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WEBINAR MAINTENANCE SERIES

PREDICTIVE MAINTENANCE IN TURBOMACHINERY

Outline

First Session

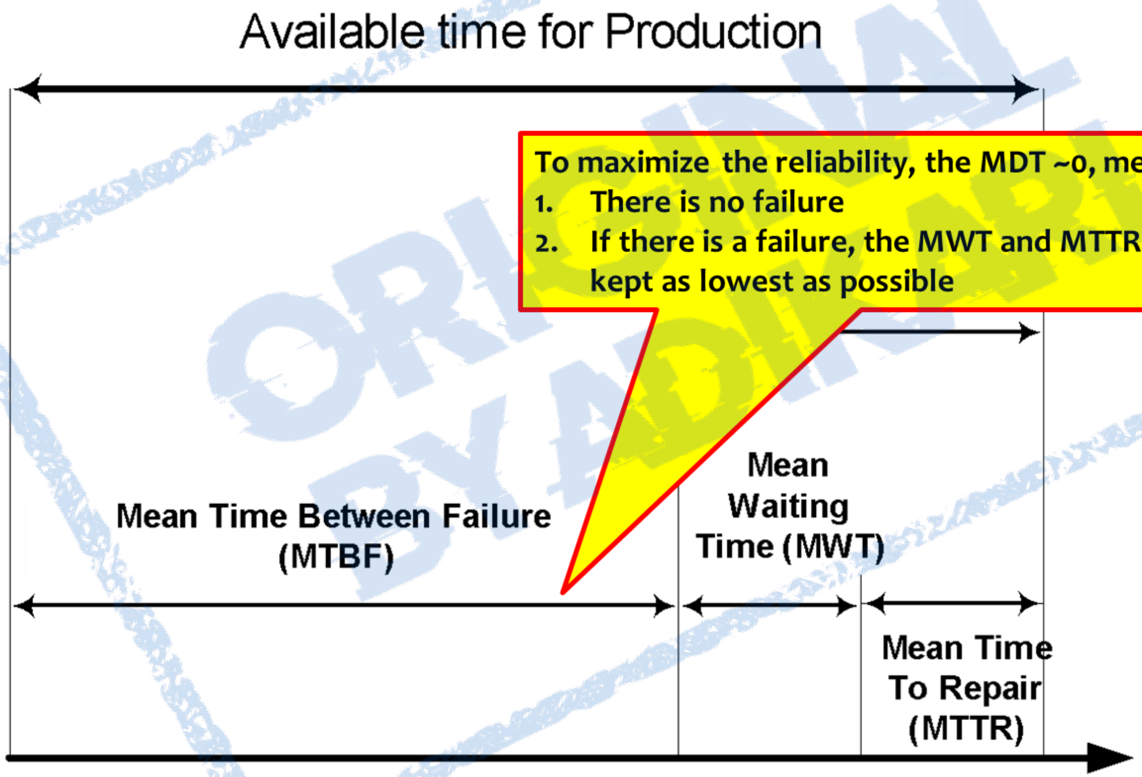
- Maintenance Strategy
- Predictive Maintenance Designing Program

Second Session

- Predictive Maintenance Technologies
- Predictive Maintenance Implementation
- Case Study

First Session

Maintenance Strategy



The Changing World of Maintenance

First Generation
- Fix it when it broke

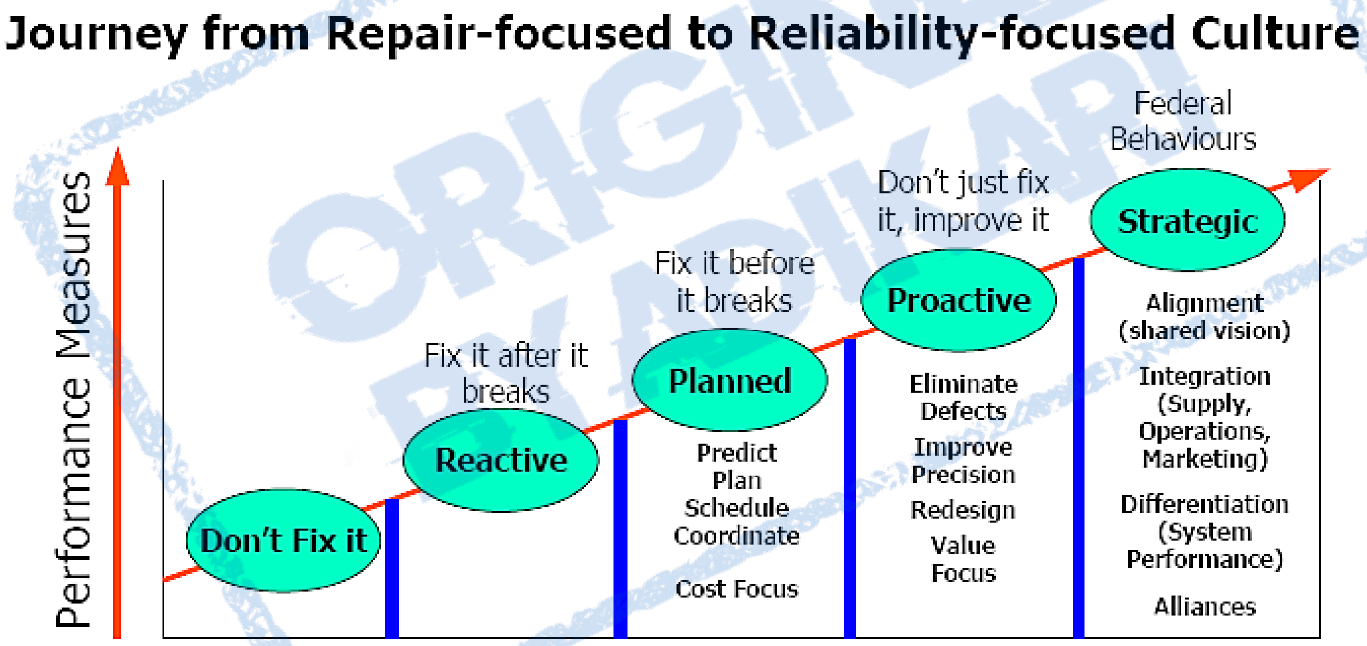
Second Generation
- Scheduled overhauls
- Systems for planning and controlling work
- Big, slow computers

Third Generation
- Condition monitoring — New maintenance techniques
- Design for reliability and maintainability — Design emphasizing on Reliability and Availability
- Hazard studies
- Small, fast computers
- FMEA
- Expert systems

