Multi-disciplinay Measurement

Claes Fredö

Elisabet Blom

Root Cause Analysis: *Automotive style*

Qring

- D0: **Plan**:
  - Plan for solving the problem and determine the prerequisites.
- D1: **Use a Team**:
  - Establish a *team* of people with product/process knowledge.
- D2: **Describe the Problem**:
  - Specify the problem by identifying in quantifiable terms the who, what, where, when, why, how, and how many (5W2H) for the problem.
- D3: **Develop Interim Containment Plan**:
  - Define and implement containment actions to isolate the problem from any customer.
- D4: **Determine and Verify Root Causes and Escape Points**:
  - Identify all applicable causes that could explain why the problem has occurred. Also identify why the problem was not noticed at the time it occurred. All causes shall be verified or proved. One can use five whys or Ishikawa diagrams to map causes against the effect or problem identified.
- D5: **Verify Permanent Corrections (PCs) for Problem will resolve problem for the customer**:
  - Using pre-production programs, quantitatively confirm that the selected correction will resolve the problem. (Verify that the correction will actually solve the problem.)
- D6: **Define and Implement Corrective Actions**:
  - Define and Implement the best corrective actions.
- D7: **Prevent Recurrence / System Problems**:
  - Modify the management systems, operation systems, practices, and procedures to prevent recurrence of this and similar problems.
- D8: **Congratulate main contributers to your CAR team**:
  - Recognize the collective efforts of the team. The team needs to be formally thanked by the organization.8Ds has become a standard in the automotive,[1] assembly, and other industries that require a thorough structured problem-solving process using a team approach.

Philosophy

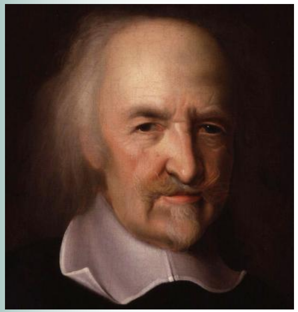
Law of the instrument:

"I suppose it is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail.“

Abraham Maslow

“If the result confirms the hypothesis, then you've made a measurement. If the result is contrary to the hypothesis, then you've made a discovery”

Enrico Fermi



”For between True Science and Erroneous Doctrines, Ignorance is in the middle.”

Thomas Hobbes

“All models are wrong but some are useful”

George E.P. Box

QRING

Confirmation Bias

- To better accept the unknown *– try catching it using two or more sensor types.*
  - Use sensors of different make and design, e.g. accelerometer, laser vibrometer, proximiter, etc.
- Collect and systemize data
  - Register data 24/7
  - Automate processing
    - ***Put the effort into understanding results instead of on generating the plots/tables.***
- Structured analysis process
  - Start from the helicopter view
  - Dive into detail only for a defined purpose, i.e. to examine a hypothesis.
- Embraze sensor 'errors'
  - First make sure the sensor is working as it should
  - Next, explain why it is behaving strange – ***this may well be the key to unlocking the mystery.***

Example:

