include:

- Fabrication defects like casting, forging, welding defects, etc.
- Processing defects like hardening, grinding, heat treatment cracks, etc.
- Service defect like fatigue, stress corrosion, thermal shock cracks, etc.

Magnetic Particle Test (MT)

The magnetic particle testing is used for the detection of surface defects of ferromagnetic materials. 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 on, or just below the surface (~0.5mm), then the lines of the magnetic flux at these places are disturbed and secondary poles are created. At these poles, the magnetic particles adhere, making the defects visible.

The direction of magnetization plays a very important role. The mentioned formation of poles appears only if the discontinuities are at maximal 45° to the direction of the magnetic field. Discontinuities parallel to the magnetic field are no obstacle to the flux lines and hence no poles are formed. As a consequence a part must always be magnetized in two directions which are 90° turned to each other.

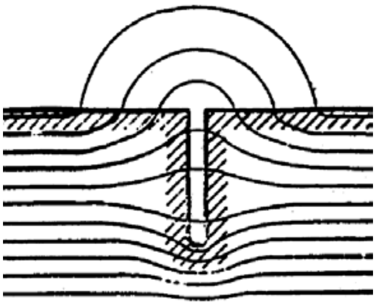


Figure 58: Defect at the surface perpendicular to the flux lines

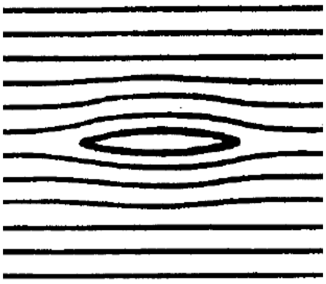


Figure 59: Defect in the direction of the flux lines: no detection

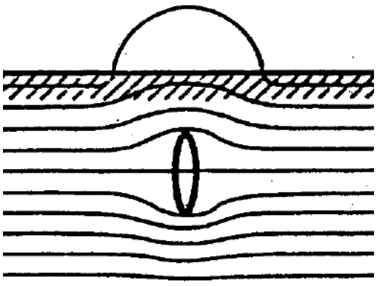


Figure 60: Defect under the surface perpendicular to the flux lines

Applications include:

- Welds
- Castings
- Forgings
- Finished parts (grinding cracks)

Ultrasonic test (UT)

A short ultrasonic pulse is sent into the material 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. Based on the characteristics of an indication it is possible to make certain statements about the defect like exact location, estimate of the size, direction/orientation, etc.

UT can mainly be divided in two techniques: straight beam inspection (direction of sound normal to the contact surface) and angle beam inspection (direction of sound beam inclined with respect to the contact surface). The straight beam inspection allows detection of defects lying parallel to the contact surface, whereas angle beam inspections allows detection of defects in any orientation. Angle beam inspections are also applied if a straight beam inspection is not possible because of geometrical reasons.

Note that UT is not suitable for detection of surface cracks.

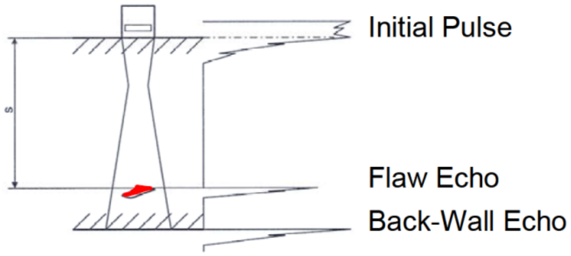


Figure 61: Principle of straight beam inspection

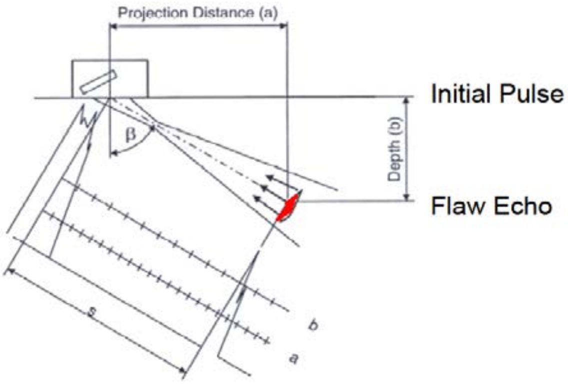


Figure 62: Principle of angle beam inspection

Applications include:

- Semi-finished products (sheets, rods, etc.)
- Forged components (rough machined forged slugs)
- Finished forged pieces (simple shapes)
- Castings (steel, nodular cast iron)
- In-service inspection (welds, fatigue cracks kiln tires, rollers, roller shafts, VRM)
- Measurement of wall thickness

6.7 Wear measurement

Wear is especially important in our industry, where a high amount of material, under various conditions of stress, speed, chemical and temperature is handled. There is a wide range of possibilities to improve in order to optimize the lifetime of components through:

- Design solutions
- Ceramic material solutions
- Elastic material solutions
- Metallic material solutions
- Maintenance strategy (when to change what and how)

Nevertheless wear management can strongly improve the maintenance in our plants in terms of both cost and availability.

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).

Measure always in the same point and with the same procedure and reference profile

For wear points and recommended frequencies for wear measurements refer to the chapter “Key PMR’s”.

6.8 Electric motor diagnostics (EMD)

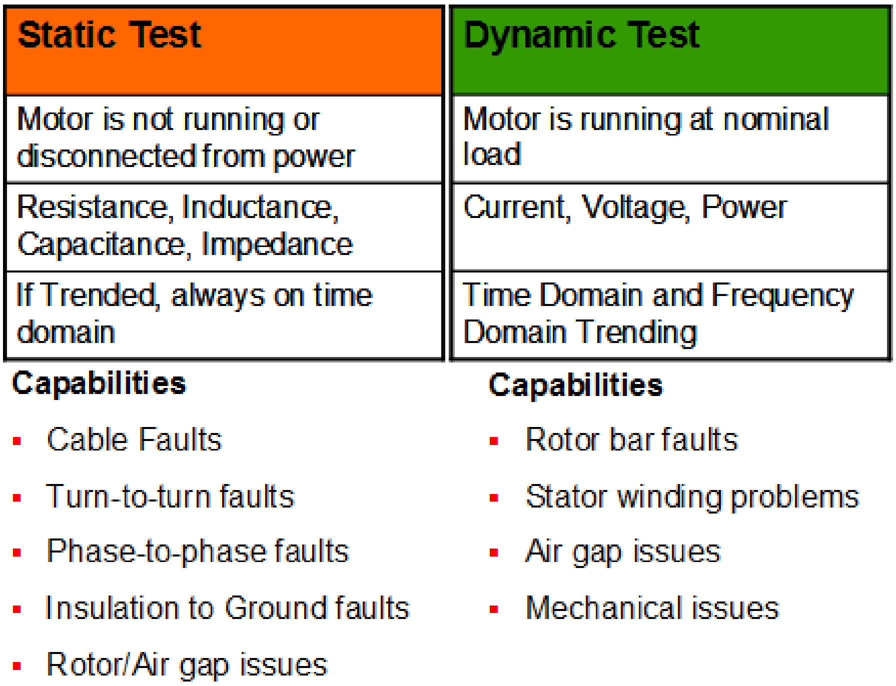


Figure 63: Types of test encompassed by EMD and their detection capabilities

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

Table 28: Parameters measured during a static test and possible faults

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)	

Table 29: Power analysis (dynamic test) parameters and possible faults

- > 500 M Ohm Good
- > 100 to < 500 M Ohm Observe
- > 50 to < 100 M Ohm Caution-closer monitoring
- > 10 to < 50 M Ohm Caution (plan action)
- < 10 M Ohm **Severe (alarm) (take action)**

Figure 64: Alarm levels for Resistance To Ground (RTG) measurements on electric motors

6.9 Emission monitoring systems

Objectives of Emission Monitoring

In order to comply with environmental standards and regulations, continuous emissions monitoring (CEM) equipment has to be operated and maintained well. The importance of this topic should not be underestimated since non compliance with legal requirements could lead to consequences, in the worst the license to operate can be lost.

The equipment contains a set of three measuring devices:

- Measuring device for **dust** (in-situ)
- Measuring device for **inorganic gases** SO2, NOx (extractive or in-situ)
- Measuring device for **volatile organic compounds** [plus O2, H2O] and optional for HCl, NH3, CO, CO2 (only extractive)

The system target for CEM availability is >90% as a standard and >95% as a target referred to the yearly operating hours of the respective cement kiln.

Instrument air

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.

Air conditioning of CEM equipment container

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 flame ionization detector (FID) 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.

Required maintenance routines for CEM equipment are equipment specific and are therefore not further explained here. For detailed information consult the Maintenance Manual, the Instrumentation Guideline or the document owner.

7. Key PMR's

The following table shows the recommended key PMR's to be included in the preventive maintenance program as minimum. Note that the frequencies may require adjustment in accordance with the equipment condition, wear rates and maintenance requirements defined by the OEM.

