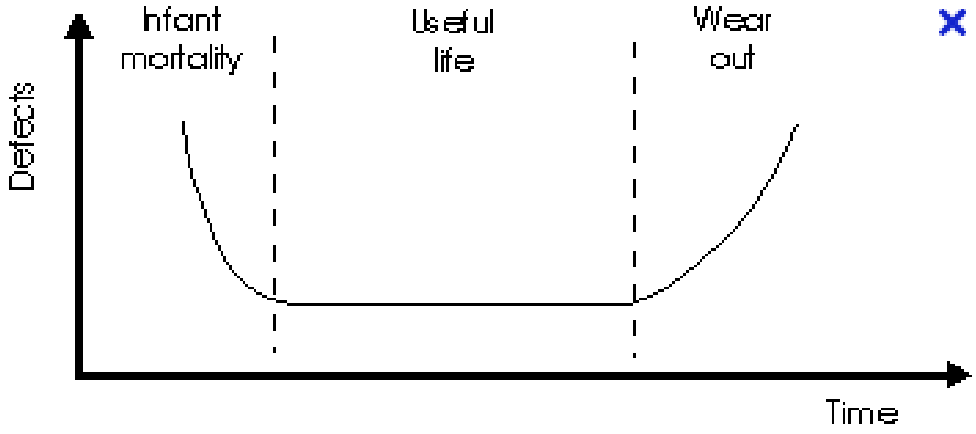
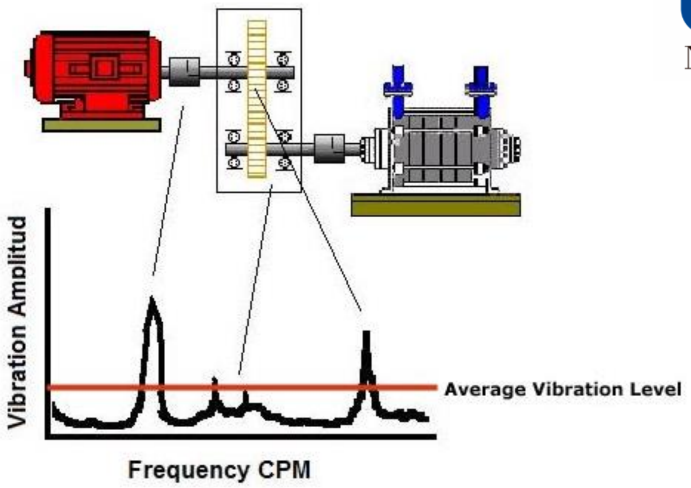
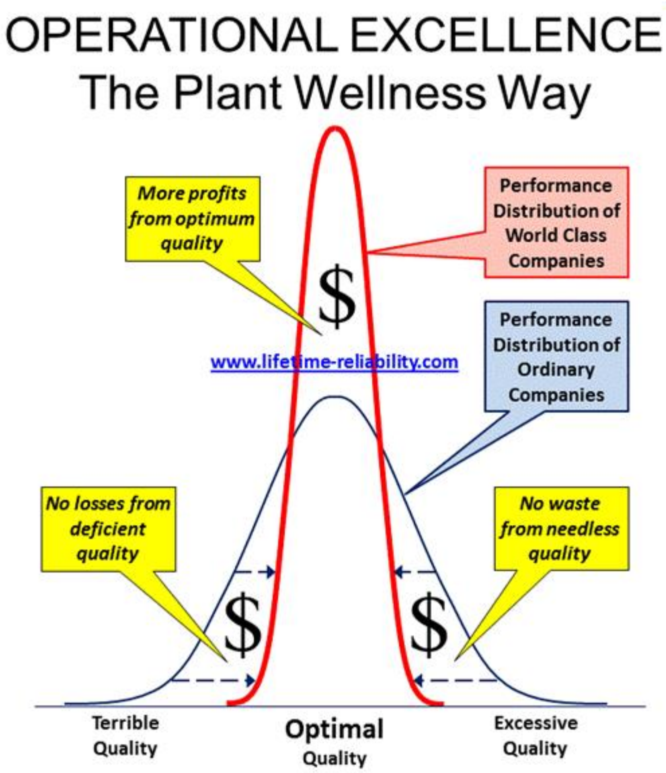






Condition Monitoring data collection – data quality

Viggo Pedersen

My name is Viggo

Worked in operation and maintenance positions in

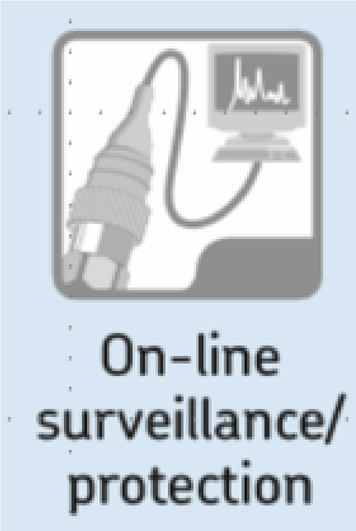
- Hydropower & Wind power- 10 years
- Oil & Gas– 8 years
- Research & teaching (bachelor) – 8 years

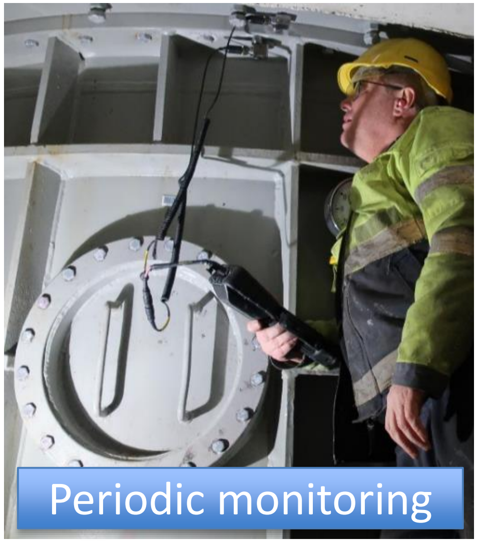
Todays lecture – some thoughts on condition monitoring data collection

Condition Monitoring (CM)

8.2
condition monitoring
activity, performed either manually or automatically, intended to measure at predetermined intervals the characteristics and parameters of the physical actual state of an item

EN-13306:2017





An item

EN-13306:2017

3.1

item

part, component, device, subsystem, functional unit, equipment or system that can be individually described and considered

Failure development

- Changes in characteristics and parameters of the physical actual state of an item (Condition monitoring data) is indicative of a developing failure.
- Early detection of changes depend on the selected CM method and it's implementation.