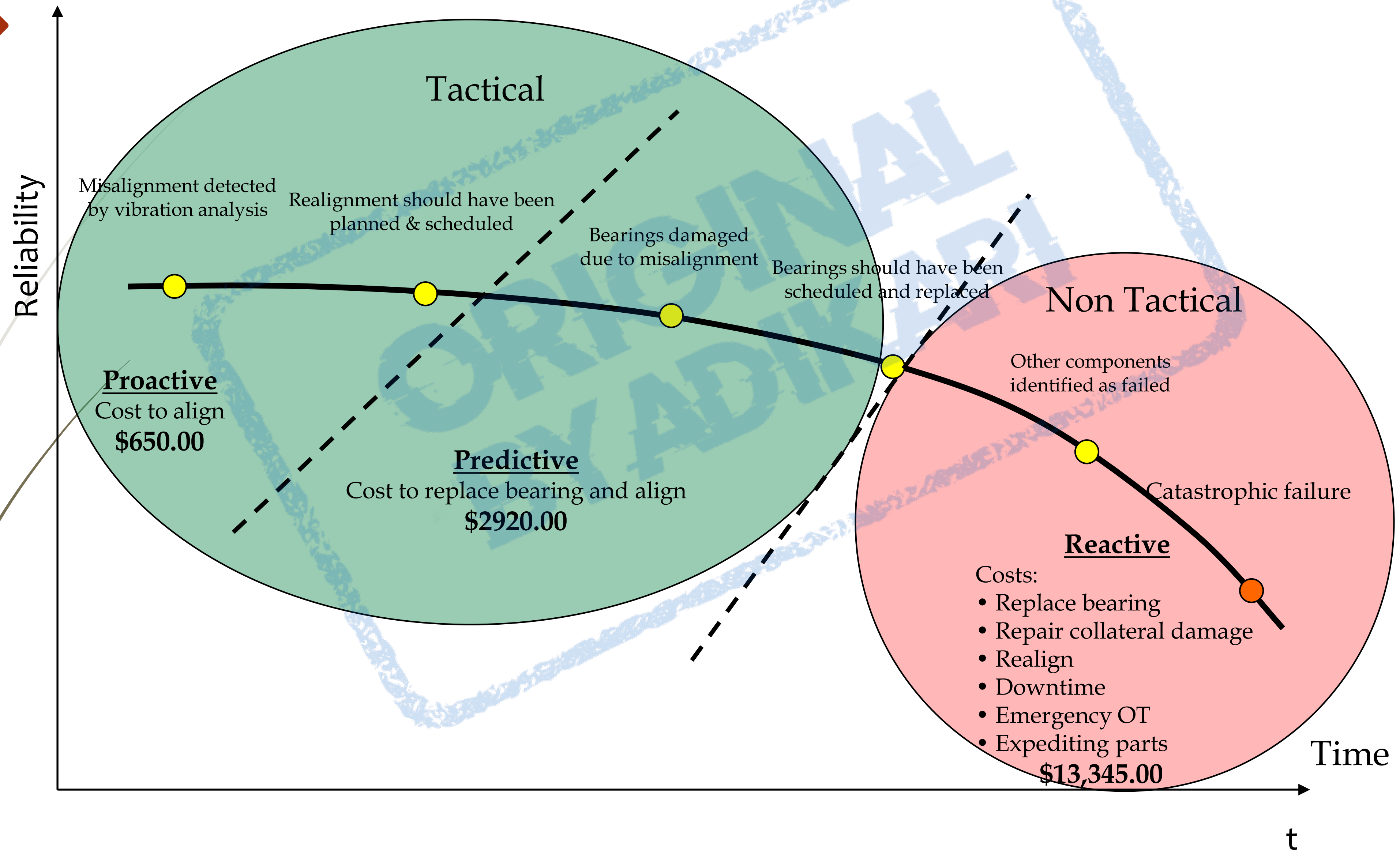
  — Decision support tools
- Multi skill and teamwork — Major shift in organizational thinking