Equipment / PMR	**Recommended Frequency**[1] [week]	**Comments**
Electrical installations		
Check the resistance of the grounding systems	48	may be regulated by country law
Motor Control center (MCC)		
Thermography inspection of MCC's	24	
High voltage switchgear		
Thermography inspection of switchgear and cable connections	24	
Medium voltage switchgear		
Thermography inspection of switchgears	24	
Parameter check and functional test of protection relay incl. recording of reaction time	96	
Insulation test	48	
Transformer		
Thermography inspection of the transformer	24	
Oil analysis on oil filled transformers and on load tap changers	48	6 part Basic test and DGA, Furan analysis every 5 years until transformer is 25 years old, then every year
Insulation test and Polarization Index measurement on dry type transformers	48	
Low voltage switchgear		
Thermography inspection of switchgears	24	
Parameter check and functional test of protection relay incl. recording of reaction time	96	
Motors >= 250 kW		

[1] Frequency to be adjusted according to equipment condition and wear rates and according to the maintenance requirements defined by the OEM

Thermography inspection on motors	12	
Off-line test for motors Electrical motor diagnosis (EMD)	48	
On-line tests for motors Electrical motor diagnosis	only if issues have been detected	
Steel - bin, tank, silo		
Shell thickness on critical steel silos	16	
Stack, chimney		
Shell thickness on stacks	16	
Belt conveyor		
Belt conveyor rubber belt hardness measurement	48	85 Shore A: order 90 Shore A: replace However consider also results from visual inspection and X-ray monitoring
Additional for steel cord belt conveyors: X-ray or eddy current testing on steel cords	5 years	Decrease frequency with increasing age
Bucket elevator		
Bucket conveyor rubber belt hardness measurement	48	
Measurement of chain elongation	48	2% maximum (in general)
Chain or belt alignment	48	
Ultrasonic test for crack detection on drive shaft	48	
Ball mill		
Measure wear of the mill diaphragm	12	
Measure wear of the mill liners	4	
Visual inspection of the mill head	24	
Magnetic particle / Dye penetrant test / Ultrasonic on mill head	48	
Magnetic particle test of dye penetration on mill shell weld seams	48	
Mill trunnion bearing play and condition	24	Clearance measurement between trunnion and bearing
Cyclone		

Shell thickness on cyclones (corrosive environment)	16	
Emergency power generator		
No-load run of emergency power generator	4	
On-load test with thermography	48	Load to be connected to the switchgear
Fan		
Wear measurement of the impeller	Kiln area: 48w Other areas: 12w	
Ultrasonic test for crack detection on drive shaft	48	For main process fans
Girth Gear Drive (kilns and mills)		
Backlash measurement	48	
Tooth root clearance	48	
Visual inspection of teeth surface	48	
Spray pattern check	2	
Temperature distribution over flank width	1	Maximum delta temperature of 3°C along the flank
Measure axial and radial run-out of girth gear	48	
Gyratory crusher		
Wear measurement of shell / liners	12	
Grate cooler		
Ultrasonic test for crack detection on drive shaft	48	
Frame alignment	48	
Gap management (between grate plates and lateral)	48	Vertical gap (clearance) between grate plates is 1.5 mm, gap between side castings and grate plates (side clearance) is approx. 3.0 mm (cold clearance)
Wear measurement of the plates	48	
Hammer crusher		
Wear measurement of hammers	48	
NDT (MT or PT) test for crack detection of rotor hubs	144	
Horomill		

Wear pattern on roller	12	
Wear measurement pattern wear ring	12	
Impact crusher		
Ultrasonic test for crack detection of the drive shaft	144	
Wear Measurement of the roller discs, liners	1	
Kiln		
Visual inspection of axial thrust collar of roller shaft	1	
Roller shaft bearing play	48	
Visual inspection of axial thrust roller system	2	
Ovality measurement	24	
Relative movement (creep)	1	Between 10-15mm/rev; Maximum 30mm/rev
Migration (axial movement)	1	
Axis alignment	48 (cold), 144 (hot)	
Shell thickness measurement	48	
Magnetic particle test on kiln shell weld seams	48	Especially on sections with diameter transition
Wear measurement on tire / rollers: rectilinearity	48	2mm max (concave or convex)
Wear measurement on rollers: Conically of roller	48	5mm max
Ultrasonic test for crack detection on tire	48	
Ultrasonic test for crack detection on roller shaft	48	
Preheater		
Wear measurement of the refractory (concrete and bricks)	48	
Pan conveyor		
Pan conveyor chain elongation	48	
Chain alignment	48	
Ultrasonic test for crack detection on drive shaft	48	
Reclaimer		

Measure elongation of the chain	6	
Roller mill, vertical roller mill		
Ultrasonic test / Magnetic particles test for crack detection of the pull rod and piston rod	48	
Wear measurement pattern on rollers	12	May also be shorter depending on the material to grind
Ultrasonic test for crack detection on roller	48	
Wear measurement on separator blades	8	
Wear measurement pattern table	12	May also be shorter depending on the material to grind
Wear measurement of the table liners	4	
Roller press		
Wear measurement on roller	4	
Fuel tanks		
Shell thickness on fuel tank	16	
Critical Drives		
Vibration monitoring of critical drives	2 to 4	
Oil analysis on critical gearbox, bearings and hydraulic systems	4 to 24	

Table 30: Recommended Key PMR's

8. Reliability Analysis

8.1 The DADA Cycle

The DADA cycle is a simple concept which supports decision making. It basically states, that before taking a decision on a specific action, sufficient data must be analyzed in order to draw the right conclusions. This concept can be applied on all the following topics.

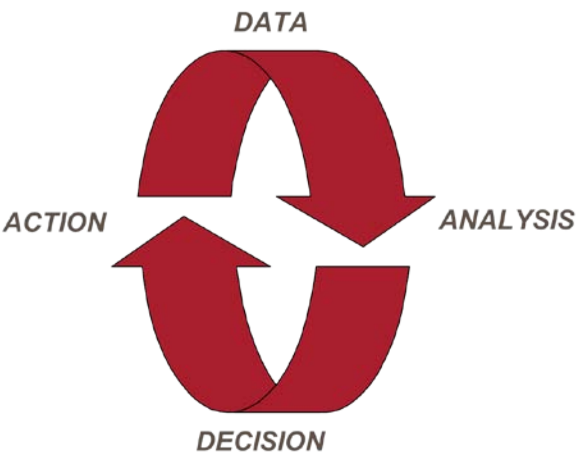


Figure 65: The DADA cycle

8.2 Pareto Analysis

Pareto Analysis is a must where many possible courses of action are competing for our attention.

Typical areas of usage are to analyze the causes of machine down times. The question here is which major failures (20%) account for the majority (80%) of the machine downtime. In the area of cost reduction Pareto Analysis is useful in understanding the distribution of costs across a range of stock items.

A typical approach is the check where the 20% of items are that account for the 80% of the costs. A small reduction in this area will achieve far more than an appreciable reduction in a minor cost area.

