Condition Monitoring - Part 2

New IO Link Vibration sensor with Temperature Monitoring - Machine classification

ifm condition monitoring Webinar - Part 2

Wednesday 14 October

15H00 PM

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Presenter

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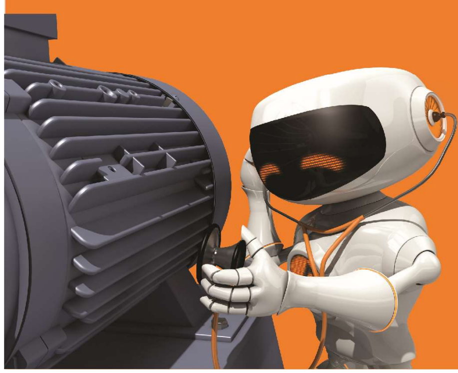
Host



Condition Monitoring

Machine Classification for Condition Monitoring – Part 2

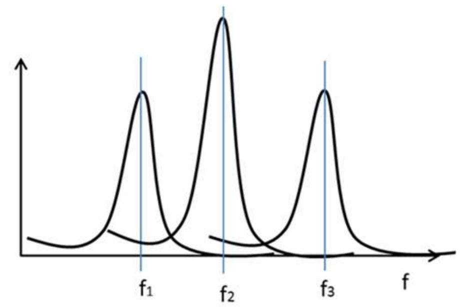
Product group text here

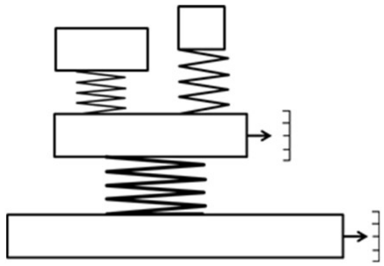
Agenda

- Introduction
- Categories of **Vibration** according to their **Generating Force**
- Categories of **Machines** according to their **Vibration Behaviour**
- Monitoring Strategies
- Summary

Introduction

- Acceleration is generated by power transmission processes as per Newton‘s 2nd Law (F = m x a)
- Machines are multiple-mass oscillators interacting with each another
- The lowest natural frequency often is the most critical one, as it is excited by rotating forces like unbalance as its kinetic energy is highest (vibration velocity)





Categories of **Vibration** according to their **Generating Force**

- Construction-based excitation (C-forces)

  Pre-defined by the construction of the machine

- Process-based excitation (P-forces)

  Caused by the process itself

- Failure-based excitation (F-forces)

  Caused by a defects or failure

Construction-based excitation (C-forces)

- The constructive design of a machine acts like a frequency-dependent amplifier with the excitation coming from an external source such as unbalance
- Construction-based forces are always present when the machine is in operation
- Examples of forces based on constructive design (C-forces):

Source	Frequencies in multiples of the shaft speed
Unbalance	1x rpm
Coupling / Pulley Misalignment	2x rpm
Gear mesh (N = number of teeth)	Nx rpm (=GMF)
Vane and fan blades (N = blades)	Nx rpm (=BPF)
Piston machines	Double & Half and integer multiples of shaft speeds can be measured
Screw compressors and roots blowers	Nx rpm (output frequency)
Frequency converter drive	Line frequency and its modulation
DC motors	3 or 6x SCR frequency

Process-based excitations (P-forces)

- Process-based excitations are dynamic forces resulting from the process
- As a rule, these forces occur within the machining process such as mechanical forces caused by the forming process, machining, separation, etc. of materials and parts
- Examples for external, process-based excitations (P-forces):

Source	Frequencies in multiples of the shaft speed
Cutting with defined cutting edges (milling, drilling, etc.) N = number of machine tool blades	Nx rpm
Machining with undefined cutting edges (grinding)	High-frequency noise
Forming	Transient (one time or periodic events)
Grinding mechanisms	Chaffing rate, cutting rate

Failure-based excitations (F-forces)

- Failure-based excitations are dynamic forces that can be either high or low in amplitude or not easily visible when the machine is in nominal operation

Source	Frequencies in multiples of shaft speed
Unbalance (increase in unbalance due to errors)	1x rpm
Misalignment	2x rpm
Internal or external loose parts	2x, 3x, 4x, 5x .. rpm
Rolling element bearing	BPFO, BPFI & BSF
Gear mesh problems (spalling, chipping & wear)	Sidebands with 1 x RPM on both sides of GMF (tooth mesh frequency)
Electrical problems	Sidebands around 2x line frequency, sidebands around rotor bar pass frequency, and a few other visible details
Problems with hydrodynamic sleeve bearings	0.40x – 0.48x rpm (subharmonic)
Belt vibrations	Belt resonance frequency (subharmonic)
Chatter vibrations on machine tools	Natural vibrations of the work piece or the machining tool
Cavitation in fluids	High-frequent noise due to implosion of gas bubbles on impellors