1940	1950	1960	1970	1980	1990	2000

Repair to Reliability Focus

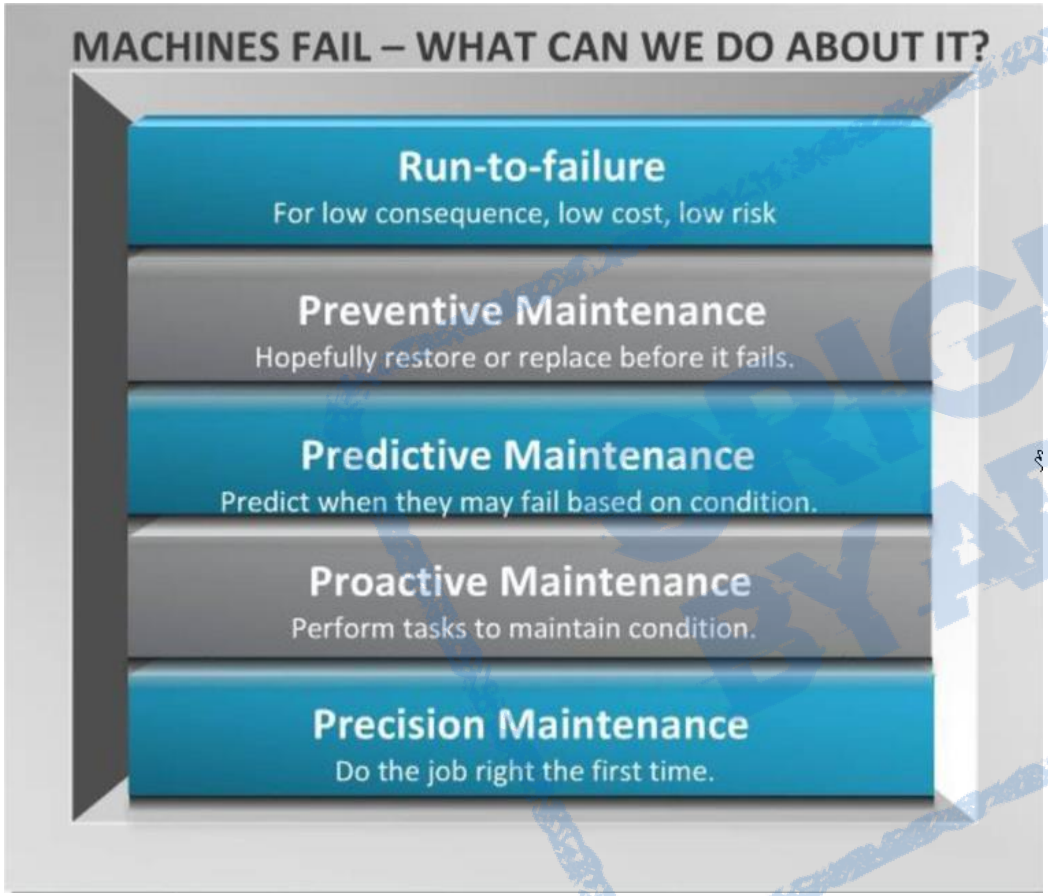


Stage of Failure



Ref : John Mitchell, Physical Asset Management Handbook

Maintenance Types



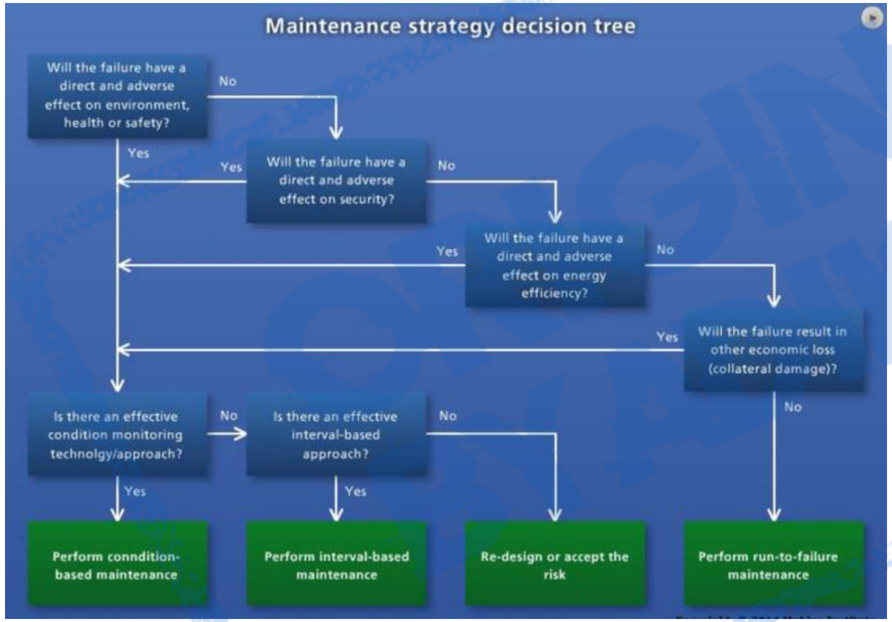
Why Predictive Maintenance is Important?

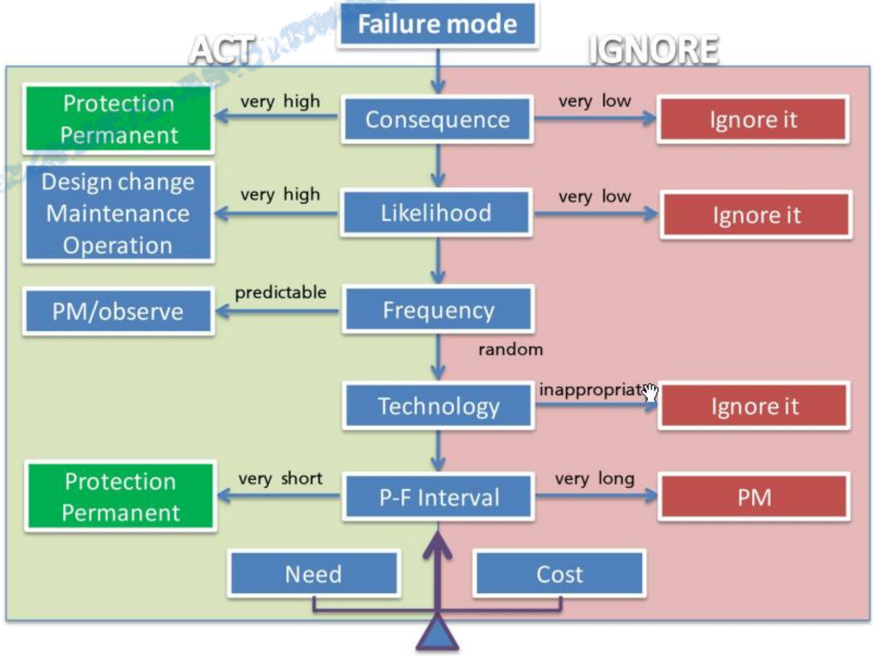
- Degradation of different parts
- Although the cost, repair and refurbishment expenses might not be substantial but the cost associated with down time is enormous.
- Predictive maintenance provides
  - ✓ Adequate warning of imminent failures
  - ✓ Diagnosing present maintenance needs
  - ✓ Schedule future preventive maintenance and repair works
  - ✓ Minimum downtime and optimum maintenance schedules
- Diagnosis
  - ✓ Allow planner to have the necessary spare parts before the equipment is disassembled, thereby reducing mean waiting time (MWT)
  - ✓ Can be integrated into the maintenance activities, therefore the usual maintenance at specified intervals can be customized based on equipment conditions

Predictive Maintenance Designing Program

Ref: 17359:2003(E)

Equipment Audit





Ref : Moubray, Mobius

Reliability and Criticality Audit

1. CRITICALITY
2. P-F INTERVAL
3. FAILURE MODES

Criticality

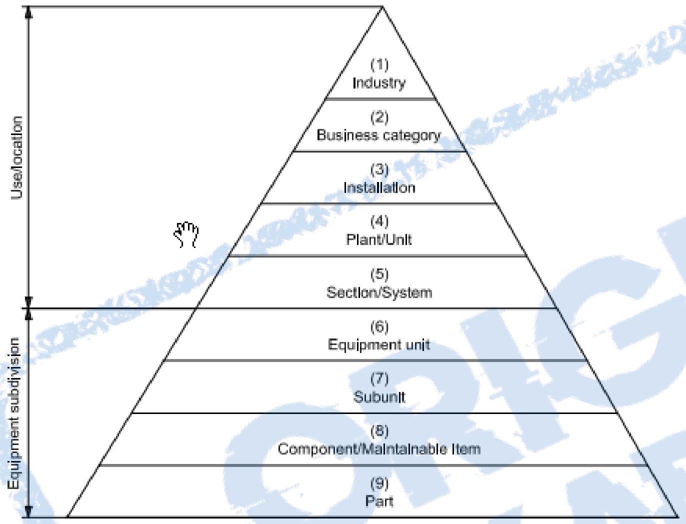
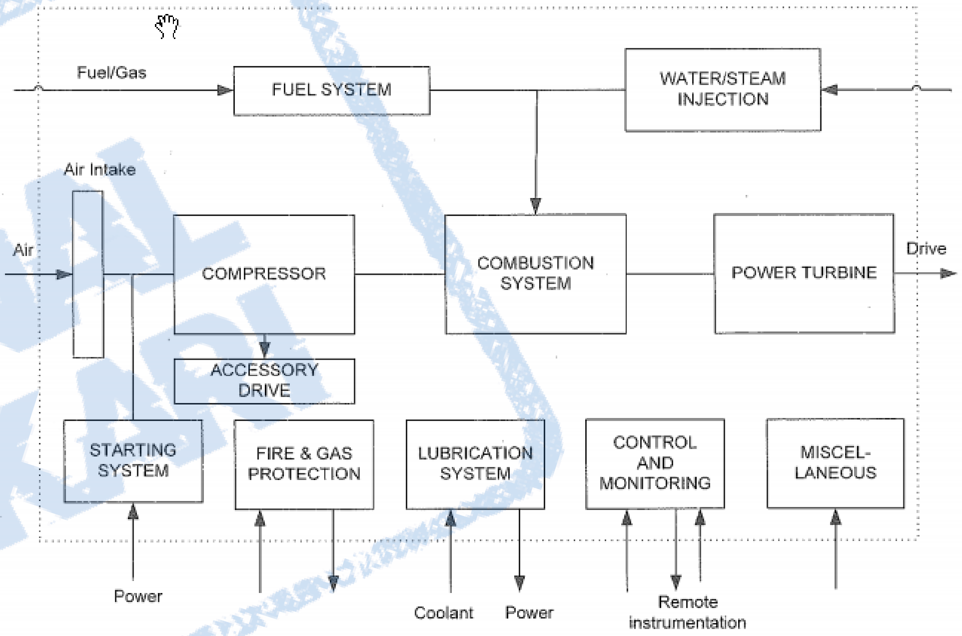