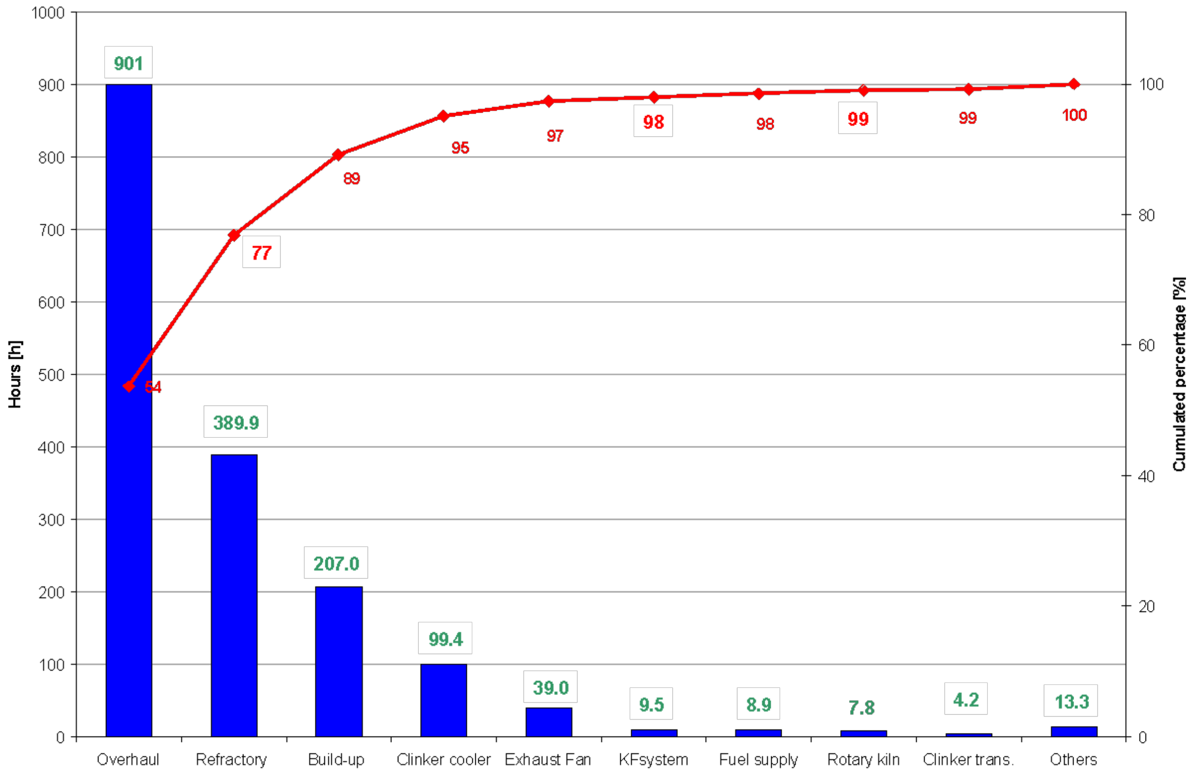


Figure 66: Kiln stop Pareto example by hours

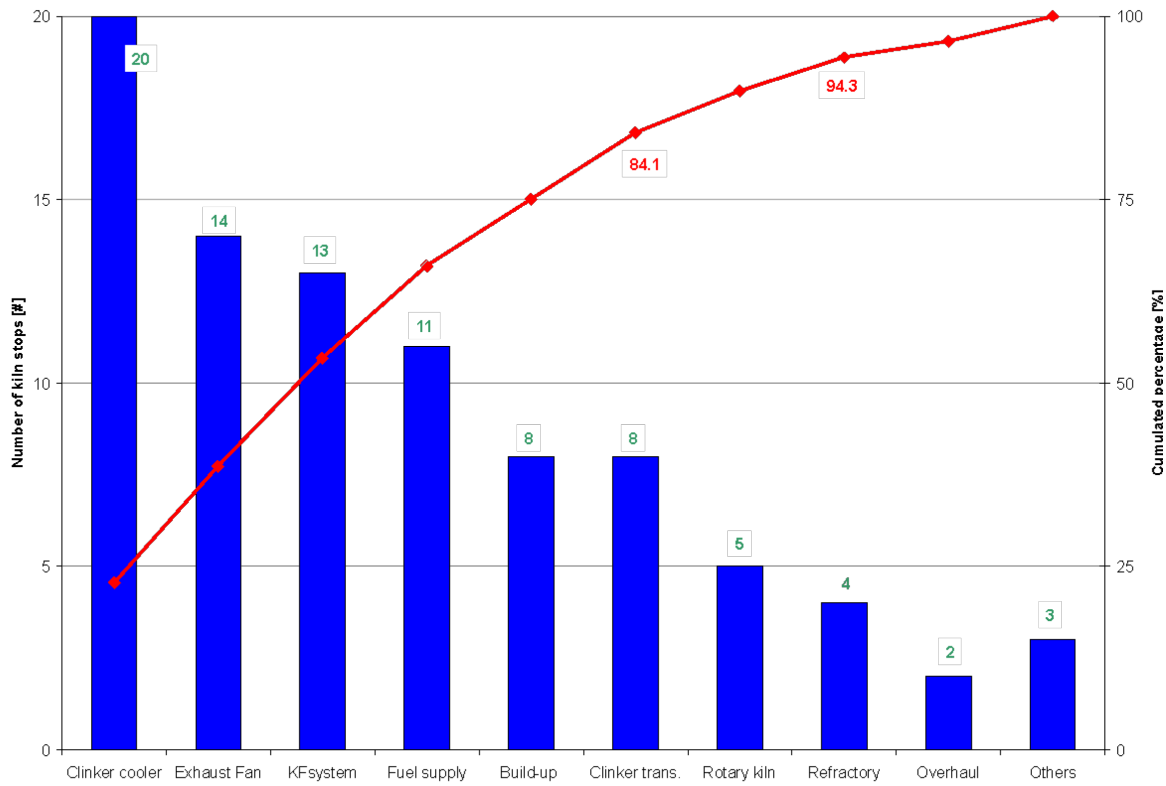


Figure 67: Kiln stop Pareto example by frequency

Pareto charts are usually created for operation loss in hours and for frequency. By analyzing the data towards "hours lost" the focus is set on the NAI. The chart gives an indication of the severity of the single incidents since it shows how long the equipment was down. On the other hand by monitoring the frequency the accent is set towards the detection of repetitive failures, which affect the MTBF.

8.3 Root Cause Failure Analysis (RCFA)

Root cause and failure analysis is a methodology/tool which aims on identification of the most probable cause of a failure and implementation of measures (corrective/preventive) in order to prevent the failure from reoccurring. It belongs to "cause analysis" in the LafargeHolcim standard problem solving approach Unlock (see further below).

Searching for the most probable root cause is done by creating a cause and effect chart as indicated on the Figure 68.

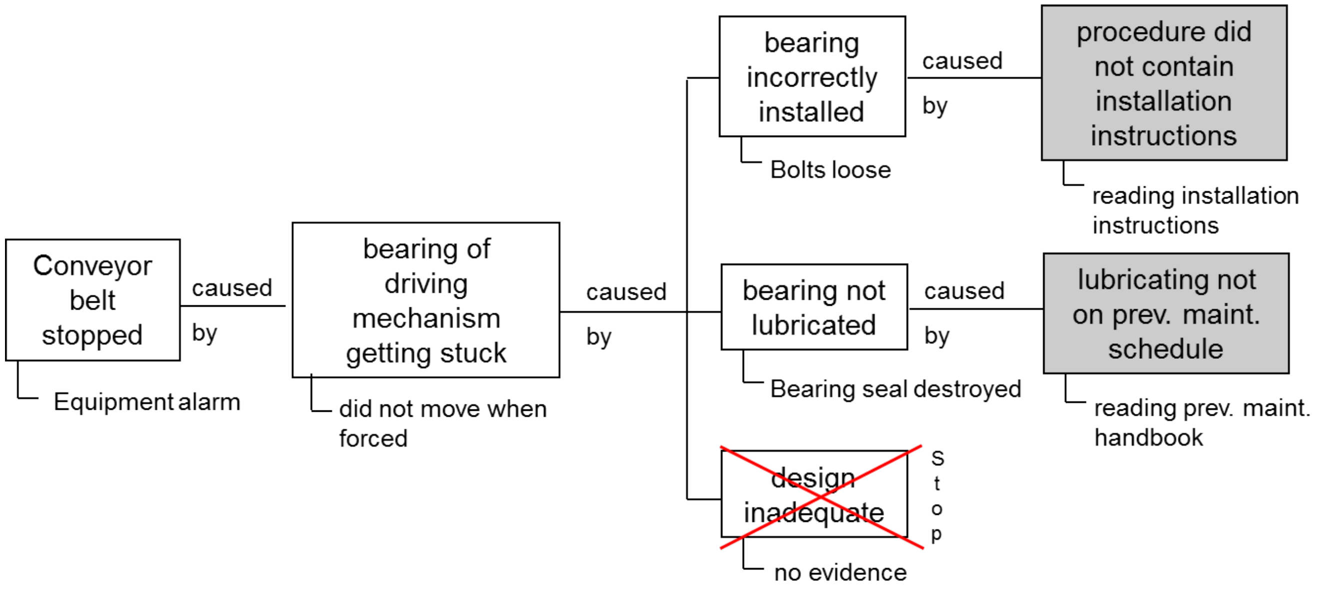


Figure 68: Example for a RCFA of a belt conveyor stoppage

8.3.1 Criteria for conducting a RCFA

All plants must develop their own threshold criteria and decision making process for conducting a RCFA. Note that downtime pareto analysis has a strong influence on the decision making process. Possible criteria can be:

- Production related issues (OEE below target, low MTBF)
- Equipment failure
- Recurring failures that occurred for more than 3x or more in a month
- Failure that stops the main assets (Kiln, Raw Mills and Finish Mills) for an established number of lost production hours or more
- Equipment costs of repair is more than an established level for the cost
- Environmental Issues such as dust emission higher than LafargeHolcim standards

8.3.2 Unlock

Note that in the frame of the merger the terms “Solve!” (exHolcim) and “RCA” (exLafarge) were replaced by “Unlock”. The tool itself was not changed.

Unlock is systematic and standardized approach for sustainable problem solving. Main steps include definition of problem, analysis of causes, identification of possible solutions and implementation of the best solution.

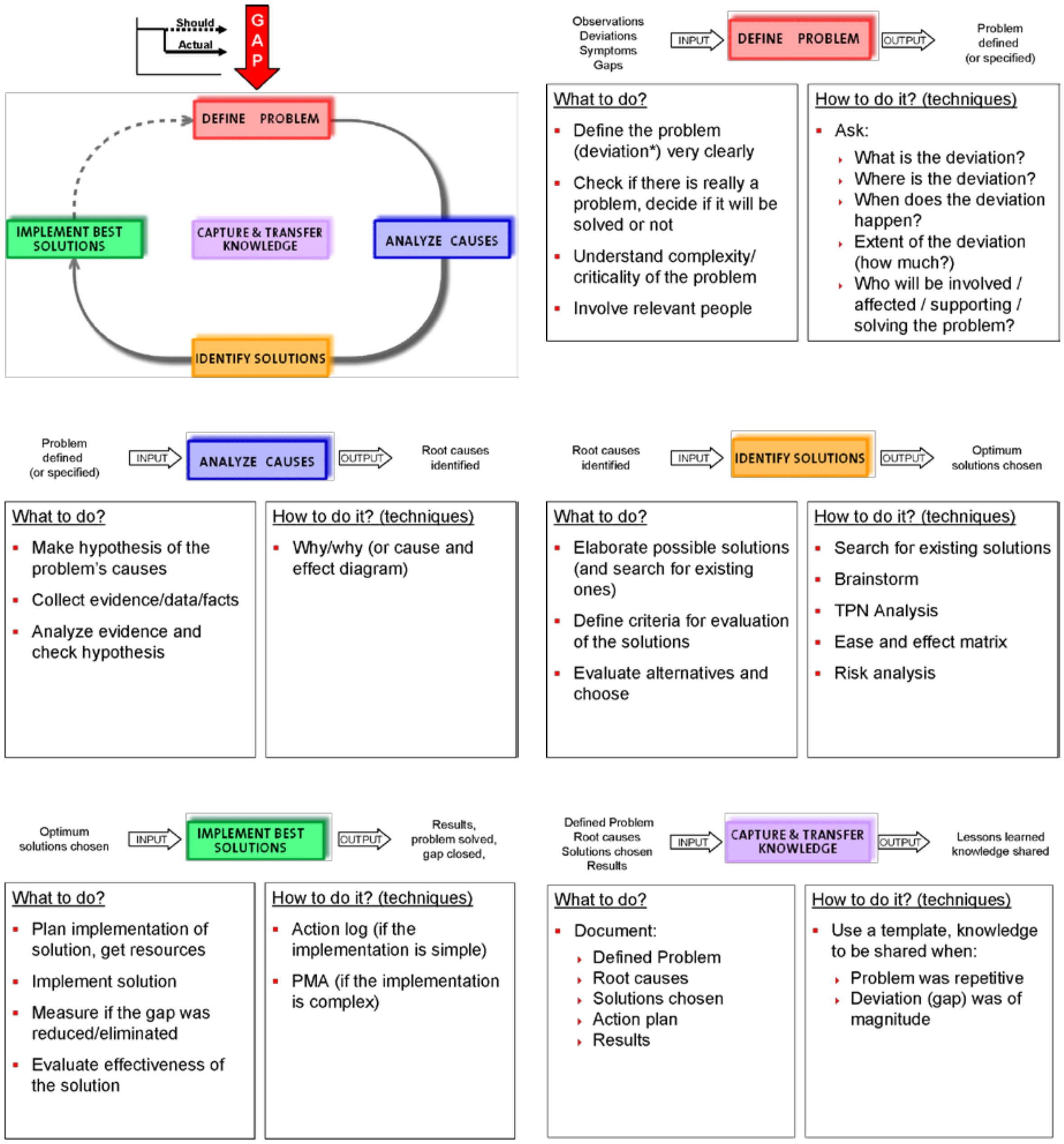


Figure 69: Unlock the LafargeHolcim systematic problem solving process

8.4 Failure Mode and Effect Analysis (FMEA)

Note that the figures shown here are just to illustrate the working principle of an FMEA. There is an official “software” to carry out such analysis. For further info please contact the document owner.