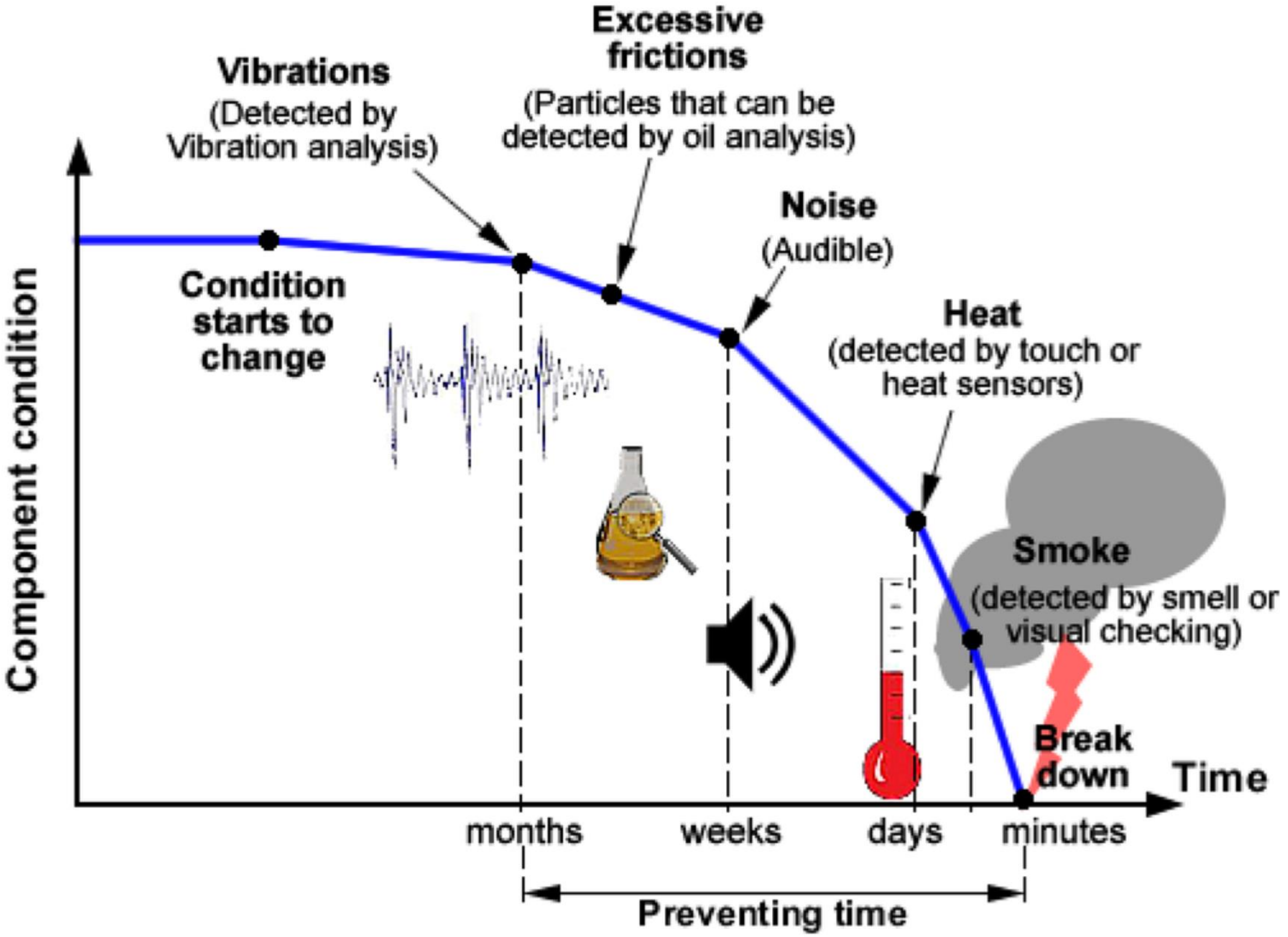
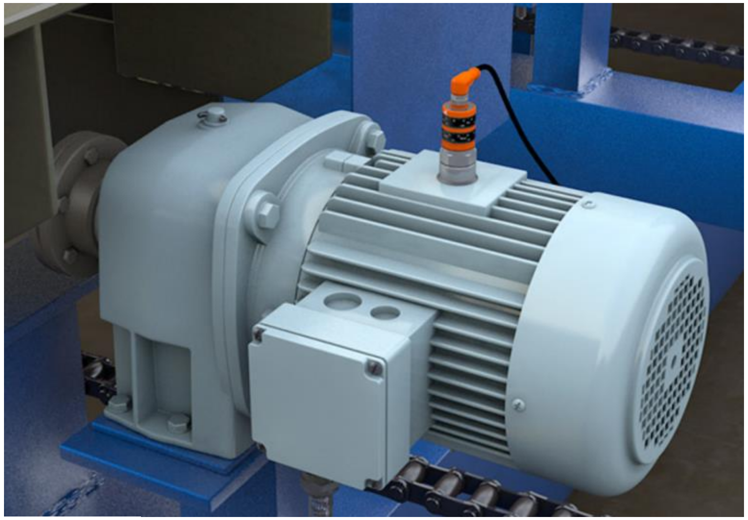
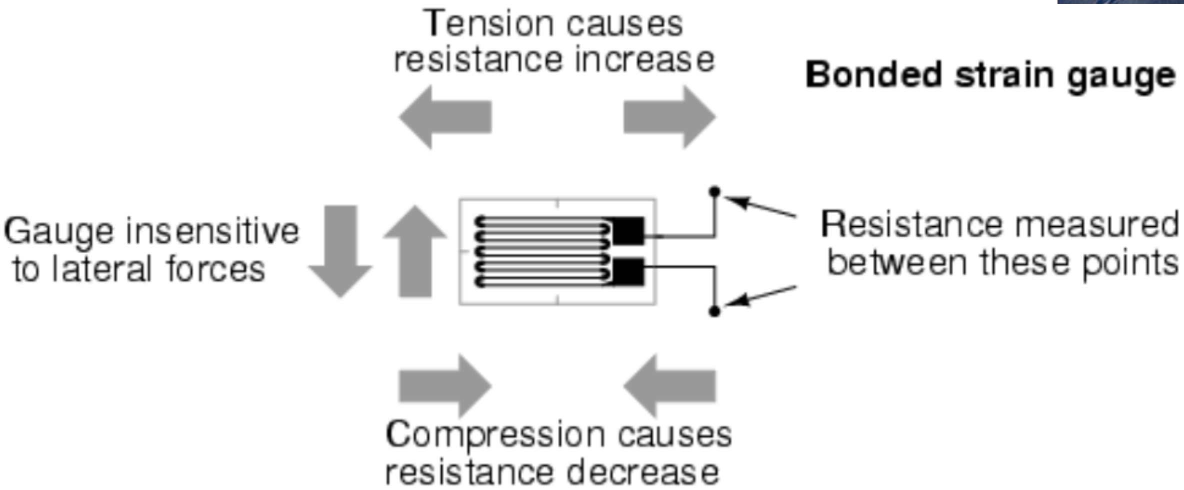


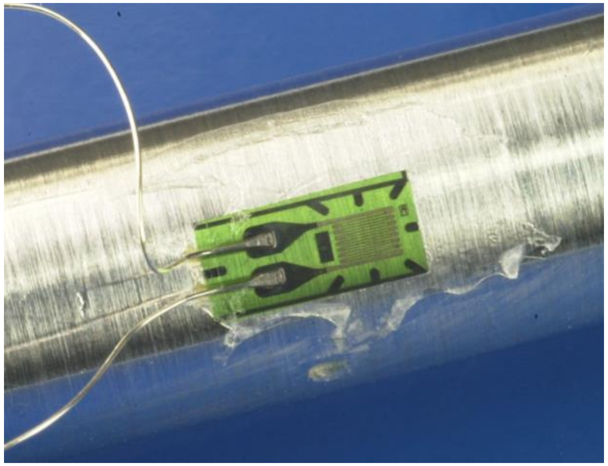
Figure by mdpi.com

Typical CM parameters

- Vibration
- Temperature
- Strain
- Etc.