Figure 3 — Taxonomy classification with taxonomic levels

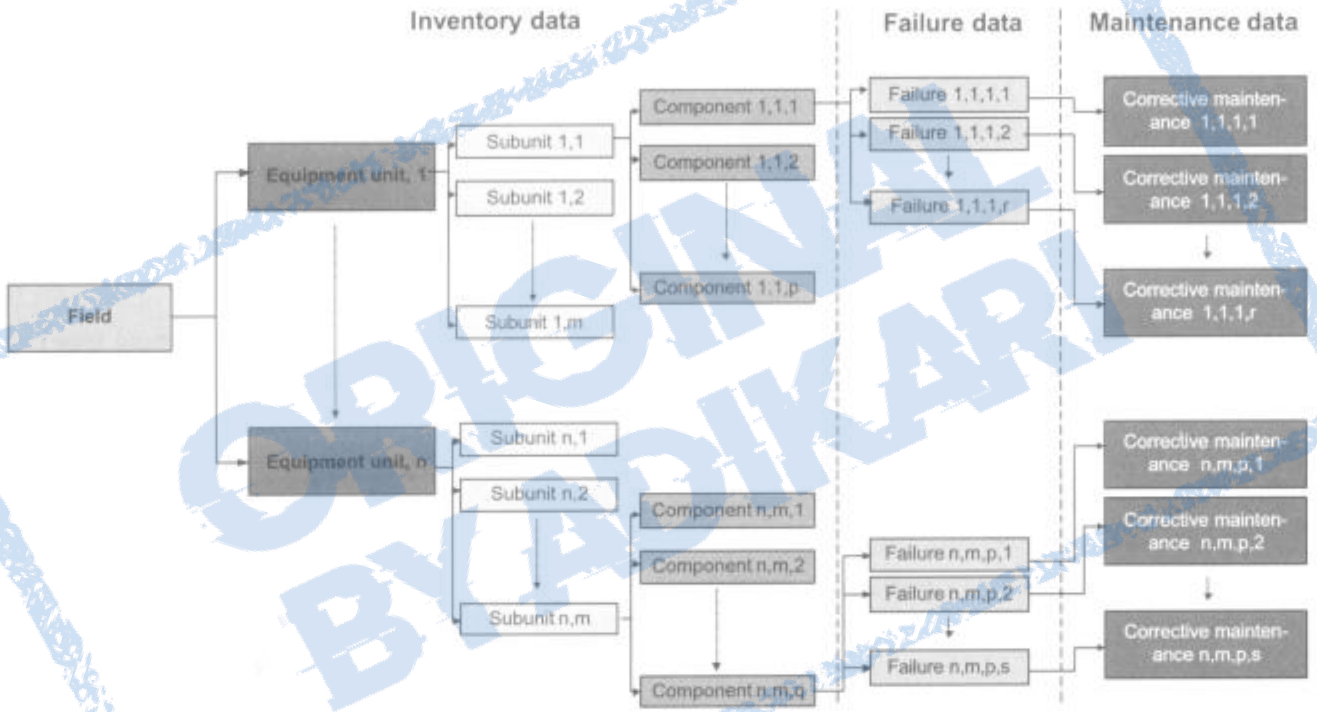


GAS TURBINES (part 1 of 2)

Starting system	Air intake	Combustion system	Compressor	Power turbine	Control and monitoring
Filter(s)	Air cooling	Combustor	Anti-icing valve	Casing	Actuating devices
Piping	Anti icing	Fuel nozzles	Anti-surge valve	Piping	Control unit
Pump(s)	Filters	Seals	Aux. bleeding system	Radial bearing	Sensors
Start control	Intake duct		Casing	Rotor	Internal power supply
Start energy (e.g. battery, air)	Inlet vanes		Cooling system	Seals	Monitoring
Starting motor			Piping	Stator	Seals
Valve(s)			Radial bearing	Thrust bearing	Valves
			Rotor	Valves	Wiring
			Seals		
			Stator		
			Thrust bearing		
			VGV system		

Ref : OREDA, ISO 14224

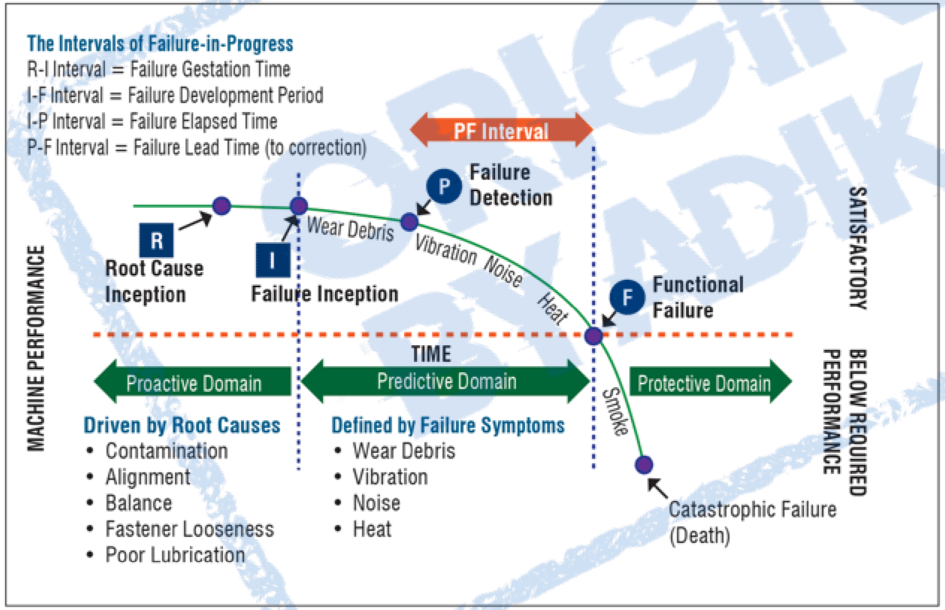
Failure Modes

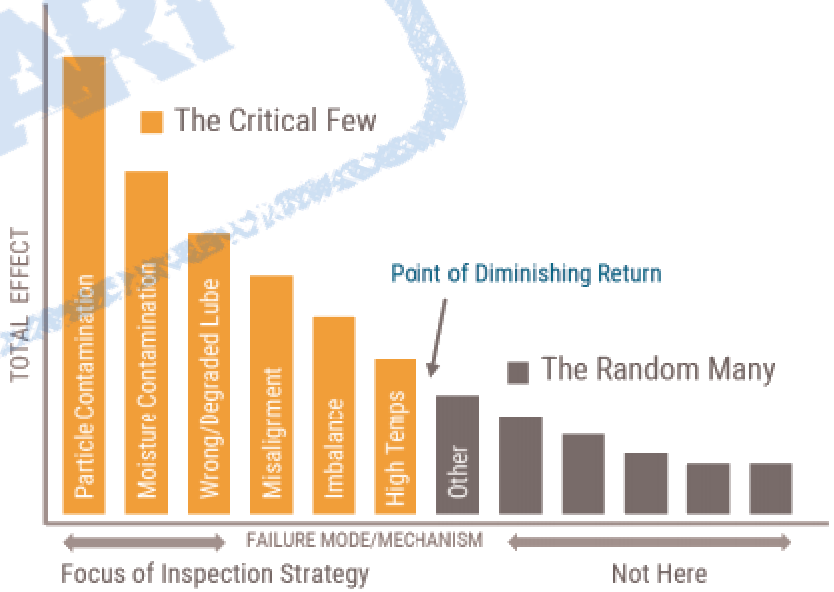


Ref : OREDA

P-F Interval

The P-F Interval is influenced by the nature of individual failure modes and the condition monitoring strategy. This makes the conventional guidance to monitor at a frequency of ½ the P-F Interval impractical.