FMEA is a proactive approach in defining maintenance strategies through a structured and systematic process that is used to determine economically justifiable actions to reduce the severity or probability of a failure. An FMEA consist of three main steps which are definition of the risk profile, the actual FMEA and definition of measures and is typically performed in case of new installations and in case of many different and distinct failure modes within an installation.

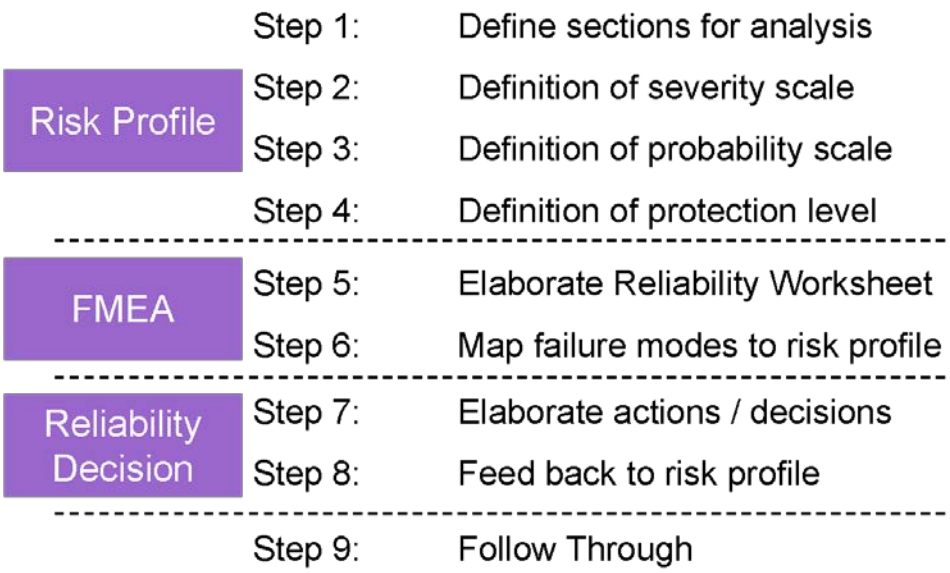


Figure 70: Risk analysis process

The risk profile for the area to be analyzed is case specific. Risks which are still lying in the acceptable range might be unacceptable for other areas. Also the severity rating (impact on costs and downtime) is case specific.

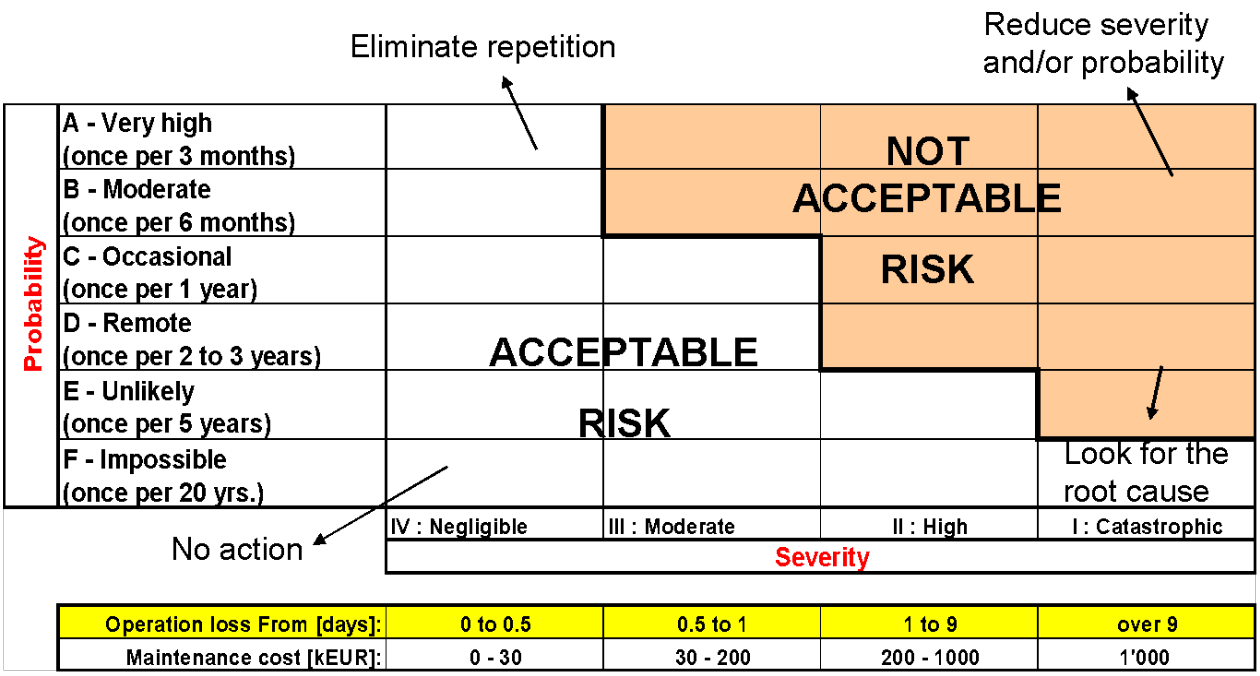


Figure 71: Example of a risk profile. By defining and implementing measures (later in the FMEA process) risk and/or probability can be reduced.

Raw Mill											
	Failure Mode Risk / Event	Consequence	Effect / Failure		MTTR incl. Lead time to spare [days]	Severity *I = highest* *IV = lowest*	Probability *A = highest* *F = lowest*	Explanation of Risk Rating Recomendation / Remarks	Severity *I = highest* *IV = lowest*	Probability *A = highest* *F = lowest*	MTTR [days]
					NO ACTIONS CONSIDERED				ACTION TAKEN		
	Belt 332-FB6										
	Drive pulley:										
21	Bearing failure	Stop of the belt	21.1	Raw mill stops	6	I	E	Hold bearing on stock	III	E	1
22	Broken shaft	Stop of the belt	22.1	Raw mill stops	2	II	F	Shaft welded temporary	III	F	1
	Drive:										
23	Gear box bearings failure	Belt stoped	23.1	Raw mill stops	5	II	F		III	F	1
24	Gear box gear wheel failure	Belt stoped	24.1	Raw mill stops	14	I	F		II	F	2
25	Gear box shafts failure	Belt stoped	25.1	Raw mill stops	14	I	F		III	F	1
26	Electrical motor bearing failure	Belt stoped	26.1	Raw mill stops	2	II	D	Hold bearing on stock	III	D	0.5

Figure 72: Example of a FMEA for a belt conveyor in the raw mill area showing probability and severity of a certain failure with and without measures.

Probability				
A - Very high (once per 3 months)				
B - Moderate (once per 6 months)				
C - Occasional (once per 1 year)				
D - Remote (once per 2 to 3 years)			6	
E - Unlikely (once per 5 years)				1
F - Impossible (once per 20 yrs.)			2 3	4 5
	IV : Negligible	III : Moderate	II : High	I : Catastrophic
	Severity			
Operation loss From [days]:	0 to 0.5	0.5 to 1	1 to 9	over 9
Maintenance cost [kEUR]:	0 - 30	30 - 200	200 - 1000	1'000

Figure 73: Example for mapping of failure modes before implementation of measures

When defining measures which primarily aim on reduction of the severity, in a first step the focus shall be put on the improvement of preventive maintenance (e.g. implementation of additional PMR's or reviewing PMR frequencies). If this is not sufficient to bring the risk in an acceptable range, a contingency plan shall be defined (e.g. replacement of a component by a component from an uncritical equipment). Buying a spare part shall only be considered as last option.

In terms of reducing the probability of a failure, focus needs to be set on the running conditions of the equipment. Assuring a clean working environment, proper alignment, adequate lubrication etc. will help reducing the probability of a failure.