Categories of **Machines** according to their **Vibration Behaviour**

- **Type 1: simple machines**
  - Predominately construction-based excitation (C-forces)
- **Type 2: process machines**
  - Predominately process-based excitation (P-forces)
- **Types 3a/b/c: complex machines**
  - High vibration (high C- and P-forces)
  - Variable operation
  - Low-speed machines and multiple-shaft drives (gearboxes)

Type-1 machine (C-dominant, single-shaft machines)

- **Constructive Forces** in type-1 machines are normally at low levels and **Failure** based changes can easily be monitored during operation
- Centrifugal pumps, blowers and electric motors are examples of type-1 machines that permanently run at a constant speed or process-related operating point
- Examples:

	C-Forces	P-Forces	F-Forces
Pumps	Unbalance	Flow noise	Bearing damage, alignment, cavitation
Motor	Unbalance	Electrical fields	bearing damage, alignment, coupling
Fans	Unbalance Belt	Flow noise	bearing damage, alignment, clearance, belt resonance

Type-2 machine (P-dominant)

- Clearly dominant **Process Forces** and low **Constructive** based vibration
- **Failure** based vibration is much lower than **Process** based vibration
- **Process Forces** can be strongly dependent on the type of process and the process step (machine tool - CNC)
- The machine operator can influence the process, so that an operating error or overload is possible (crusher infeed conveyor is too fast)
- Operating vibration that exceeds a certain fatigue level will lead to a reduced machine life expectancy

Type-2 machine (P-dominant)

- Differentiation between **idling** and **machine operation** time **is** possible
- Monitoring of **Fault Forces** are normally only possible in a **reference run**
- It is not possible to estimate the remaining machine lifetime based on the operating hours alone. Data such as load, temperature, pressure using historians, etc. also has to be evaluated
- These are normally production machines performing cutting or crushing type processes
- Examples:

	C-Forces	P-Forces	F-Forces
Machine tool	Unbalance	Cutting frequencies and their multiples	Bearing damage
Crushing plant	Unbalance, Coupling Alignment	Shredding / Impacting vibration	Bearing damage

Type-3a machine (continuously high C- and P-forces)

- Continuously high **Constructive** and **Process Forces** during **machining** and **idling** mode
- **Failure** based vibration is much lower than **Process** based vibration
- Simple strategies, such as a reference run, does not normally work
- In order to detect **Fault Forces**, diagnostic algorithms may have to be used:
  - High frequency resolution and narrow search bands
  - Separation of carrier- and interference-frequencies by applying an HFFT filter
- Examples:

	C-Forces	P-Forces	F-Forces
Piston machine	Unbalance	Piston impact and harmonics	Bearing damage, piston friction
Combustion engine	Unbalance	Piston impact and harmonics	Bearing damage, piston friction, backfire
Compressor and Roots blower	Unbalance Belt Frequencies	Output frequency	Bearing damage, alignment, clearance

Type-3b machines (variable C-forces, single-shaft machines)

- Like **Type 1**, but dependent on process parameters (like speed and torque)
- **Fault Forces** cannot be detected over the whole operating range
- In order to detect a **Fault Force**:
  - Perform reference runs using constant process parameters
  - Create narrow operating areas or “diagnosis windows”
  - If the connection between the **Fault Forces** and the **Operating Parameters** are known then “signal weighting” can be applied
- Examples:
  - Same as type-1 machines

	C-Forces	P-Forces	F-Forces
Pumps	Unbalance	Flow noise	Bearing damage, alignment, cavitation
Motor	Unbalance	Electrical fields	bearing damage, alignment, coupling
Fans	Unbalance Belt	Flow noise	bearing damage, alignment, clearance, belt resonance

Type-3c machines (several shafts with different gear ratios)

- This type is usually a gear box
- There are many different types of forces and gear ratios
  - A large number of different basic frequencies and their multiples
  - Sound of faster shafts “masking” the slower shafts
- In order to detect a **Fault Force** we use:
  - High frequency resolution and narrow search bands under constant conditions
  - Several measurement points to localise the fault
  - Narrow operating areas and/or constant speed
- Examples:

	C-Forces	P-Forces	F-Forces
Gear Box	Unbalance, gear mesh frequencies	Process variables affect the levels of C-forces	Bearing damage, sidebands
Belt driven machines	Unbalance, gear mesh frequencies	Process variables affect the levels of C-forces	Belt vibrations, belt frequencies

Monitoring Strategies

C+P+F (Overall) Vibration Monitoring (ISO 10816)

- Monitoring of all stationary forces
- No differentiation between C-, P- and F-forces
- Overall vibration or vibration intensity is compared against a limit value in order to:
  - Protect the machine (e.g. prevent fan from bouncing around on it's mountings)
  - Avoid or reduce consequential damage
  - Extend the lifetime of the machine
  - Optimise the machine's operating point
- Generally applied to machines of types 1, 3a and 3b
- Types 2 and 3c: application only possible with restrictions (CNC, Gearboxes, Crushers, etc.)