Ref : Noria

Maintenance Task

Maintenance Strategy	Action Required	RCM-Based Application
Run to failure (reactive)	Repair or replace upon failure.	Non-critical. Costs to control or detect failure exceeds benefits.
Scheduled discard or restoration (preventive)	Repair or replace on time or Cycles.	Asset has a well documented MTBF and a small standard Deviation.
On-condition maintenance (predictive)	Employs condition monitoring to detect early stage failures. Replacement or repair are scheduled on-condition.	Asset fails randomly. Critical nature justifies early detection techniques.
Redesign and condition-control (proactive)	Changes in hardware, loading or procedures. Condition monitoring detects the presence of root causes of failure.	Objective is to reduce the failure rate for a given time period.
Redundancy	Deploy active shared-load or stand-by redundant systems.	Mission critical assets for which no other approach is acceptable.

Ref : Moubray

Predictive Maintenance Technologies

Technology

Application	Vib	Lube	Wear	MCA	IR	US	Vis
Generator	✓	✓	✓	×	✓	✓	✓
Turbine	✓	✓	✓	×	✓	✓	✓
Pump	✓	✓	✓	✓	✓	✓	✓
Electric motor	✓	✓	✓	✓	✓	✓	✓
Diesel engine	✓	✓	✓	×	✓	✓	✓
Fan	✓	✓	✓	✓	✓	✓	✓
Gearbox	✓	✓	✓	×	✓	✓	✓
Cranes	✓	✓	✓	✓	✓	✓	✓
Electric circuit	×	×	×	✓	✓	✓	✓
Transformer	×	✓	×	✓	✓	✓	✓

	Vib	Lube	Wear	MCA	IR	US	Vis
Wear	✓	×	✓	×	×	✓	~
Heating	✓	✓	✓	×	✓	×	~
Impact	✓	×	✓	×	×	✓	~
Corrosion	×	✓	✓	×	×	×	~
Fatigue	✓	✓	✓	×	×	×	~

Ref : Keith Young

Vibration Analysis

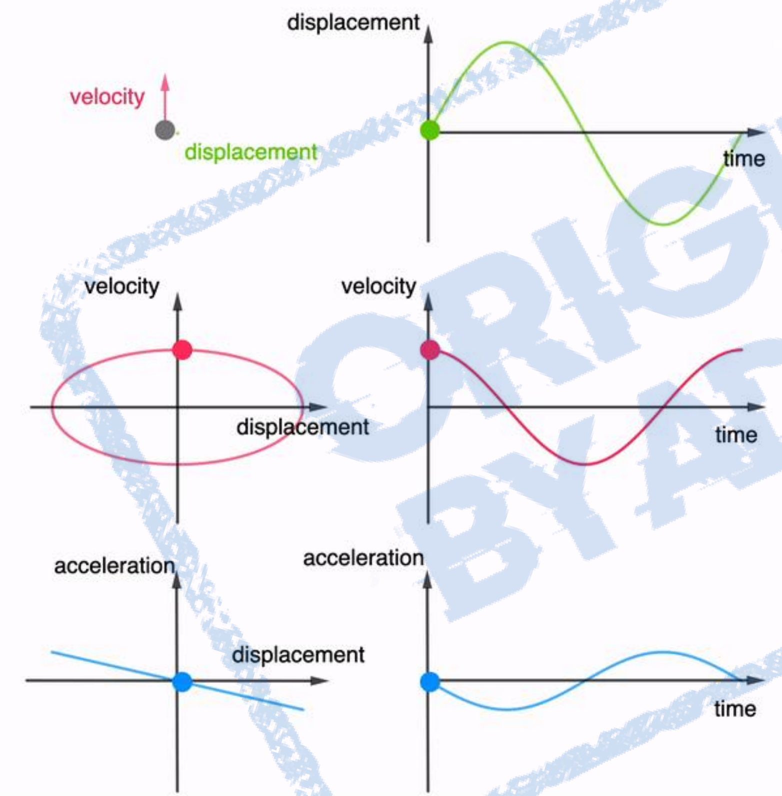
* Measure equipment vibration, look for vibration symptom, perform analysis and troubleshot
* Very effective to Detect, Analyze and Confirm plant machinery problems.
  * On-line for automated and continuous monitoring and protection of critical plant items
  * Portable Route based data collection and analysis
  * Wireless used for remote monitoring of moving or inaccessible equipment

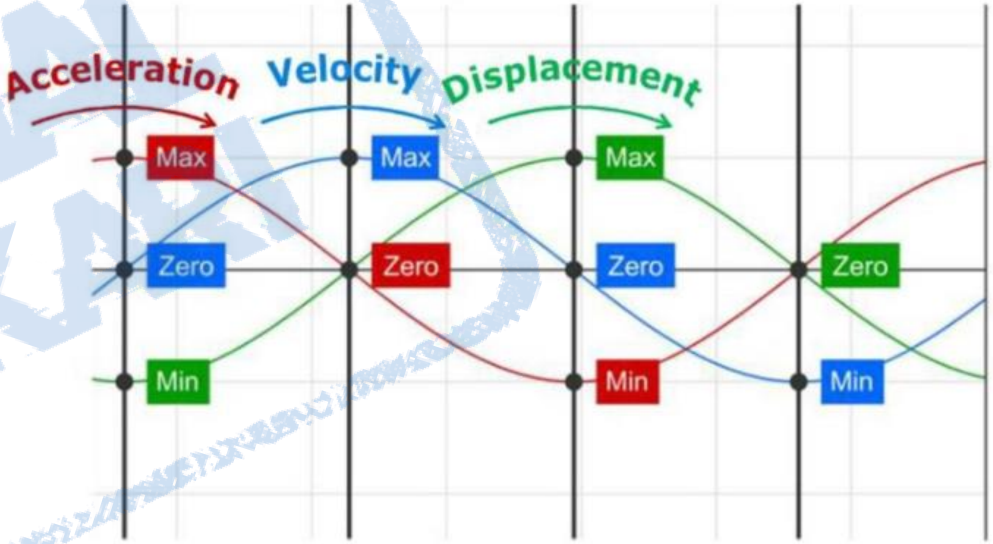
Vibration:
The 'pulse' of the machine

"Of all the parameters that can be measured non-intrusively in industry today, the one containing the most information on machinery health is the vibration signature."