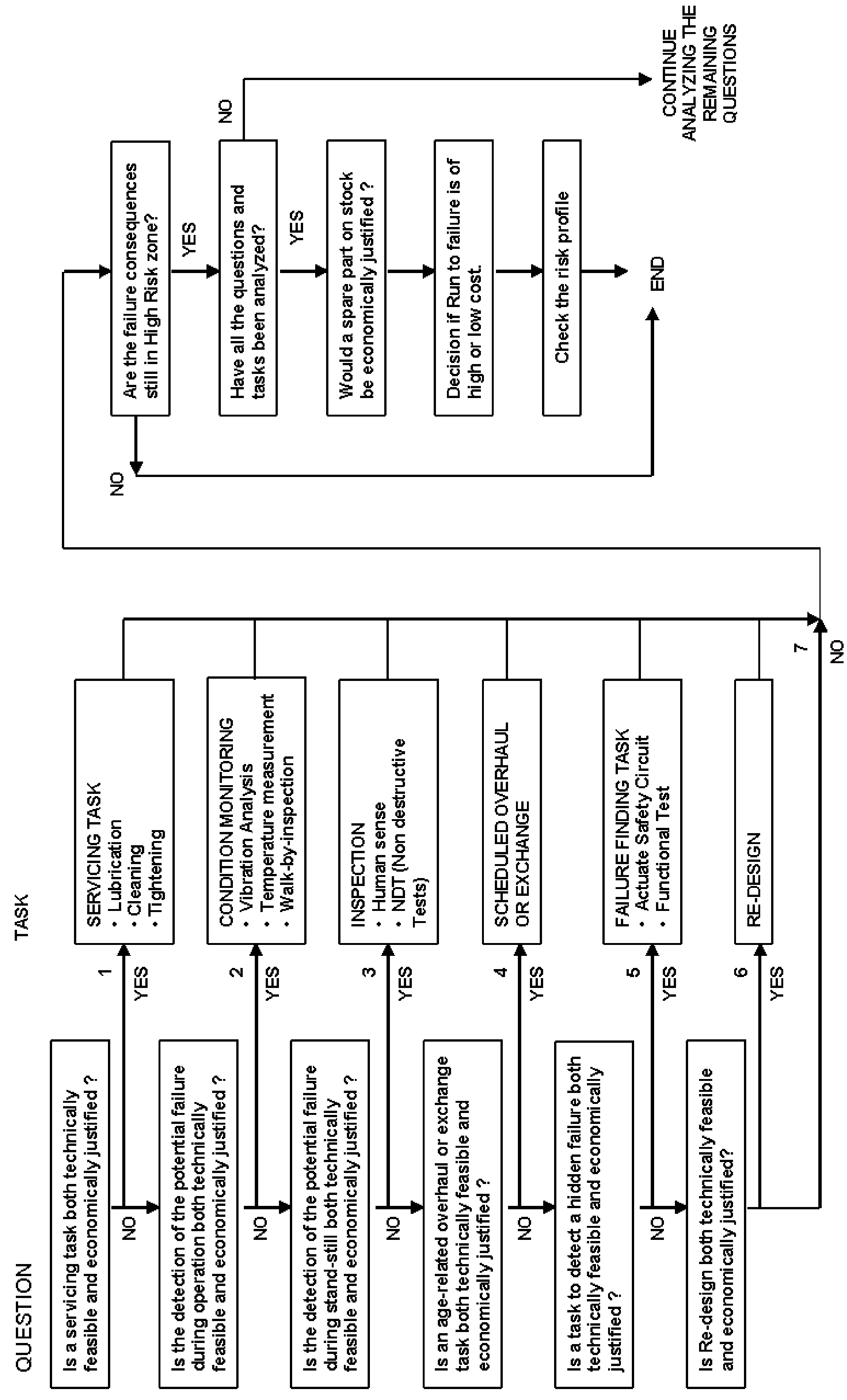


Figure 74: Elaborate actions and take decisions (Reliability decision tree)

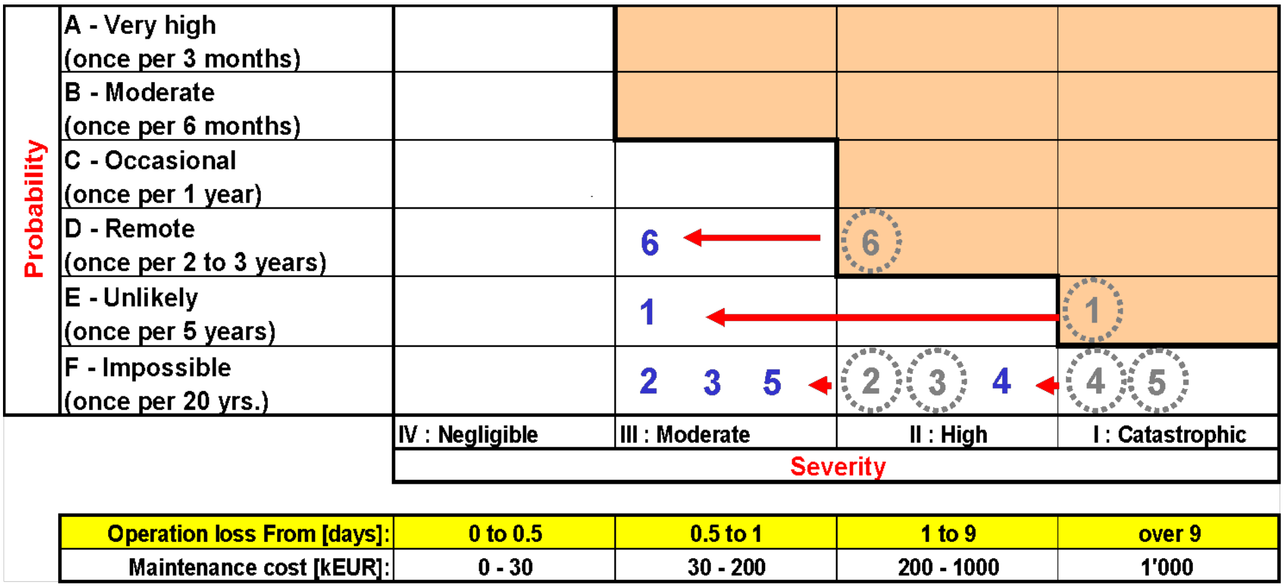


Figure 75: Example for mapping of failure modes after implementation of measures

9. Spare parts management

9.1 Strategic and critical spare parts

A part is considered as strategic (not to be confused with “critical” according to LHARP) if it is critical from the technical point of view i.e. when its non-availability could cause a shutdown of major equipment of a production line.

Usually these parts are included in BOMs for specific equipment and should be identified through FMEA. Actions like definition of safety stock and preventive maintenance routines should be implemented to reduce the risk of a major shutdown.

The following decision tree helps to assess whether a part is considered as strategic.

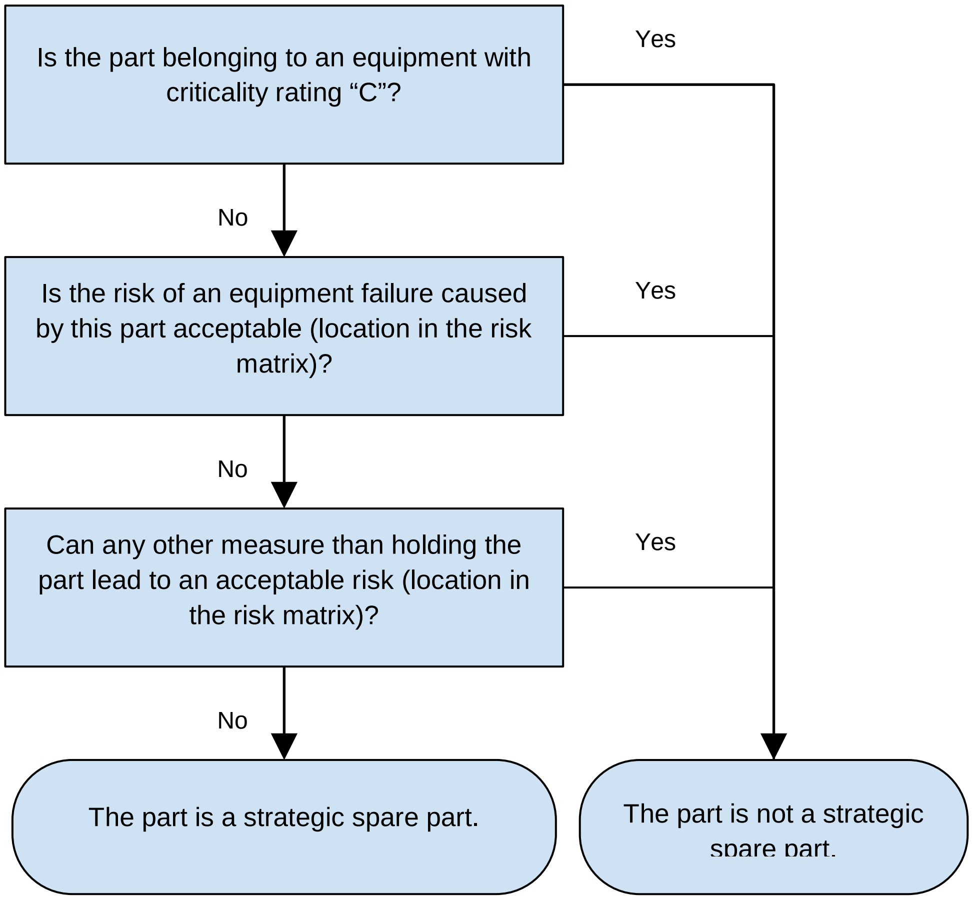


Figure 76: Decision tree for strategic spare parts

In addition some spare parts or materials can become more critical when it is supplied by limited sources and/or if it has long lead time and/or if there is a shortage in the market.

Once critical parts are identified, as a result of a risk assessment and market analysis, it is possible to determine, whether these parts have to be capitalized or not. In this context capitalization means that it enters the balance sheet as plant property and equipment (PPE) and is not depreciated. The respective decision tree is show below. For more info regarding this topic consult LHARP.