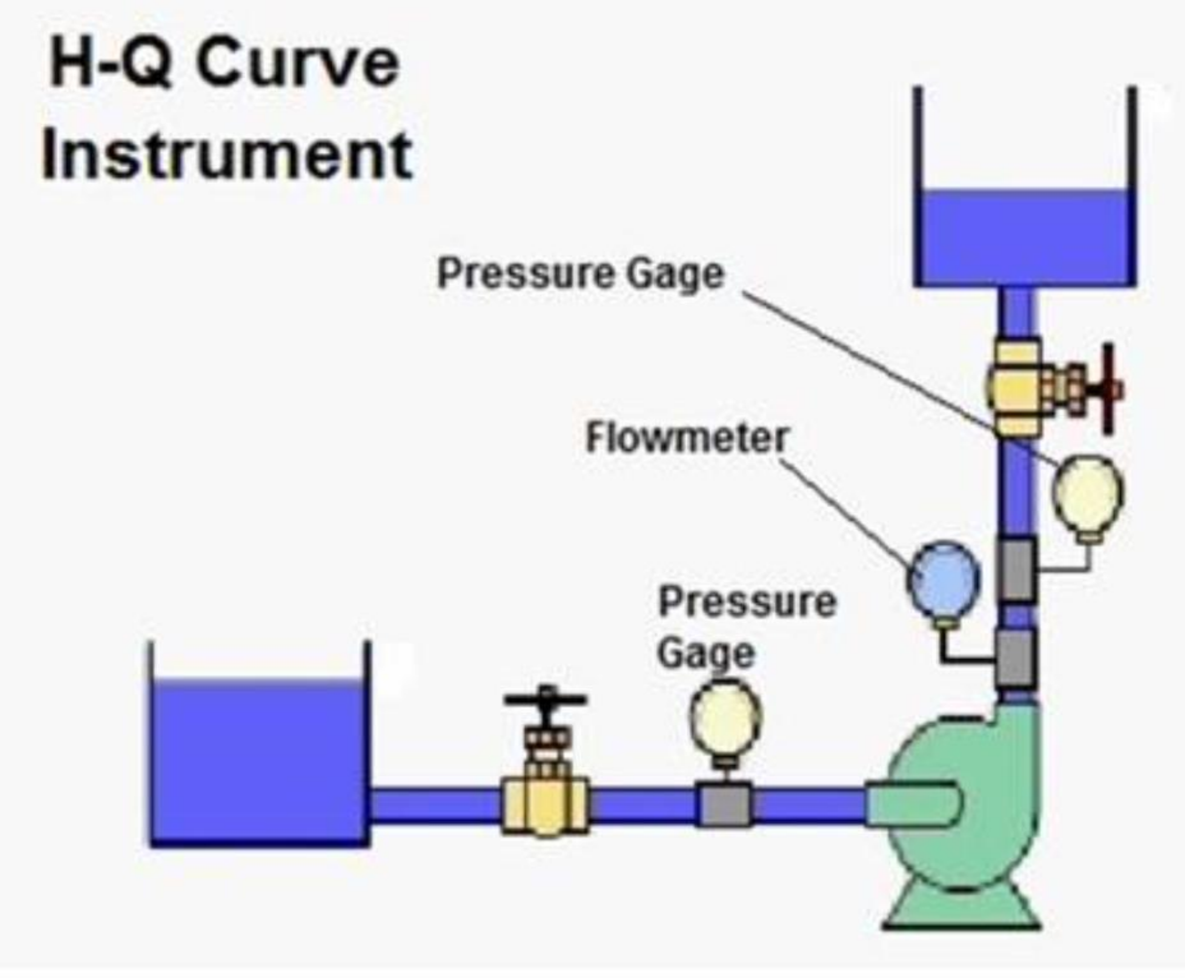






Typical CM - parameters

- Power consumption (example pump motor – measure Ampere)
- Flow rate (example pump – measure m^3 pumped)
- System pressure
- Sound
- Etc.



Example of a CM data collection set up

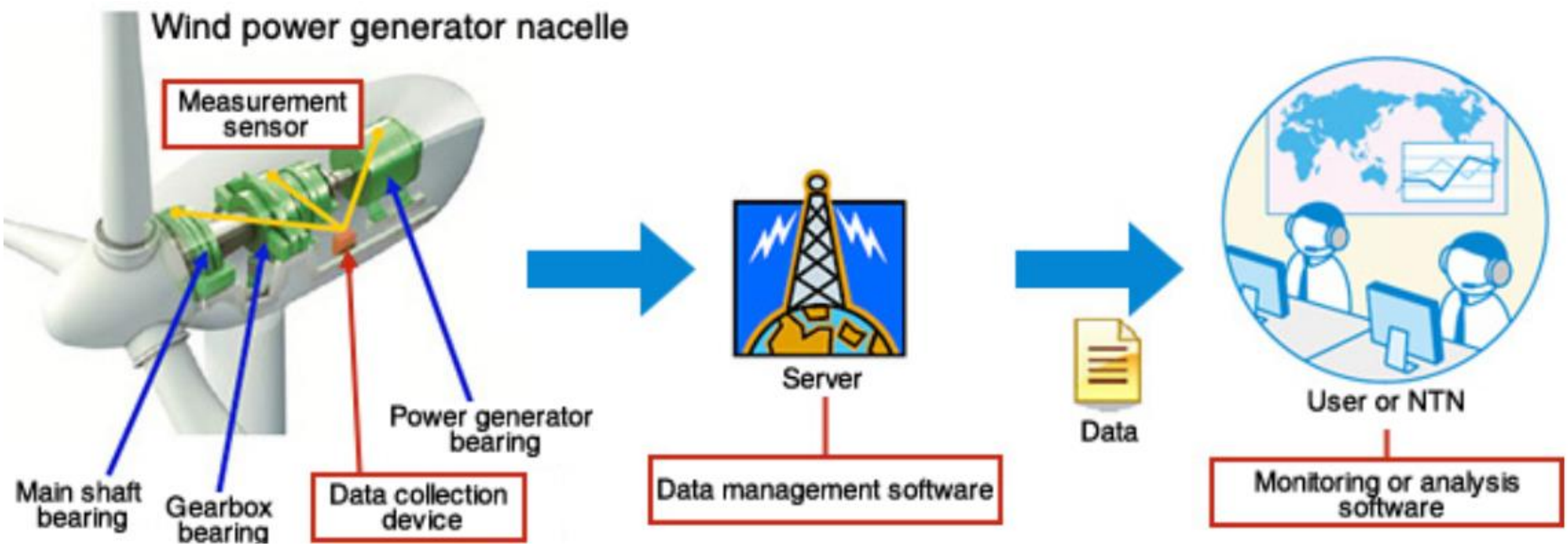
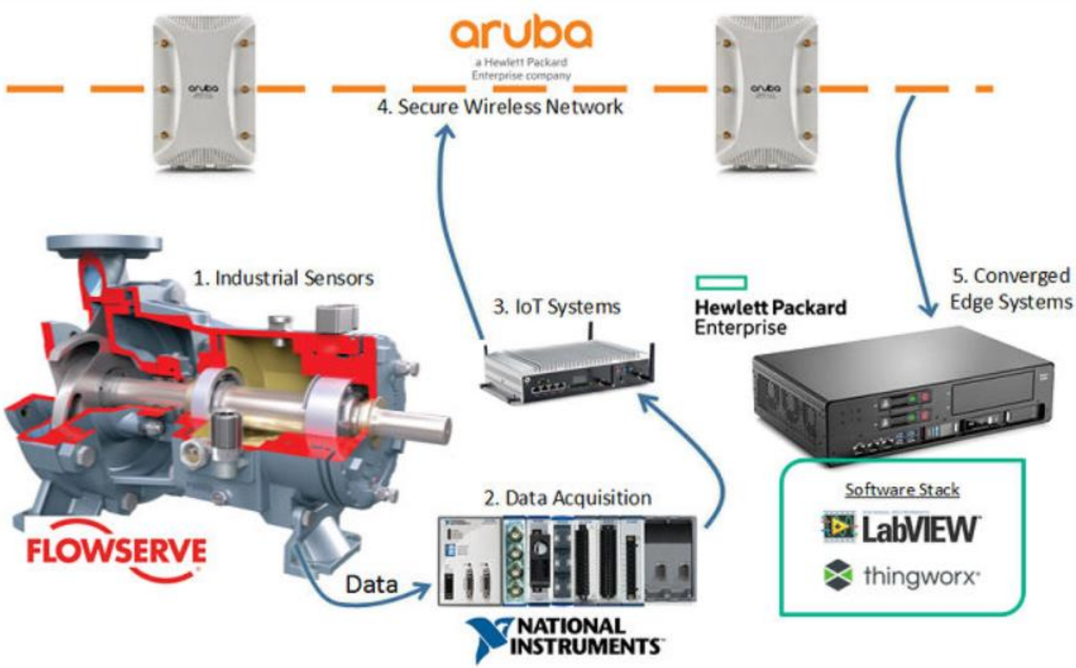