Art Crawford
Acknowledged expert in the field of vibration analysis

Vibration Analysis





Ref : physicslens.com; Mobius

Oil Analysis

Friction Control	Reduces Heat Generation and Energy Consumption
Wear Control	Reduced Mechanical and Corrosive Wear
Corrosion Control	Protects Surfaces from Corrosive Substances
Temperature Control	Absorbs and Transfers Heat
Contamination Control	Transports Particles and Other Contaminants to Filters/Separators
Power Transmission	In Hydraulics, Transmits, Force and Motion

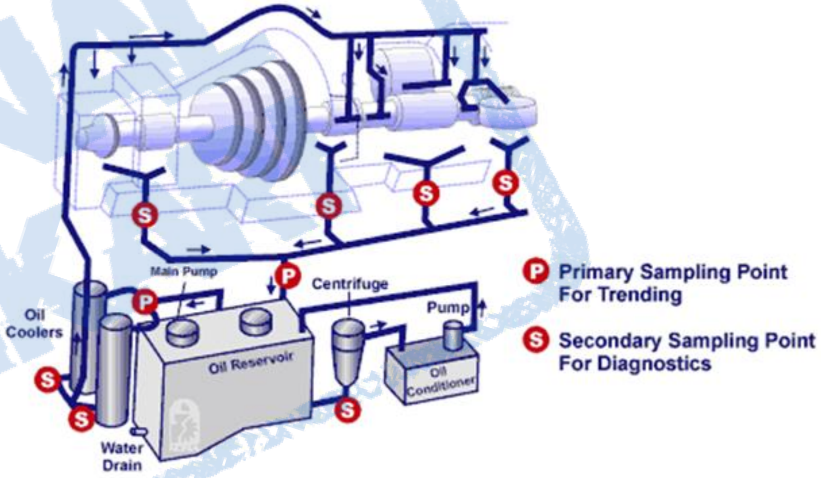
Oil Analysis

What is analyzed	1. Fluid Properties Physical and chemical properties of used oil (aging process)	2. Contamination Fluid and machine destructive contaminants	3. Wear Debris Presence and identification of wear particles
Possible Tests:			
Particle counting	○	●	⊖
Moisture analysis	○	●	○
Viscosity analysis	●	⊖	○
Wear debris density	○	○	●
Analytical ferrography	○	⊖	●
AN/BN	●	⊖	⊖
FTIR	●	⊖	○
Patch test	○	●	⊖
Flash point	⊖	●	○
Elemental analysis	●	⊖	●
	Proactive	Proactive	Predictive

● Primary benefit ⊖ Minor benefit ○ No benefit

Ref : Noria

Oil Analysis



- Right machines to sample
- Right sampling frequency
- Right sampling location
- Right sampling procedure
- Right lab selection
- Right tests to perform
- Right alarms and limits
- Right data interpretation strategy

Oil Analysis

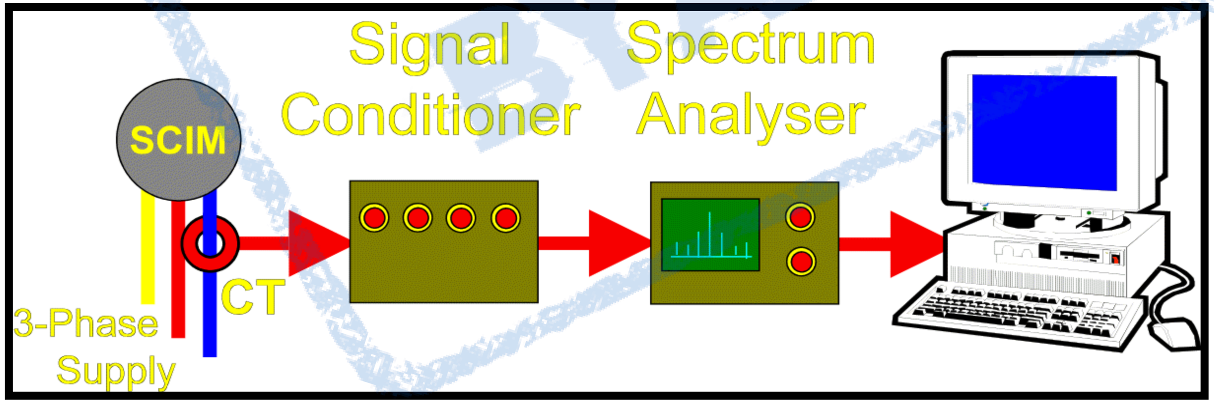
Test	Measures…
Oil Bath 40c and 100c	Viscosity
R. D. E. Spectroscopy	Elemental Concentrations
FT – IR (Infrared)	Degradation, contamination, additive depletion
Total Acid	Acid Levels
Total Base	Base Levels
Water Crackle Karl Fisher	 Concentrations to 200ppm Concentrations to 10ppm
Particle Count	NAS & ISO Cleanliness

Electric Motor Testing

This technology is used to know motor condition in order to ensure uninterrupted processes and minimize unscheduled downtimes

This test fall into two categories :

- Static / offline tests
- Dynamic / online tests



Infrared Thermography

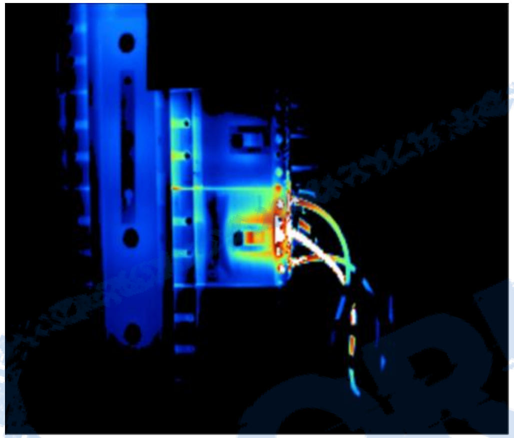
Infrared thermography is the study of radiated energy using a thermal infrared imaging system

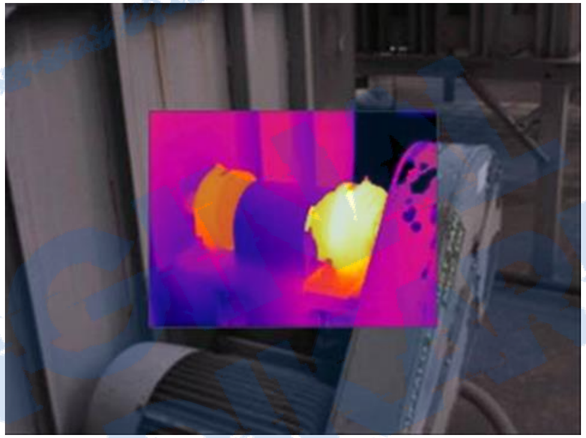
The technology uses sensor that are sensitive to the radiated electromagnetic energy associated with heat