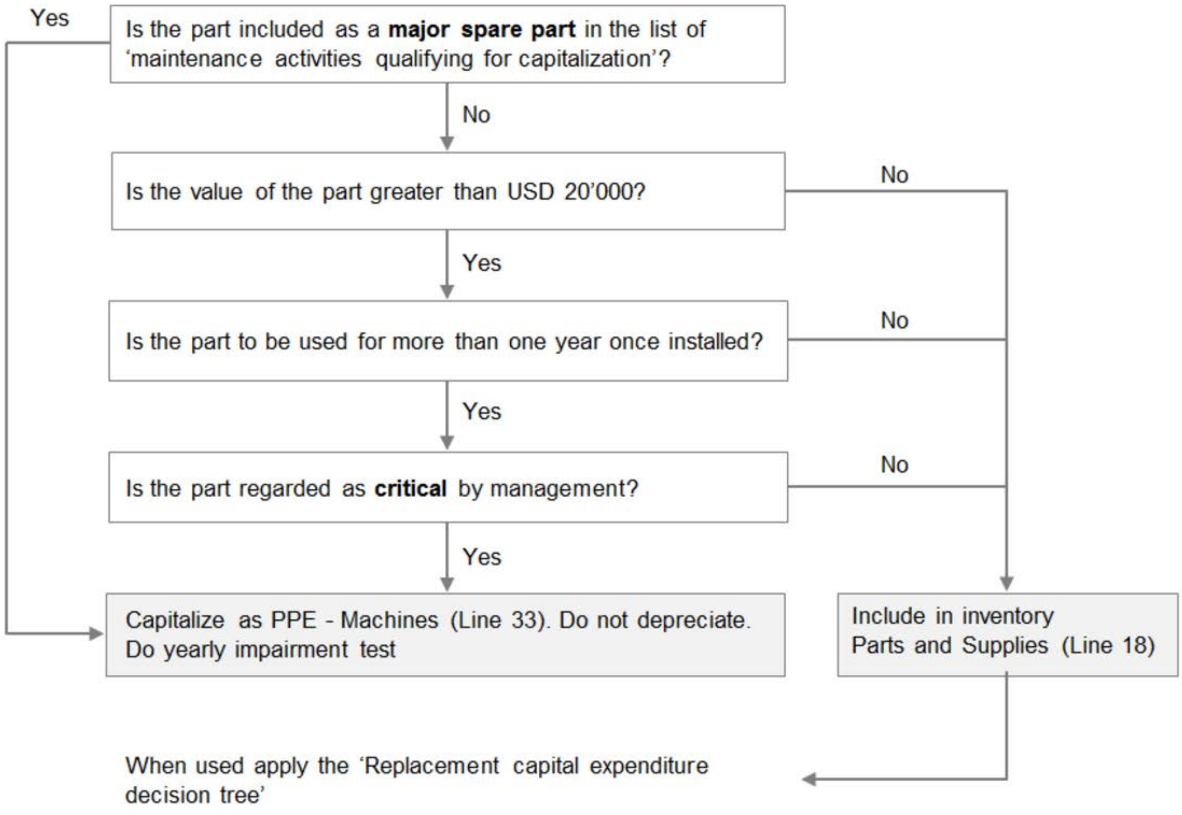


Figure 77: Capitalization of major spare parts according LHARP principles

9.2 Spare parts PMR's

The warehouse is not just an area to store items. It also has to guarantee that items are stored in proper conditions to support plant reliability. This is through proper warehouse layout, proper operational processes and proper maintenance of spare parts held.

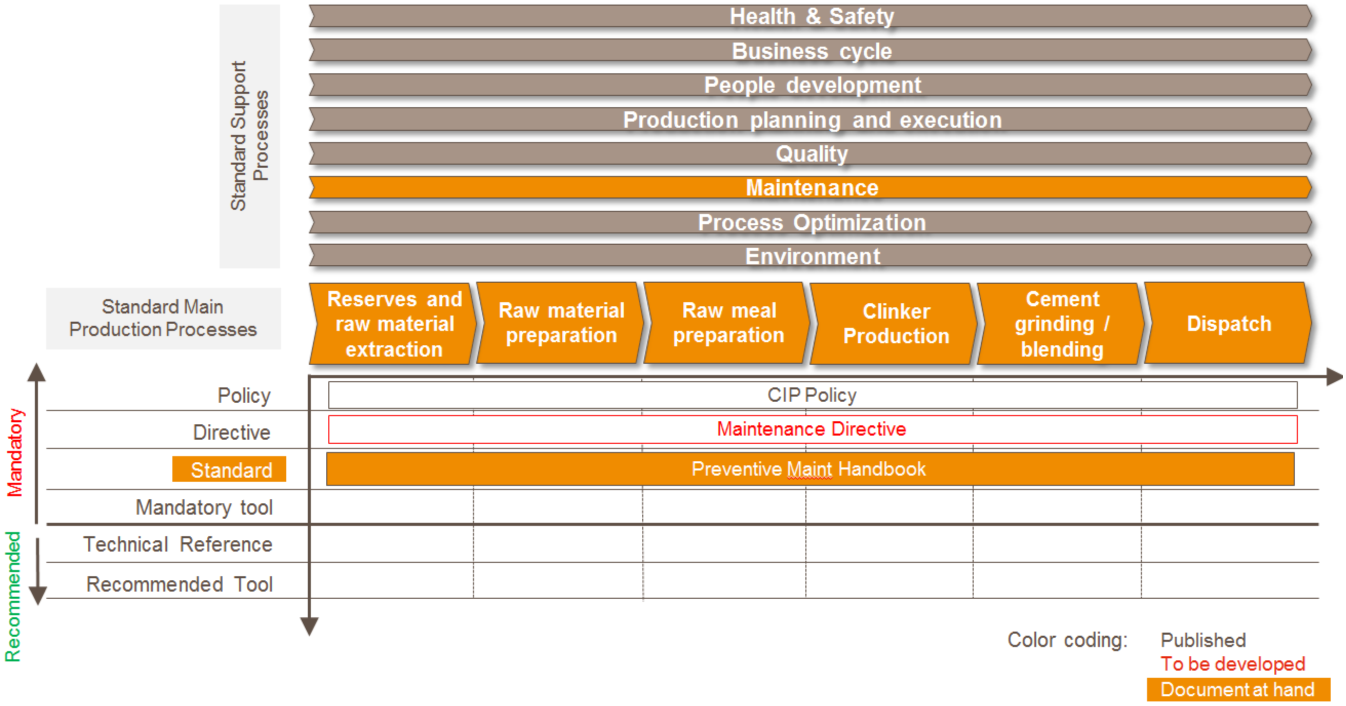
For more detailed information on warehouse management, refer to the Inventory Management Business Process Recommendations or contact the document owner.

Part Type	Task description	Visual Check	PMR	Frequency [weeks]
General	Ensure proper housekeeping is in place	X		24
	Ensure driving ways are free of obstacles	X		24
Bearings	Ensure bearings are kept in a very clean, dry and vibration free environment	X		24
	Ensure bearings are kept in a closed bag and stored horizontally	X		24
Electrical motors	Ensure shafts of electrical motors are turned on a regular base		X	24
	Ensure heating system for motors bigger than 500 kW is connected		X	24
Electronic cards	Ensure all cards are kept in anti-static bags	X		24
Belts of conveyors	Ensure big belts are kept suspended on a steel bar and are not under direct sunlight	X		24
Welding Material	Ensure welding rods are kept in a dry place	X		24
Kiln rollers	Ensure kiln rollers are kept under a roof	X		24
	Ensure surfaces are covered with an anti-corrosive layer	X		24
Girth gear	Ensure girth gear is kept under a roof	X		24
	Ensure girth gear is kept horizontally (leveled!)	X		24
	Ensure surfaces are protected with an anti-corrosive layer	X		24
Kiln shell	Ensure cross-bars to support kiln shell are in place	X		24
Steel plates, profiles and pipes	Ensure steel plates, profiles and pipes are stored under a roof	X		24
Cables, chains and hooks	Ensure cables, chains and hooks are regularly inspected (visually and NDT)		X	48
	Ensure cables, chains and hooks are protected against corrosion	X		24
Gas cylinders	Ensure full and empty cylinders are clearly separated	X		24
	Ensure gas cylinders are properly labeled	X		24
Filters and bag filters	Ensure filters are kept in a closed box	X		24
	Ensure filters are kept in a dust free environment	X		24

Table 31: Recommended spare parts PMR's and their frequency

10.Document management

10.1 Cement Industrial Framework



10.2 Document information & revisions

Content owner	Nicolae Bara, Head of Maintenance & Equipment		
Author(s)	**Ignacio Diaz, Dacian Candea, Alino Bertolo, Michael Schmid**		
Reviewed by	CIP Maintenance		
Validated by	CIP Standards and Tools		
Revisions	**Version**	**Date**	**Main changes**
	1.0	01.07.2008	Ignacio Diaz First version (legacy Holcim)
	2.0	01.07.2009	Ignacio Diaz Content updated: Lubrication storage and handling, Test, warning and condemning limits for oil samples, Oil testing frequencies for, vibration analysis frequencies. New: Included unit conversion table, list of abbreviations
	3.0	07.08.2014	Dacian Candea New template applied Updating of the Maintenance Key Performance Indicator according with Maintenance Indicators Guide_Rev6.1 Minor spelling corrections
	4.0	21.12.2016	Michael Schmid and Alino Bertolo Total revision & conversion to LafargeHolcim template

10.3 Related Documents

	Type	Name
I	Policy	CIP policy
II	Directive	Maintenance Directive
III	Standard	
IV	Mandatory Tool	
VI	Technical Reference	
VI	Recommended Tool	