Figure by ntnglobal.com

The future is here - IoT

- Internet of things (IoT) is about monitoring and controlling all kinds of items
  - Motors
  - Cars
  - Factories
  - Buildings
  - etc
- Using software and internet connected electronics, sensors and actuators



Condition Monitoring data usage

- CM data is fed into computers – out put is:
    - prognosis and suggestions on decisions (e.g. maintenance activities)
    - direct actions (e.g. autonomous cars).

- Does the collected CM data represent the physical actual state of an item?
- Can sensors be trusted at all times ?

Sensor Malfunction

Russian plane crash (2018) a result of conflicting data due to ice on speed sensors. 71 people killed.

The crew turned on the autopilot after taking off but took manual controls back when they saw the conflicting speed data, with one indicator showing the speed at 0 kmh and the other about 550 kmh.

Before the plane slammed into the ground, one of the sensors continued to show a speed of 0 kmh while the other showed a speed of 800 kmh, according to TASS.

Iced-over Pitot tubes were cited as the likely reason behind the tragedy of an Air France flight that crashed into the Atlantic in 2009, killing 228 people on board.

http://www.news.com.au/travel/travel-updates/incidents/russian-plane-crash-a-result-of-conflicting-data-due-to-ice-on-speed-sensors/news-story/1eb8de28b9ab9dd5f59d0c032c1c1fc5

Sensor Malfunction

- **Sensor malfunctions.** The airbag will only deploy if the vehicle's sensors detect the correct speed, braking, and impact. A malfunctioning sensor can cause the airbag to activate when there isn't a crash, or not deploy when a crash occurs.

http://www.mylegalneeds.com/faqs/sensor-problems-and-other-major-causes-of-airbag-injuries.cfm

Sensor malfunction

- A French governmental report revealed a doubling in the average number om «sensor accidents» per year over the periods 1992-1999 and 2000-2008 for Metallurgy, petroleum refining, food processing and chemical & pharmaceutical industry

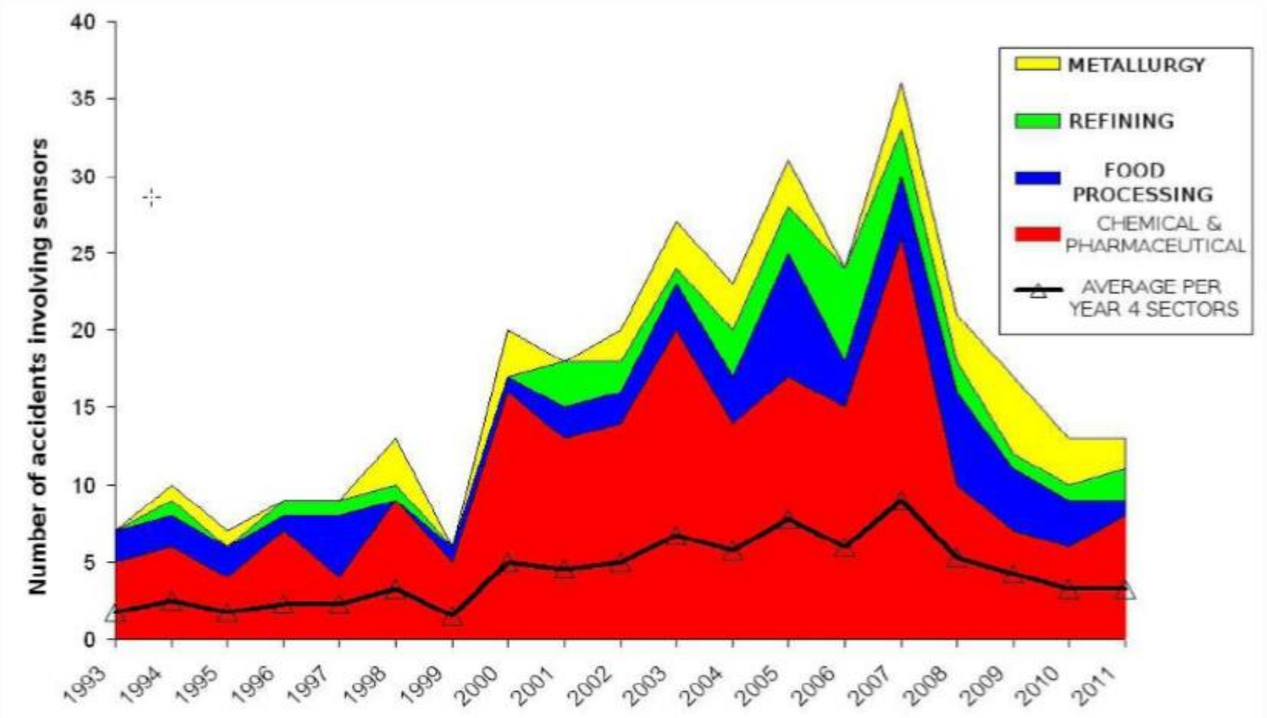


Fig. 1 : Annual number of accidents involving sensors for the most highly automated industrial sectors (ARIA base - 345 accidents)

https://www.aria.developpement-durable.gouv.fr/wp-content/files_mf/Sensorsindustrialautomation_GB.pdf

Sensor malfunction - causes

- The causes of malfunction among sensors were classified into three major categories (page 18 in the report)

- **Sensor noncompliance with the expected function:** specification error (ergonomics, design, materials, sensitivity, measurement accuracy, etc.); adjustment error (detection threshold, indication, time lag or sampling frequency); and inappropriate location (risk of clogging or leak on the sampling lines, non-representative measurement);

- **Sensor malfunction:** installation or connection error, harsh weather event (lightning, frost, wind, humidity, etc.), clogging/fouling/jamming, loss of utility, deliberate or non-deliberate shunt, corrosion/rust (of the sensor body, tapping, cables or sensor casing connections), other unidentified malfunctions;

- **Erroneous sensor information:** flawed calibration, measurement drift (poisoning of the catalytic cells, dormancy of the electrochemical cells in the gas or fire detectors), and electromagnetic disturbance.