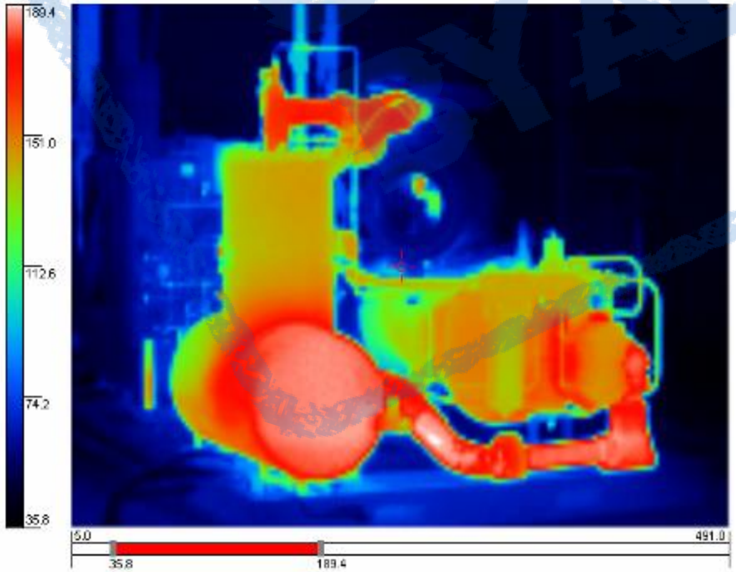
Infrared thermography is typically used in the following applications :

- Mechanical
- Machines, bearings, belts, pipe, valves
- Electrical equipment

Infrared Thermography



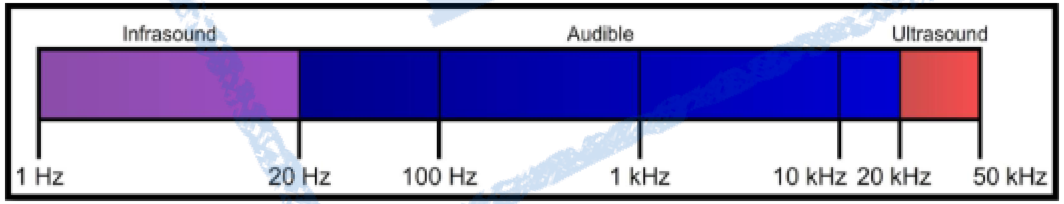




Ultrasound

Ultrasound sensor Is used to measure the signal and demodulate it to a frequency range within the human range

Ultrasound application :
- Detecting air leaks
- Detecting boiler, heat exchanger, and condenser leaks
- Detecting faulty steam traps
- Detecting ultrasonic and electrical problems
- Detecting lubrication condition



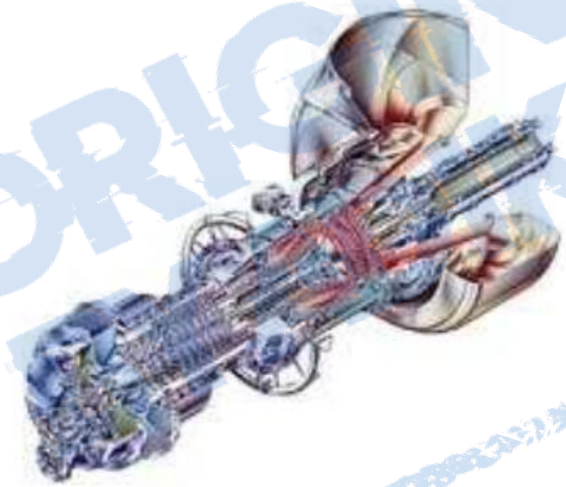
Predictive Maintenance Implementation

- Preparation
  - Equipment data collecting
  - Equipment database building
  - Sampling location
  - Routine Test and Exception Test Selection
  - Limit Setting / Standard
  - Person with special ability and certification
- Data measurement
- Interpretation Data and Analysis
- Decision making & Continuous Improvement

Study Case #1 – Vibration Analysis

GTC 623 Taurus 60 Gas Turbine Compressor set

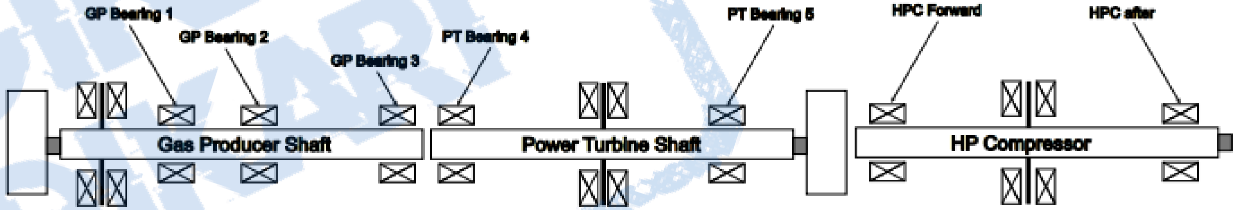
Equipment Data



Equipment Data

Description	Data
Compressor	
Type	Axial
Number of Stages	12
Compression Ratio	11,5:1
Max Speed	15000
Gas Producer	
Type	Reaction
Number of Stages	2
Max Speed	15000 RPM
Power Turbine	
Type	Reaction
Number of Stages	2
Max Speed	14300
Bearing	
Journal	Tilt Pad
Thrust, Active	Tilt Pad
Thrust, Inactive	Fixed Tapered Land

Machine Configuration



Measurement Point & Vibration Data

Abbreviated Last Measurement Summary
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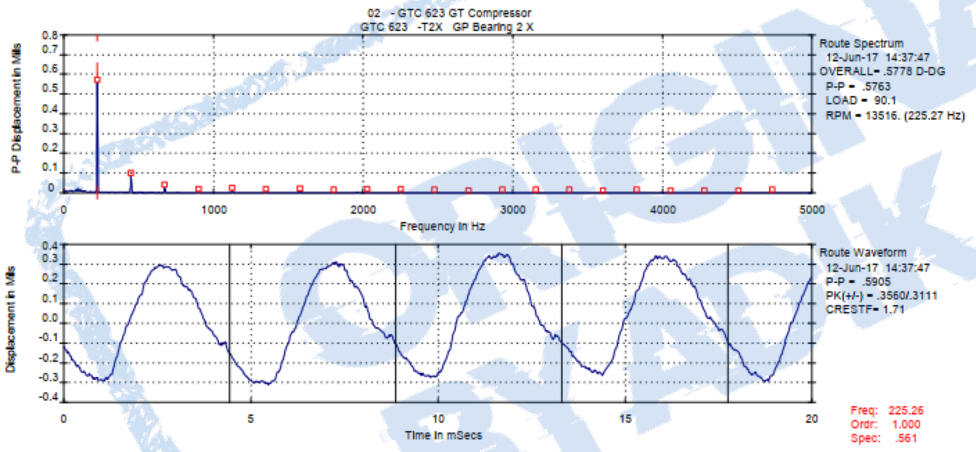
MEASUREMENT POINT	OVERALL LEVEL	PARAMETER 1
GTC 623 - GTC 623 GT Compressor	(12-Jun-17)	
	OVERALL LEVEL	PK-PK WAVEFORM
T1X - GP Bearing 1 X	.615 Mils	.746 Mils
T1Y - GP Bearing 1 Y	.500 Mils	.625 Mils
T2X - GP Bearing 2 X	.578 Mils	.668 Mils
T2Y - GP Bearing 2 Y	.467 Mils	.574 Mils
T3X - GP Bearing 3 X	.174 Mils	.277 Mils
T3Y - GP Bearing 3 Y	.270 Mils	.410 Mils
T4X - PT Bearing 4 X	.199 Mils	.338 Mils
T4Y - PT Bearing 4 Y	.230 Mils	.377 Mils
T5X - PT Bearing 5 X	.241 Mils	.344 Mils
T5Y - PT Bearing 5 Y	.230 Mils	.365 Mils
C1X - HPC Forward X	1.086 Mils	1.242 Mils
C1Y - HPC Forward Y	.775 Mils	.848 Mils
C2X - HPC After X	.295 Mils	.393 Mils
C2Y - HPC After Y	.087 Mils	.258 Mils