This document replaces:

Type	Name
Legacy Holcim	Preventive Maintenance Handbook, Third Edition, August 2014
Legacy Lafarge	

11.Annexes

11.1 Annex 1: List of abbreviations

AN	Acid Number
BN	Base Number
BOM	Bill of Materials
CEM	Continuous Emission Monitoring
CM	Condition Monitoring
CTC	Cycle Time Compression
DADA	Data Analysis Decision Action
DE	Drive End
DGA	Dissolved Gas Analysis
DMS	Document Management System
EMD	Electrical Motor Diagnostics
EP	Extreme Pressure
FFT	Fast Fourier Transformation
FID	Flame Ionization Detector
FIFO	First In First Out
FMEA	Failure Mode & Effect Analysis
FPE	Fatality Prevention Element
FTIR	Fourier Transform Infrared Spectroscopy
gSE	g Spike Energy (g = $9.81 m/s^2$) in relation with SPM
ICP	Inductive Coupled Plasma
KPI	Key Performance Indicator
LTIFR	Lost Time Injury Frequency Rate
LTISR	Lost Time Injury Severity Rate
MAC	Maintenance Cement
MCC	Motor Control Center
MT	Magnetic Particle Test
MTBF	Mean Time Between Failure
NAI	Net Availability Index
NDE	Non-Drive End
NDT	Non Destructive Testing
OEE	Overall Equipment Efficiency
OEM	Original Equipment Manufacturer
PMR	Preventive Maintenance Routine
PPE	Personal Protective Equipment (or Plant Property and Equipment)
PPM	Parts Per Million (1 ppm = 1ml per 1000l or 1000 ppm = 0.1%)
PT	Paint Test (Dye Penetrant Test)
RCFA	Root Cause Failure Analysis
RMS	Root Mean Square
RDE	Rotating Disc Electrode
SPM	Shock Pulse Monitoring or Shock Pulse Method
UT	Ultrasonic Test
VI	Viscosity Index
VRM	Vertical Roller Mill
VT	Visual Test
ZDDP	Zinc dialkyldithiophosphates

11.2 Annex 2: Job descriptions

LafargeHolcim

Job Description Guidelines and Main Responsibilities

Job Title:	Preventive Maintenance Head

Purpose/Mission:
Contribute to reach maximum long term availability / reliability of the equipment and installations in the plant by implementing the appropriate preventive maintenance actions at the lowest cost and in compliance with the H&S regulations.

Dimensions	
Scope of authority:	▪ Plan preventive and corrective maintenance activities and develop maintenance routines, contribute to plan annual shutdown programs. Follow the creation of bill of materials (BOM) and ensure spare parts availability through warehouse control ▪ Lubrication preventive maintenance routines development and execution ▪ Condition monitoring inspections: walk by inspections (WBI), lubricant analysis, vibration analysis, non-destructive testing (NDT), thermography analysis, wear measurements, electric motor diagnostic, gear measurements, other specific measurements ▪ Department skill matrix preparation, and people development
Spending authority:	Defined within budget
Report to:	Maintenance Manager
Functional report	Maintenance Manager
Location	
Department / Group	
Management level	

Critical Tasks:	Critical Tasks achievement measurement:
1. (Maintenance operations) Determine and plan the necessary preventive and corrective actions to assure long term proper functioning of equipments and installations. Contribute to plan annual shutdown programs. Establish preventive maintenance plans in cooperation with Production Manager, Electrical and Mechanical Maintenance Supervisors and Capex department	NAI MTBF Maintenance Cost PMR ratio Scheduling compliance Planning accuracy Mayor Shutdown evaluation Call out Outstanding work (13w) Overdue Schedule Ratio PMR efficiency PMR not performed BOM mat PRequest ratio Spare parts inventory value PM02 manual call ratio Aging maint request PM01 w/out maint request Material reservation usage Aging work order Unplanned LTIFR LTISR # Of Legal issues
2. (Maintenance operations) Monitor the implementation and execution of the preventive maintenance tasks and procedures. Record equipment and installation history. Control lubrication and condition monitoring tasks of equipment and installations to identify needs of maintenance actions and reduce risks of unplanned downtime.	
3. (Management – Planning & Cost control) Support the Maintenance Manager in the elaboration and control of the maintenance budget, ensuring planning and follow-up of costs. Lead planning for all foreseeable operations (weekly, master, shutdown).	
4. (Standards) Communicate and implement regulations, company goals, local permits, policies and procedures; optimize the internal processes and structures. Supervise personnel to apply them consistently and ensure ISO compliance. Respect MAC standard; follow up weekly MAC targets (KPIs).	
5. (People management) Develop and motivate its team, ensuring competencies and skills development according to technical innovations, plant or personal needs. Train and coach the maintenance team on preventive maintenance and maintenance routines.	
6. (H&S and environment) Guarantee compliance with H&S, environment policies, maintenance legal policies in the definition of maintenance plans and routines.	
7. (Maintenance operations) Contribute to NWC optimization by identifying critical parts (based on risk assessment and implementation of preventive	

maintenance routines on critical equipments) and establishing optimal stock levels of spare parts	
8. (Innovation and continuous improvement) Consider new techniques and/or technologies to optimize maintenance cost and improve the technical condition and functioning of the installed equipments.	

Qualifications, including competencies, skill, knowledge:			
Preferred Education:	Degree in Electrical or Mechanical Engineering or equivalent education / experience.		
Preferred professional memberships:			
Preferred Experience:	5 years experience dealing with production or maintenance. Experience in heavy industry experience preferred 2 years experience with definition and implementation of preventive maintenance programs and routines Experience applying FMEA techniques and knowledge of basic problem-solving tools		
Computer Skills	Microsoft Office, SAP (PM, MM, PS)		
Language requirements:	Local English	Language Level:	Good written and spoken Good written and spoken
Other	Knowledge of cement production process Knowledge of MAC (Maintenance Cement), ACS, PMA , Cost Preventive Maintenance Certification		
1. *Think the business:* Strategic alignment; analysis and problem solving; business and financial acumen			
2. *Deliver results:* Manages execution; customer focus; supports action, change and innovation; leads for performance			
3. *Energize people:* Communication; engages and inspires; develops employees; cultivates relationships and networks; fosters teamwork and cooperation			
4. *Act as a role model:* Adapts and learns; establishes trust and confidence			

Other requirements:

JD written by: JD controlled by:	Pier Gribaudi, Beatriz Méndez-Villamil Jean-Pierre Grozellier, Strategic Cement Manufacturing	Version Number: Date issued:	4.0 November 2016

Job Description Guidelines and Main Responsibilities

Job Title:	**Condition Monitoring Technician**

Purpose/Mission: Prepare, plan & schedule the yearly program for all condition monitoring technics under his responsibility. Evaluate data and findings, take actions and inform his superior if a condition is in a critical situation. Coordinate third party services for special monitoring technics. Assure the right condition of the machine after the repair and before the start-up

Dimensions	
Scope of authority:	▪ Condition Monitoring Technics as: Vibration, thermography, ultrasonic test, magnetic particle test, dye penetrant test, wear measurement, elongation measurements, hardness measurement, ovality measurement, shaft deflection measurement, ultrasonic applications for high voltage lines inspection or gas/air leakages, girth gear, pinions and gearbox measurements ▪ Responsible for prepare, follow up and optimize yearly condition monitoring schedule based on inputs and history from the executed work orders ▪ Administrate work order system by generating notifications, closing condition monitoring work orders and recording data base and trends
Spending authority:	Defined within budget
Report to:	Preventive Maintenance Head
Functional report	Maintenance Manager
Location	
Department / Group	
Management level	

Critical Tasks:	**Critical Tasks achievement measurement:**
1. (Maintenance operations) Create and revise in a yearly bases the condition monitoring chart and the yearly program centralizing the information in the condition monitoring work-load balancing sheet. Optimize and balance the workload for each week of the year Participate in weekly planning meetings as well as in the mayor shut-down meeting to coordinate jobs with other departments	NAI MTBF Maintenance Cost PMR ratio Scheduling compliance Planning accuracy Mayor Shutdown evaluation Outstanding work (13w) Overdue Schedule Ratio PMR efficiency PMR not performed PM02 manual call ratio Aging PM02 work order Unplanned LTIFR LTISR # Of Legal issue
2. (Maintenance operations) Plan, schedule and execute the condition monitoring measurements giving high priority to critical equipment. Assure condition monitoring measurements after a machine repair, before the start up. Upload the data, generate trends, analyse the data and generate conclusions. Inform his superior about critical situations. Generate notifications. Supervise condition monitoring executed by specialized third party services and assure that measurements and conclusions are correctly made. Participate actively and with relevant data in the RCFA meetings	
3. (Management – Planning & Cost control Follow and report monthly the main findings, generate third party services contracts and together with purchasing looks for the best TCO. Optimize in a yearly base the preventive maintenance program.	
4. (Standards) Creates/optimize procedures, documentation to assure the quality of the job and reduce time needed for the inspection.	
5. (People management) Establish the training needs based on the company skill matrix for a given role.	
6. (H&S and environment) Follow the H&S rules and regulations defined by the company as well as the legal ones of his country, support the elaboration of safety standards for his jobs, take care of environmental as well as maintenance legal regulations.	
7. (Maintenance operations) Takes cares of instruments	

and tools under his responsibility (as cleanliness, condition, calibration, storage ….) to assure the highest availability.	
8. (Innovation and continuous improvement) Coordinates meetings with suppliers to stay updated on new tools and technics available to optimize/facilitate the job execution	