Uncertainty of measurements

- There is always an uncertainty in any measurement

- Measurement uncertainty is often stated as a symmetric range around the measurement result:

  - Measurement $\mp$ *measurement* uncertainty

  - The measurement uncertainty may be calculated as a 95% confidence interval
  - 95% probability that the true value of the measured value is within the range of the confidence interval

- Example – the length of measuring stick: 2000mm∓1 mm
  - 95% probability that the stick is between1999 mm and 2001 mm

- The different error sources need to be identified and if possible quantified in such a way that the measurement uncertainty can be quantified

Measurement - Error

- Measurements errors may be divided into three categories

  - Human Errors
    - Can be error in:
      - Instrument use – try to measure temperature with an instrument out of measurement range
      - Instrument value reading – reading wrong, not enough digits
    - Remedial action: personnel training and introduction of procedures

  - Systematic Errors
    - Wrong measurement approach
      - Does not understand the process / machine – measure vibration in the wrong spot
    - Instrument errors
      - Calibration error, unstable instrument, poor instrument maintenance
    - Remedial measures: Focus on process/machine knowledge, proper calibration, maintenance

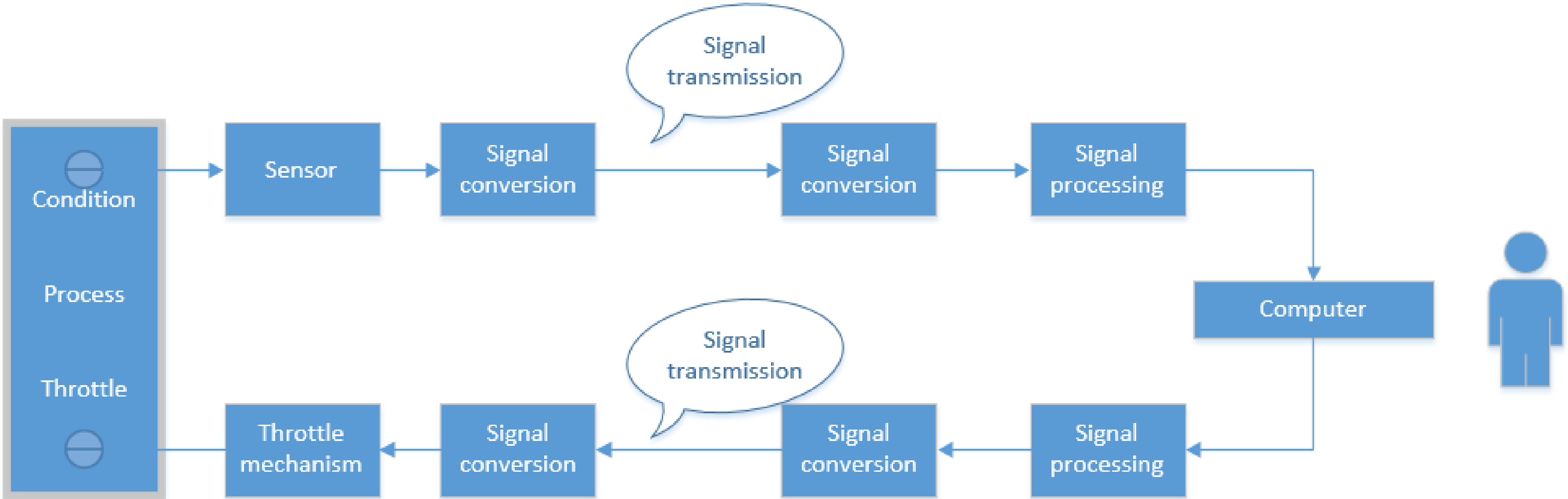
  - Random errors:
    - Difficult to find exact cause.
    - Remedial measures: Uses statistical analysis of many measurements to specify deviations between measured and true value. Great number of measurements are needed.

- Ref: Tore Hansen, Måle og instrumenteringsteknikk

An approach to CM

- Gain process & machine knowledge (loads- process data, design-strength) of the item being subject to CM.

- Take control of the measurement chain providing CM data – understand and plan it well.



Knowledge of the item to be CM

- Possible item failure must develop slowly enough to be detected at an early (enough) stage

- Know the operational conditions experienced by the item.
  - select CM equipment that can handle operational conditions.

- Is accurate as-built information of the item available?
  - load zones, where to put sensors, etc.

- (Only critical items should be subject to CM)

Measurement chain control

- The whole measurement chain has to be planned and controlled
  - The individual parts of the chain have to be customized and specified to the right robustness, accuracy, reliability etc.
  - The whole installed measurement chain has to be calibrated and if needed adjusted before it is put into operation.
  - The measurement chain is a maintenance object – must be checked to make sure it is functioning; adjusted or replaced if needed

Sensor selection

- Some factors to be considered
  - Sensor robustness
  - Sensor range
  - Sensor accuracy
  - Sensor reliability
  - Sample rate

  - There are more factors to be considered ……

  - Resolution – The smallest change in measured value giving a change in the instrument reading.
  - Sensitivity – Relationship between signal change and change measured value.

  - Etc..

Sensor robustness

- The sensor must handle the environmental conditions
  - Media exposure – humidity, fresh water, salt water, chemicals
  - Temperatures – high temperatures may call for customized material selection in the sensor
  - Electric/Magnetic fields – shielding of signal may be required
  - Acceleration/vibration – sensor may need to be customized to handle forces

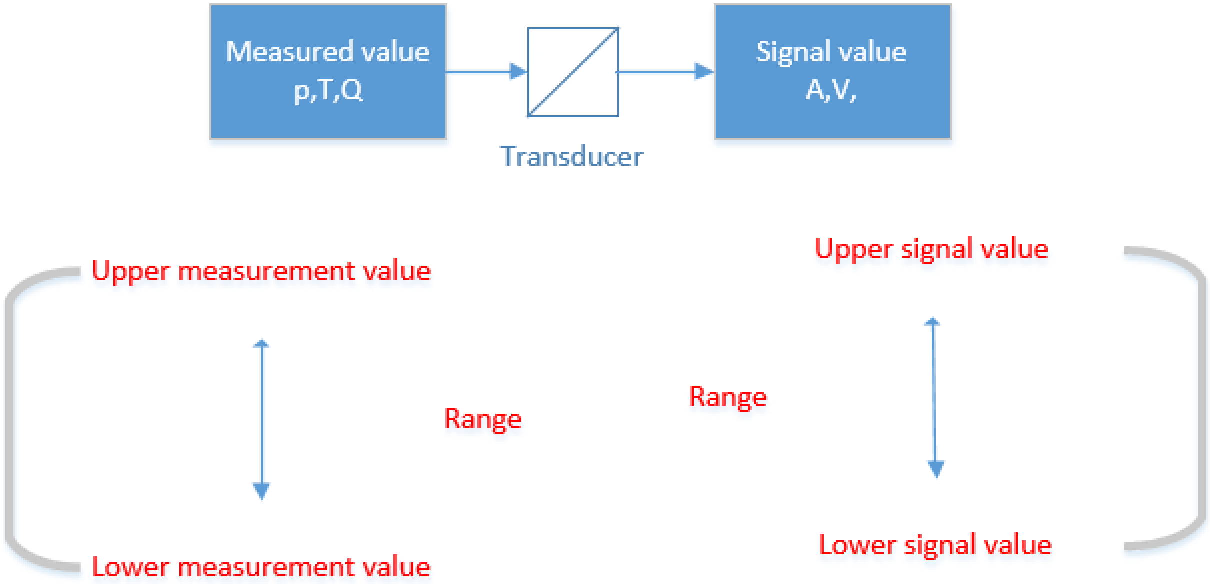
- The sensor must be protected to handle the environmental conditions
  - IP – International Protection – IEC 60529
  - IP 30 in common for plug-in contacts at home (first digit indicates protection against penetration of fixed objects (3: 2.5 mm) - second digit indicates protection against water penetration 0: no protection)
  - ATEX - EU Directive that imposes requirements for equipment used in hazardous areas

- The sensor need power supply and a communication platform
  - Is grid available – or is battery the only option?
  - Is network available – or is wireless signal transfer the only option
  - Can the data stored in the sensor (transducer) – to be collected later

Sensor range

- Lower range value – The lowest value the transducer can handle
- Upper range value – The highest value the transducer can handle
- Measurement Range – Upper range value minus Lower range value

- Lower signal value – The lowest electrical signal output from the transducer (4 mA)
- Upper signal value – The highest electrical signal output from the transducer (20 mA)
- Signal range – Upper range value minus Lower range value



Measurement - range

- The sensor range must handle the highest and lowest parameter to be measured.