Clarification Of Vibration Units:

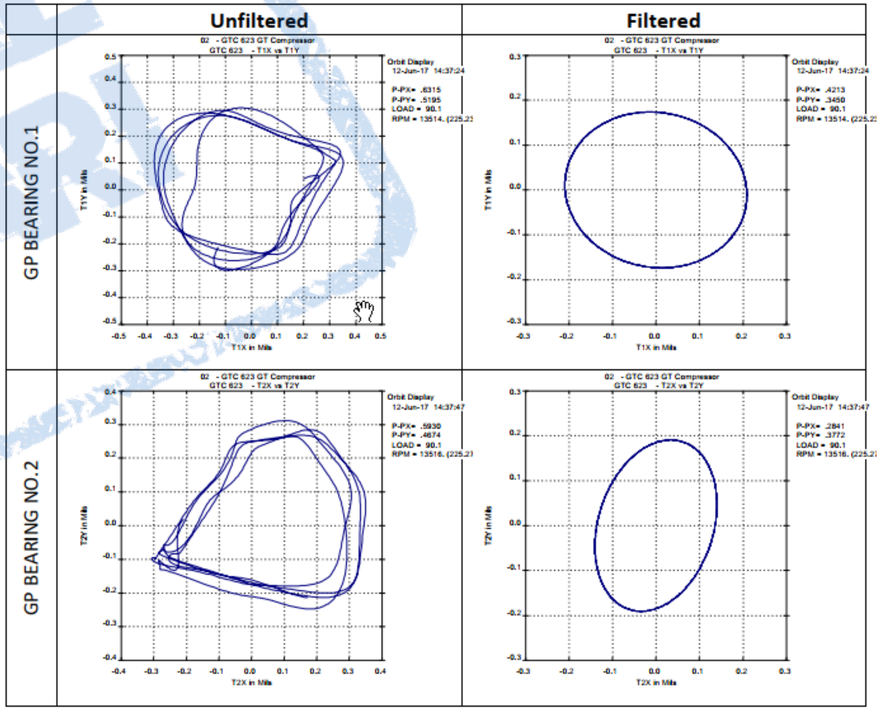
Vel	-->	In/Sec	RMS
Dsp	-->	Mils	P-P

Vibration Data

GP Bearing 2



- **Orbit**



Study Case #2 – Lube Oil Analysis

Machinery Data

Tag Number	:	GTC623
Equipment Description	:	PPP Gas Turbine Compressor Taurus 60
Equipment Type	:	Gas Turbine Compressor
Manufacturer	:	Solar Turbine
Model Number	:	S.O No : 2-3F541
Serial Number	:	TC 09617
Lubricant	:	Pertamina Turbo 46
Running Hours	:	15716
Sampling date	:	12 November 2017

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Trend Data

Oil Condition

DATA SUMMARY							
SAMPLING DATE			10-Jun-17	6-Jul-17	24-Aug-17	6-Oct-17	11-Nov-17
RUNNING HOUR on Oil			-	-	-	-	-
RUNNING HOUR on Unit			55131	55133	55135	55137	55138
OIL CONDITION							
PARAMETER	**UNIT**	**REFERENCE**	**RESULT**				
Visc @40C	cSt	-	-	-	-	-	-
Visc @100C	cSt	12.5-16.3	13.06	13.06	13.81	13.35	13.16
TAN	mg KOH/g		0.91	0.92	1	0.79	0.89
TBN	mg KOH/g	Min 2.6	4.51	4.55	3.27	4.69	5.15
Oxidation	Abs/0.1mm	Max 0.4	0.11	0.11	0.13	0.11	0.04
Nitration	Abs/0.1mm	Max 0.4	0.03	0.04	0.04	0	0

Trend Data

Wear Analysis

DATA SUMMARY							
SAMPLING DATE			10-Jun-17	6-Jul-17	24-Aug-17	6-Oct-17	11-Nov-17
RUNNING HOUR on Oil			-	-	-	-	-
RUNNING HOUR on Unit			55131	55133	55135	55137	55138
WEAR ANALYSIS							
WEAR ELEMENT	**UNIT**	**REFERENCE**	**RESULT**				
Iron (Fe)	ppm	Max 25	3	3	3	3	3
Copper (Cu)	ppm	Max 20	5	4	5	5	5
Aluminium (Al)	ppm	Max 15	1	1	1	1	1
Chromium (Cr)	ppm	Max 10	< 1	< 1	< 1	< 1	< 1
Nickel (Ni)	ppm	Max 5	< 1	< 1	< 1	< 1	< 1
Tin (Sn)	ppm	Max 5	< 1	< 1	< 1	< 1	< 1
Lead (Pb)	ppm	Max 15	1	1	1	1	1

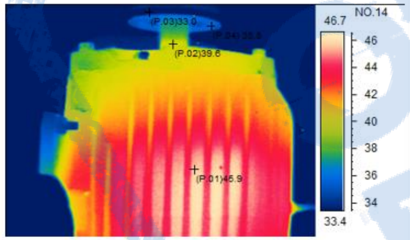
Trend Data

Contamination

DATA SUMMARY							
SAMPLING DATE			10-Jun-17	6-Jul-17	24-Aug-17	6-Oct-17	11-Nov-17
RUNNING HOUR on Oil			-	-	-	-	-
RUNNING HOUR on Unit			55131	55133	55135	55137	55138
CONTAMINATION							
CONTAMINANT	UNIT	REFERENCE	RESULT				
Natrium (Na)	ppm	Max 35	2	< 1	< 1	2	< 1
Silicon (Si)	ppm	Max 10	2	2	1	2	2
Soot	Abs/0.1mm	Max 0.1	0	0	0	0.08	0
Sulfation	Abs/0.1mm	Max 0.4	0.05	0.05	0.06	0.07	0
Water by FTIR	%	Max 0.1	0	0	0	0	0
Glycol	%	Max 2	0	0	0	0	0
Fuel Dilution	%		0	0	0	0	0
Water by Distillation	% vol		-	-	-	-	-

Study Case #3 – Infrared Thermography

Lube Oil Cooler Motor PM-623 Poleng Process Platform	
Emissivity (ε)	0,95
T ambient	33 °C
Description	Electrical Motor
Date	13-01-2017



Hot Spot	Description	T Point (°C)	ΔT Tmax-Tamb (°C)	Allowable Temp Rise (°C)	Max Allowable Temperature (°C)	Status
1	Pulley	35,8	2,8	N/A	100	Normal
2	Belt	33	0	N/A	60	Normal
3	Drive End Bearing	39,6	6,6	N/A	125	Normal
4	Motor Frame	45,9	12,9	105	145	Normal
5						

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THANK YOU

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extreme-maintenance.com