Qualifications, including competencies, skill, knowledge:			
Preferred Education:	Mechanical or Electrical Technician Certification level II in at least one condition monitoring technic		
Preferred professional memberships:			
Preferred Experience:	3 years of maintenance experience in cement of heavy industry		
Computer Skills	Microsoft Office, SAP PM (only transactions needed for the role)		
Language requirements:	Local English (preferred)	Language Level:	Good written and spoken Acceptable
Other	Knowledge of cement production process Knowledge of MAC (Maintenance Cement), ACS, PMA , RCFA Solve, Cost Basics		
1. *Think the business:* Strategic alignment; analysis and problem solving; business and financial acumen			
2. *Deliver results:* Manages execution; customer focus; supports action, change and innovation; leads for performance			
3. *Energize people:* Communication; engages and inspires; develops employees; cultivates relationships and networks; fosters teamwork and cooperation			
4. *Act as a role model:* Adapts and learns; establishes trust and confidence			

Other requirements:

JD written by: JD controlled by:	Alino Bértolo Silvano Cukon;	Version Number: Date issued:	1.0 November 16

Job Title:	Maintenance Planner

Purpose/Mission:

Improve the efficiency and productivity of own personnel and third party services through a good planning, follow up and optimization of all preventive/corrective maintenance tasks to reach the targets of equipment availability / reliability at the lowest sustainable maintenance cost, in collaboration with all involved departments or sub-departments, following the maintenance guide lines (MAC) defined by the company

Dimensions

Scope of authority:	▪ Plan, review and optimize in SAP/DMS all the PM02 routines establishing tasks, frequencies, workload balancing. Optimizes and distributes the load in 48 weeks a year. ▪ Schedule weekly plans, 13 weeks and major stops. ▪ Consolidates the detail of major repairs. Lead the mayor shut-down meetings and AAR ▪ Prioritizes and generates corrective orders based on the results of monitoring, prioritizes with other departments corrective orders ▪ Revises notifications, workload, defines needs of third party services. Tracks the purchase requests and services of major shutdown/repairs and ensures their on-time arrival ▪ Generate and follow up purchase requests for materials, spare and wear parts, ensuring Just in time delivery and optimization of NWC
Spending authority:	Defined within budget
Report to:	Preventive Maintenance Head
Functional report	Maintenance Manager
Location	
Department / Group	
Management level	

Critical Tasks:	Critical Tasks achievement measurement:
1. (Maintenance operations) Planning and scheduling of all preventive maintenance routines in SAP/DMS together with the specific execution responsible. Generation and optimization of the 48/96 weeks workload balancing sheet by department/specialty/technic targeting a good balance during the days of the year. Generates the weekly and 13 weeks planning. Prioritizes the notifications coming from condition monitoring or others and generates corrective work orders in agreement with the requester	NAI MTBF Maintenance Cost PMR ratio Scheduling compliance Planning accuracy Mayor Shutdown evaluation Call out Outstanding work (13w) Overdue Schedule Ratio PMR efficiency PMR not performed BOM mat PRequest ratio Spare parts inventory value (NWC) PM02 manual call ratio Aging maint request PM01 w/out maint request Material reservation usage Aging work order Unplanned LTIFR LTISR # Of Legal issues
2. (Maintenance operations) Leads the preparation and consolidation of the shutdown planning (personal, third parties services, materials, spare parts, equipment, tools, time, critical path) with coordination meetings using MAC guidelines and tools.	
3. (Management – Planning & Cost control) Generates purchase orders as well as third party services contracts for mayor shutdown, assure that spares and services will be delivered on time. Control of expenses during planning as well during the execution vs budget and control the inventory level vs guide value	
4. (Standards) Assure that special and repetitive jobs come with a standard work order. Lead the weekly KPI revision meeting as well as the work planning confirmation for the next week	
5. (People management) Takes care of his own development needs and train maintenance people on planning requirements	
6. (H&S and environment) Assure that all work orders have the required H&S information, and that all legal requirements (safety, environmental, maintenance) are in the yearly preventive maintenance plan and are executed.	

7. (Maintenance operations) Monitor the realization of the plans. Follow-up tasks defined in mayor shut-downs in a daily frequency.	
8. (Innovation and continuous improvement) Leads After Action Review for shutdown or mayor repairs	

Qualifications, including competencies, skill, knowledge:			
Preferred Education:	Mechanical or Electrical Technician/Engineer		
Preferred professional memberships:	Not required		
Preferred Experience:	5 years experience dealing with production or maintenance. Experience in heavy industry preferred 2 years experience with definition and implementation of preventive maintenance programs and routines Experience applying FMEA techniques and knowledge of basic problem-solving tools Mechanical or electrical maintenance experience (preferable in heavy industry)		
Computer Skills	Microsoft Office, SAP PM (Key user level preferred)		
Language requirements:	Local English	Language Level:	Good written and spoken Acceptable written and spoken
Other	Knowledge of cement production process Knowledge of MAC (Maintenance Cement), ACS, PMA , Basics of Cost		
1. *Think the business:* Strategic alignment; analysis and problem solving; business and financial acumen			
2. *Deliver results:* Manages execution; customer focus; supports action, change and innovation; leads for performance			
3. *Energize people:* Communication; engages and inspires; develops employees; cultivates relationships and networks; fosters teamwork and cooperation			
4. *Act as a role model:* Adapts and learns; establishes trust and confidence			

Other requirements:

JD written by: JD controlled by:	Alino Bértolo Silvano Cukon;	Version Number: Date issued:	1.0 November 2016

Job Description Guidelines and Main Responsibilities

Job Title:	**Lubrication Supervisor**

Purpose/Mission: Preparation of a lubrication program that guarantees high reliability and availability of plant equipment at the lowest sustainable maintenance cost in compliance with H&S as well as environmental rules and regulations. Close supervision of jobs execution, optimization of lubricant inventories and lubricants warehouse housekeeping, development of own personnel

Dimensions	
Scope of authority:	▪ Generation of a complete lubrication chart, and a yearly lubrication preventive maintenance program, supervision of jobs quality and execution. Evaluates the results of the oil condition monitoring and take actions based on the data/information received. ▪ Coordinate with other departments and organize his personnel for weekly maintenance stops as well as for big repairs and shutdown. ▪ Optimize the use of third party services, material and spares, takes care of lubricant inventory in the warehouse ▪ Prepare in due time the the budget and report main needs of his area of responsibility to his superior
Spending authority:	Defined within budget
Report to:	Preventive Maintenance Head
Functional report	Maintenance Manager
Location	
Department / Group	
Management level	

Critical Tasks:	**Critical Tasks achievement measurement:**
1. (Maintenance operations) Supervise the execution of the daily/weekly lubrication program and monitors the realization of the tasks. Administrate work order system by generating notifications, closing lubrication work orders and recording data base and trends. Assure the cleanliness of the equipment to be lubricated (bearings, girth gears, gear-boxes), lubrication and hydraulic rooms, assure the quality of the job of lubricators in the field. Assure the right storage of lubricants and cleanliness of the warehouse and lubrication workshop, takes care of the inventory levels	NAI MTBF Maintenance Cost Oil consumption ratio PMR ratio Scheduling compliance Planning accuracy Mayor Shutdown evaluation Call out Outstanding work (13w) Overdue Schedule Ratio PMR efficiency PMR not performed Spare parts inventory value (NWC) PM02 manual call ratio Material reservation usage Aging work order Unplanned LTIFR LTISR # Of Legal issue
2. (Maintenance operations) Create and revise in a yearly bases the lubrication Chart and the yearly lubrication program centralizing the information in the lubrication work-load balancing sheet. Optimize and balance the workload for each week of the year Participate in weekly planning meetings as well as in the mayor shut-down meeting to coordinate jobs with other departments	
3. (Management – Planning & Cost control) Follow and report the Oil Consumption Ratio, grease consumption, as well as total lubrication cost compared with budget. Assure a detail planning for special lubrication jobs (annual cleaning of girth gears and inspection…….)	
4. (Standards) Creates/optimize with own personnel and/or with oil suppliers new lubrication procedures to assure the quality of the job and reduce downtime.	
5. (People management) Establish the training program needed for his personnel, schedule oil suppliers training based on Frame Contract.	
6. (H&S and environment) Follow the rules and regulations defined by the company as well as the legal ones of his country, support the elaboration of safety standards for his area, control the leakages and follow the environmental rules for lubricant cleaning & disposal	

7. (Maintenance operations) Is responsible of the lubricants condition monitoring program, preparation, guarantees the correct execution of the sampling, send samples for the analysis, interprete the results and generates actions based on the oil analysis data. Reports any abnormality in the weekly meetings. Keeps oil analysis trend available at any time	
8. (Innovation and continuous improvement) Coordinates meetings with suppliers to check new lubricant developments or new technics available to optimize the work-load and reliabitily of the equipment	

Qualifications, including competencies, skill, knowledge:			
Preferred Education:	Mechanical Technician		
Preferred professional memberships:	Not required		
Preferred Experience:	3 years of maintenance experience in cement or similar heavy industry		
Computer Skills	Microsoft Office, SAP PM (only transactions needed for the role)		
Language requirements:	Local English (preferred)	Language Level:	Good written and spoken Acceptable
Other	Tribology Knowledge Knowledge of cement production process Knowledge of MAC (Maintenance Cement), ACS, PMA , RCFA Solve, Cost Basics		
1. *Think the business:* Strategic alignment; analysis and problem solving; business and financial acumen			
2. *Deliver results:* Manages execution; customer focus; supports action, change and innovation; leads for performance			
3. *Energize people:* Communication; engages and inspires; develops employees; cultivates relationships and networks; fosters teamwork and cooperation			
4. *Act as a role model:* Adapts and learns; establishes trust and confidence			

Other requirements:

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