- Selecting too broad a sensor range will influence the uncertainty of the measurements

  – The uncertainty is often a percentage (e.g ± 1%) of the whole measurement range

  – Range of 300 degC at ± 1% = 3 degC uncertainty

  – Range of 50 degC at ± 1% = 0,5 degC uncertainty

Signal - range

- If the sensors give a signal ranging from 4 – 20 mA
- If the measurement range is 100 – 400 degC
- The amplification is = $\frac{\Delta\, Signal}{\Delta\, Measurement} = \frac{(4-20)}{(100-400)} = \frac{16\, mA}{300\, degC}$ = 0,05mA/degC
- The signal changes 0,05 mA for each degC change in temperature.
- The signal receiver must be customized to read such small currents
  - If not the measurement chain may only be able to detect temperature changes of several degrees.
- If the sensor has an uncertainty of the measured temperature value of $\mp$ 3 degC than a very sensitive signal receiver reading 0,05 mA is a waste of money.
- The two have to play together.

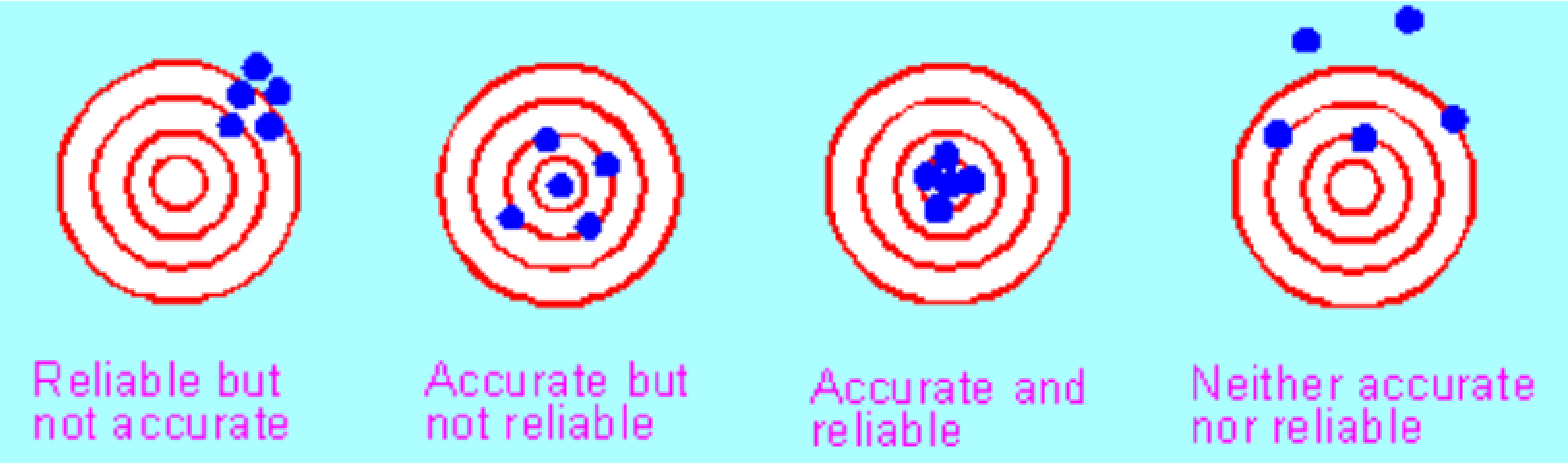
Accuracy - Reliability

Accuracy

How close the instrument reading is to the true value of the parameter being measured.

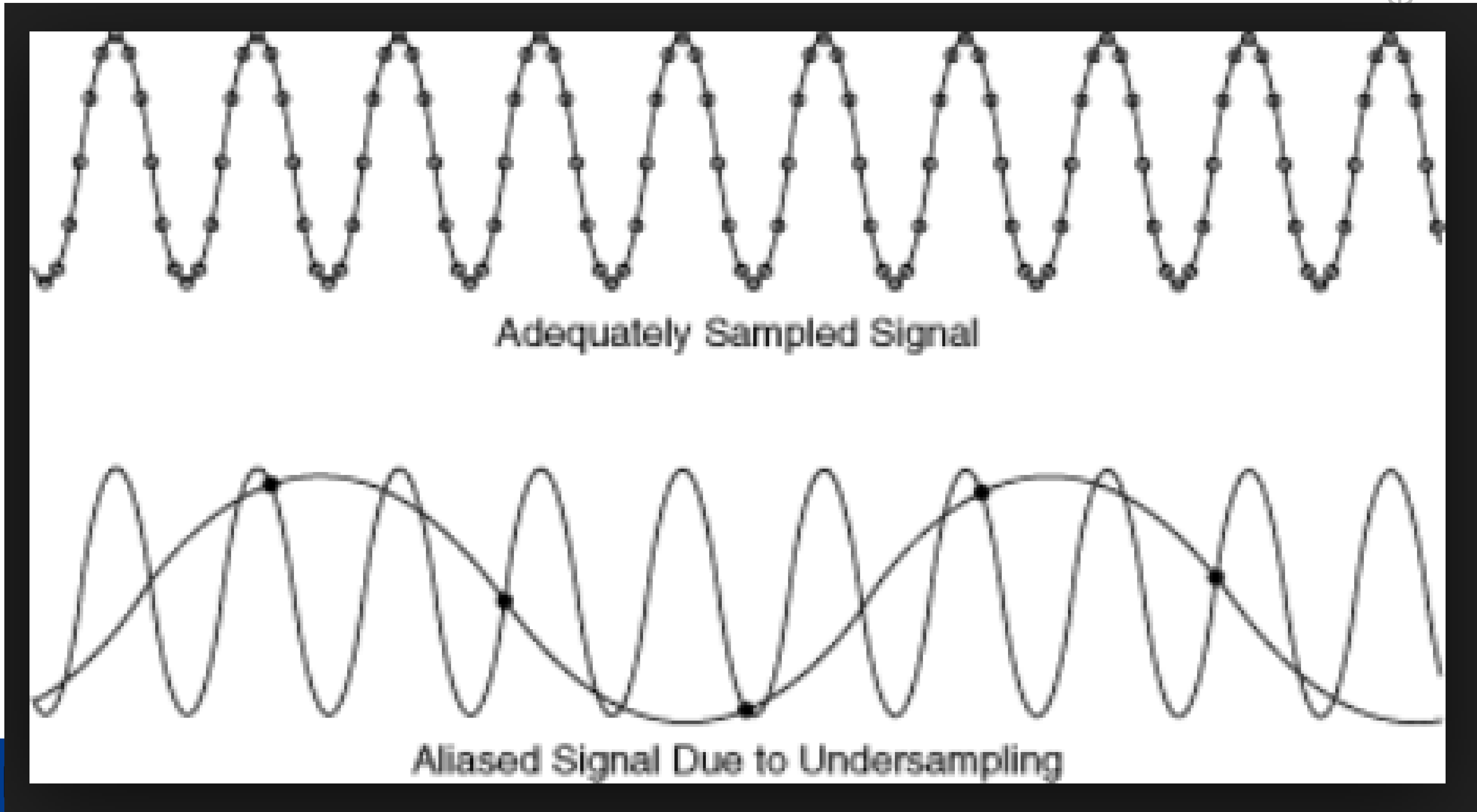
Reliability

Will one get the same values if the measurements are repeated?