Process monitoring (P-monitoring)

- Counters for load data and ratios between **production** and **idling times** are an important factor
- If the **Process** amplitudes can be assigned to a certain process or operating step, they can be monitored separately
- Global monitoring and fast reaction/counter action in the case of “extreme“ events can be implemented, in order to protect the machine
- Examples:
  - Crash of a CNC machine spindle creates an emergency stop within 1ms (reaction time of the VSE)
  - Protection of crushing systems and mills from foreign materials
  - Immediate visibility of rubbing causing abrasion (eg. in rotary gate valves, dosing screws, etc.)

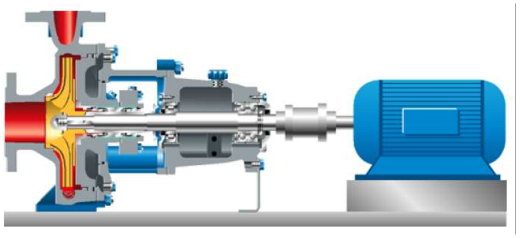
Early Fault / Damage detection (F-monitoring)

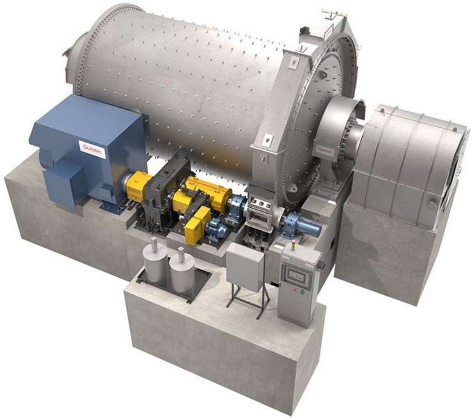
- Plays a central role in preventive maintenance
- Early damage detection by means of prognosis models to estimation the remaining machine lifetime
  - Measurement of wear indicator - diagnosis (Is the damage measurable yet?)
    - How often is there an increase in **Fault Forces**
    - How often do the **Fault Forces** occur
  - Measurement of machine usage (How does it affect the remaining lifetime?)
    - Load data
    - Number and frequency of events (starts/stop, impacts, tool changes, number of movements, operating hours, etc.)

Vibrations based on Constructive, Process or Failure Monitoring?

- The most important question for machine diagnosis is whether a vibration is **constructive-based** or caused by a **fault/failure**
- In practice conditions can be overlaid, this becomes apparent in the example of unbalance
- By using the functions like the following available in the VSE, it is generally possible to implement all three strategies:
  - “Level guard“: a-Peak, a-RMS, v-RMS
  - “Diagnostic objects“: wear indicators - such as unbalance, rolling bearing and others
  - Variant switching: run or reference measurement
  - Counters: How long is a machine in a certain condition
  - Triggers: speed ranges and other factors

Summary





Suitable strategies for different types of machines

Monitoring strategy ---->Machine type	C+P+F	P	C	F
Type 1 	Permanent measurement with constant limit values (ISO) is possible.	Not suitable.	Using frequency-selective characteristics	Possible during operation; if necessary, verify differential diagnosis using frequency-selective characteristics.
Type 2 	Differentiation between operating and idle state is necessary; Measurement of the effective time (historian) via counters is necessary during the process.	Monitoring of the process quality and process intervention is possible. Variable limit values for machine tools are required.	Measurement in idle state to check unbalance	Reference run is required.
Type 3a 	Permanent measurement with constant limit values (ISO) is possible. Partly, 2 indicators are suggested (compressors).	Not suitable.	Using frequency-selective characteristics	Conditionally possible using frequency-selective characteristics.
Type 3b 	Permanent measurement using constant limit values (ISO) is possible. Monitoring of relevant process values (speed, torque) is recommended.	Not suitable.	Using frequency-selective characteristics	Using process-triggers and frequency-selective diagnosis
Type 3c 	Overall vibration measurement is often of low significance.	Not suitable.	Using frequency-selective characteristics	Using process-triggers and frequency-selective diagnosis

Questions

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Answers ?

Webinar Schedule

28 October 2020:

PMD Profiler for object profile checking - Round Table Discussion

11 November 2020:

ifm Cooling Circuit Innovative Solutions

2 December 2020:

3D collision warning system for mobile machines - Surveillance kit

9 December 2020:

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