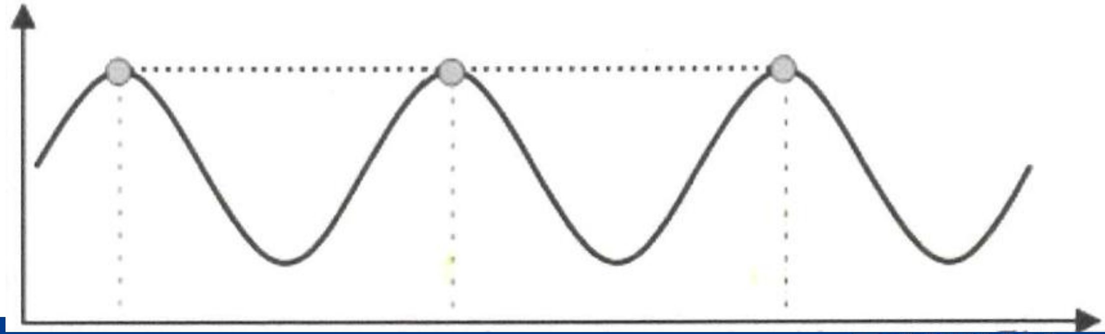
Sampling rate

- The number of samples per second from the sensor must be enough to represent the variation in a dynamic signal.
- Beware aliasing – under sampling



Sampling rate

- The rate
  - How many measurement points to be recorded over a time unit (usually 1 second)
  - The Nyquist Theorem says you must sample 2.56 times the highest frequency you want to measure to avoid aliasing.
- Eksempel
  - A signal changes 50 times a second (vibration, pressure, etc.)
  - A sampling rate of 50 times a second means that we only get one measurement point for each change = a straight line that does not show variation in the measurement signal



Filtering

- Used to highlight certain areas in the measurement signal
  - Be careful and not filter away signals of value
- Filtering – Filtering
  - Low pass filter allows low-value signal to pass
  - Band pass filter allows the signal in an area to pass
  - Band stop filter stops signal in an area
  - High pass filter allows high-value signal to pass
- Low pass filter most used - removes high frequency noise (from electrical appliances, power grids, etc.)

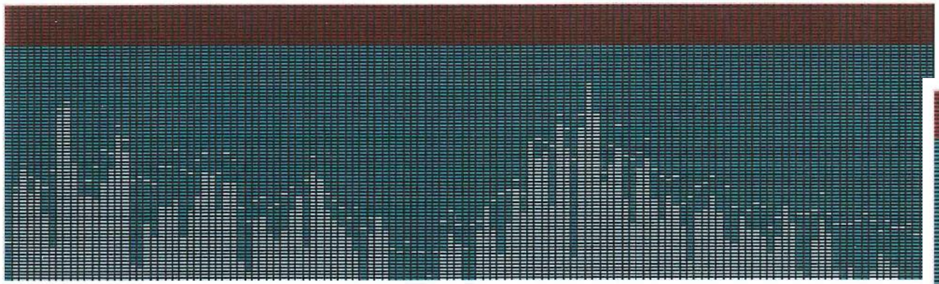


Figure 3-6 - Data from a machine, no filter applied.

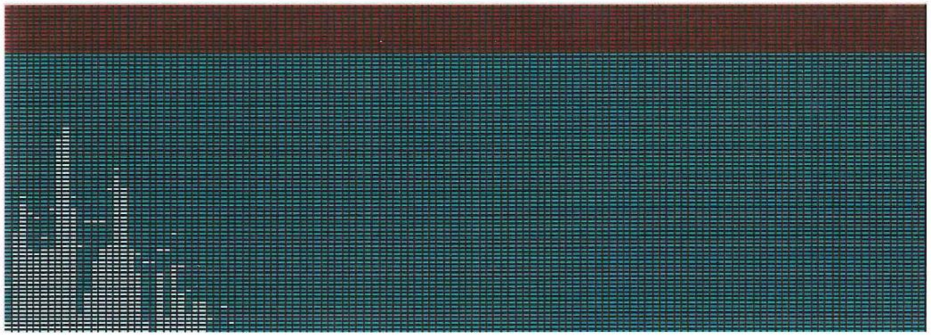


Figure 3-7 - Same data but with a Low Pass filter applied.

Statistical analysis of measurements

- Arithmetic means - a probable value of the measured variable
- $\bar{X} = \frac{X_1 + x_2 + \cdots x_n}{n} = \frac{\sum x}{n}$ (where x is measurements and n number)
- Deviation - the difference between individual measurements and the mean value
  - $a_1 = x_1 - \bar{X}$, $a_2 = x_2 - \bar{X}$, $a_n = x_n - \bar{X}$
- Average deviation (affected by all values in the dataset)
  - A = $\frac{|a_1| + \cdots |a_n|}{n} = \frac{\sum |a|}{n}$
- Standard deviation - the spread of values in a data set
  - How much a series of values differs from the average of the series
  - $\sigma_A = \sqrt{\frac{\sum a^2}{n}}$
- Variance– how much observations in an observation set on average deviates from the mean value
  - $V_A = {\sigma_A}^2$

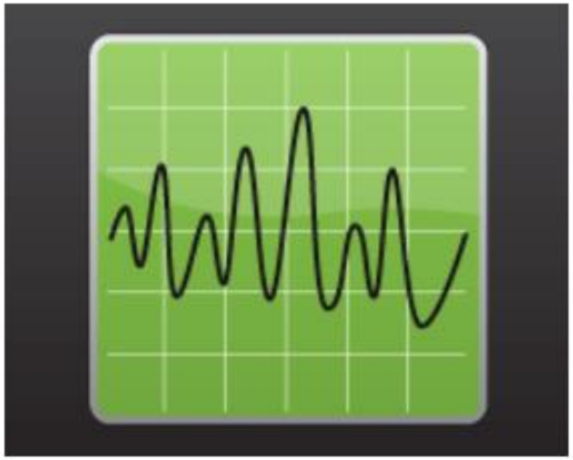
Statistical analysis of measurements - example

- We have two instruments X1 and X2 , with each instrument we make 5 equal measurements
- Based on table of data suggest and justify your choice of instrument X1 or X2.

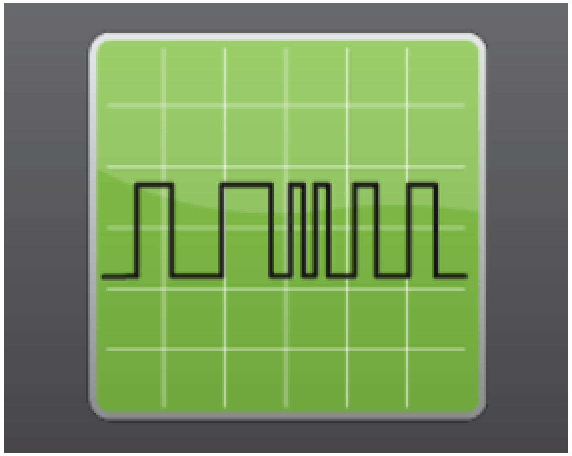
(Hint which instrument has the greatest variation in the measurement data.?)

Ins						$\bar{X}$	σ_A	V_A
X1						3	1,26	1,6
X2						3	0,63	0,4

Signal transmission
Analog - Digital signals



Oscilloscope trace of an analogue signal



Oscilloscope trace of a digital signal

Signal transmission - Noise

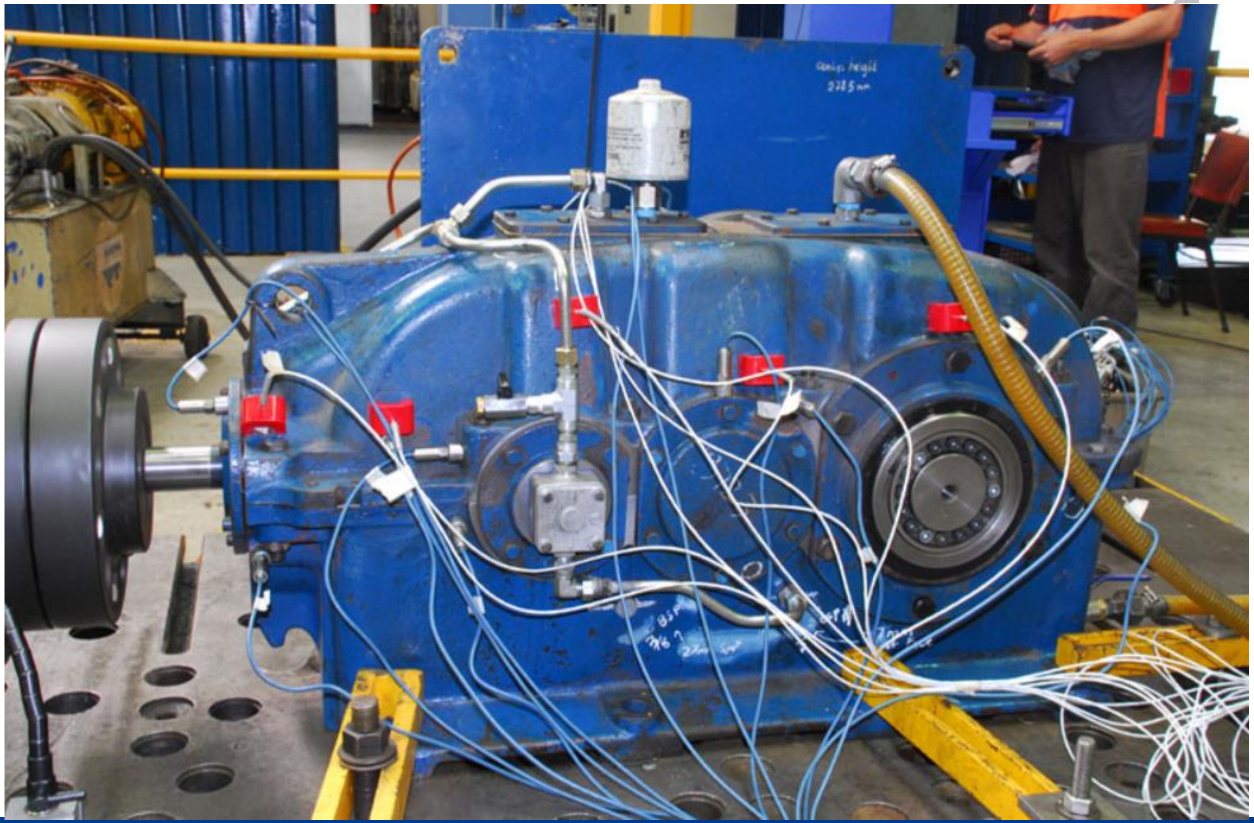
- Analog signals are more prone to noise and distortion
  - A 4-20 mA signal is constant over the cable length – magnetic fields my introduce distortion
  - A 0-10 V signal is exposed to voltage drop

- Digital signals are less prone to noise and distortion
  - The signal is composed of exact bits and bytes (1 byte = 8bits)
  - The signal sent may thus be reconstructed

- Converting signals from analog to digital is done frequently
  - The analog signal is transformed to a row of numbers

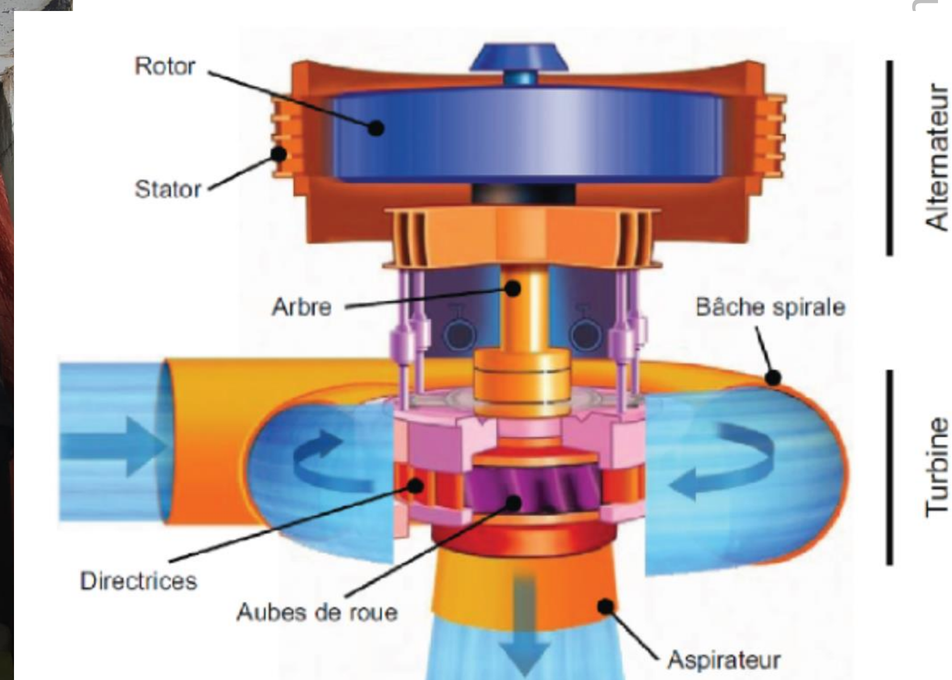
Sensor location – require knowledge

- Requires knowledge of the item
  - Load Zone, dampening of signal in the structure
  - Threaded mounting – best ; magnet = dampening?
  - Cabling – routing? Electromagnetic disturbance – cable shielding



Sensor location – require knowledge

- Svorkmo HP station – draft tube – bolts broke – vibration the cause?
- Source of vibration – the rotating turbine, the water flow, which operating point - several?
- Sensor location ? On the new bolts? On the draft tube – where? Try several locations? Worst location?



CM data quality

- Depends on the selection of CM method
  - Are the data collected suitable for operation and maintenance decisions?
  - (temperature data - the failure development is detected too late – should have monitored vibration)
- Depends on the measurement chain
  - Measurement uncertainty
  - Measurement Accuracy - reliability
  - Aliasing
  - Filtering
  - Signal transmission
  - Sensor location
  - Cabling

- Thanks for listening