V4 Dieselmotor Waterpump

Importance of differences in knowledge basis,

combining geometry with data (ODS),

the use of a ’wasteful’ attitude to measurement channels

&

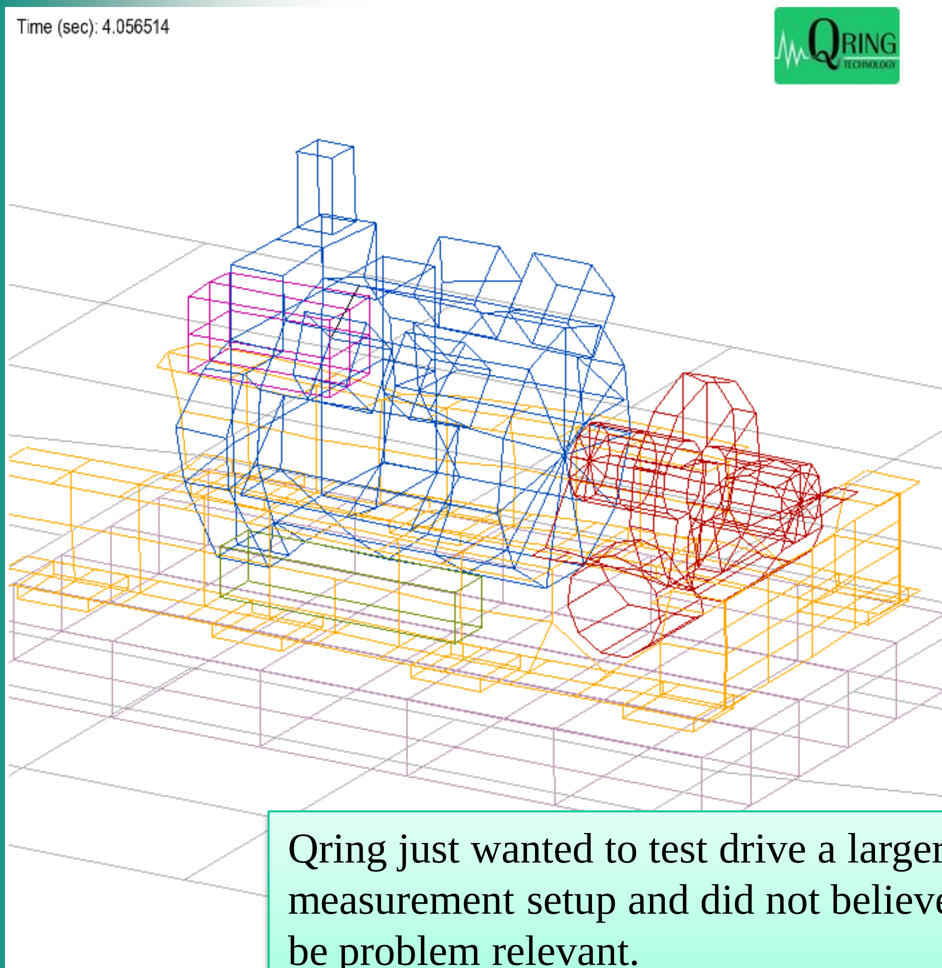
the value in buing a friend lunch

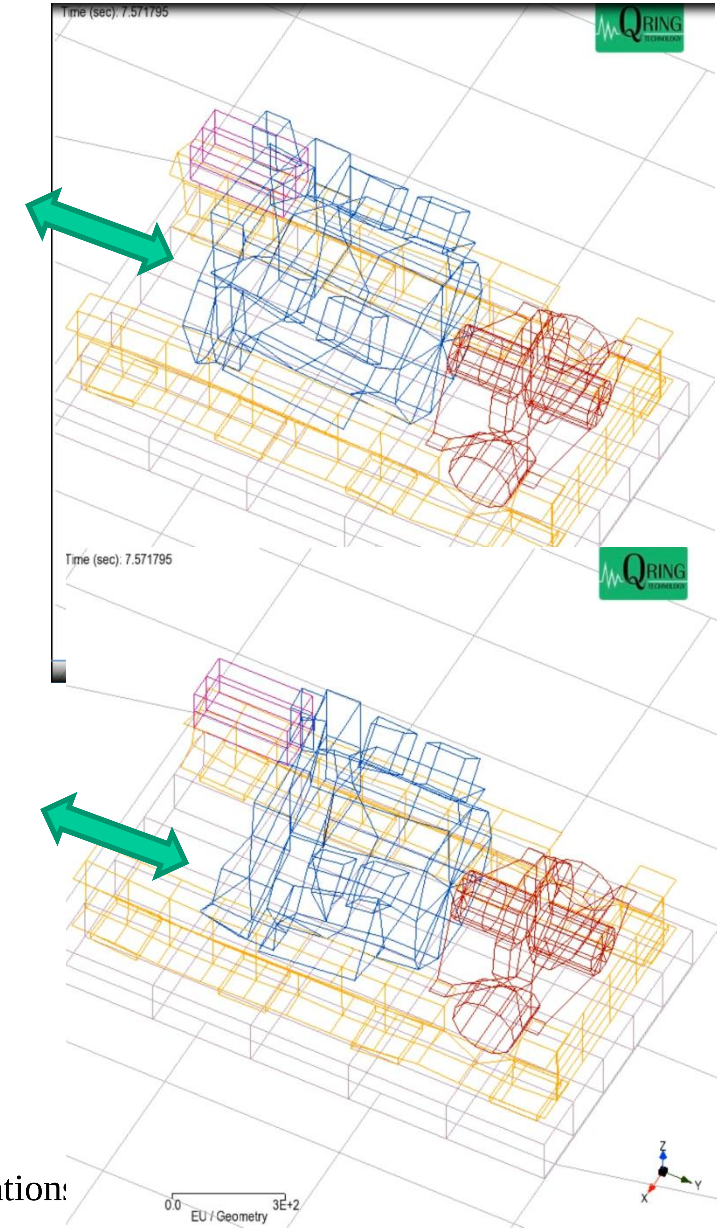
Problem

- Very high vibration levels,
  - 5g , 25000 mm/s RMS
- Poor auxiliary equipment uptime
- The unit
  - Was taken apart, balanced & renovated.
  - End result **=> *higher* vibration**

178 Ch Realtime Measurement

High *axial* direction vibration 2xRevolution?

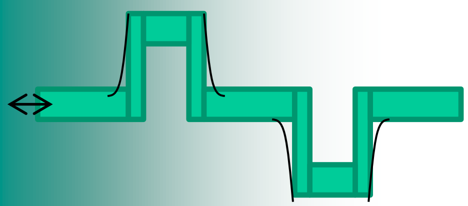




Qring just wanted to test drive a larger measurement setup and did not believe it to be problem relevant.
As it turned out – *realtime data mattered.*

What it all boiled down to

- The V4 motor design was old, from the 1940’s.
  - The V4 design was troublesome from day 1 according to the supplier.
  - Findings were submitted to the usual network but satisfactory explanation could not be found.
  - A motordesigner from another company explained the situation to Qring (over lunch)
    - ”Choose the wrong firing order for the V4 geometry.”
    - ”Have a bending weak crank web.”
    - ”And - this is what you end up with, i.e. it is a design flaw & not the way to build a V4 diesel.”



- Options:
  - *Replace* with other, better, motor.
  - *Robustify* motor auxiliaries for coexistance with the existing motor.

Example:
X-ray Machines

Importance of different sensor types

&

a ’wasteful’ attitude to data collection

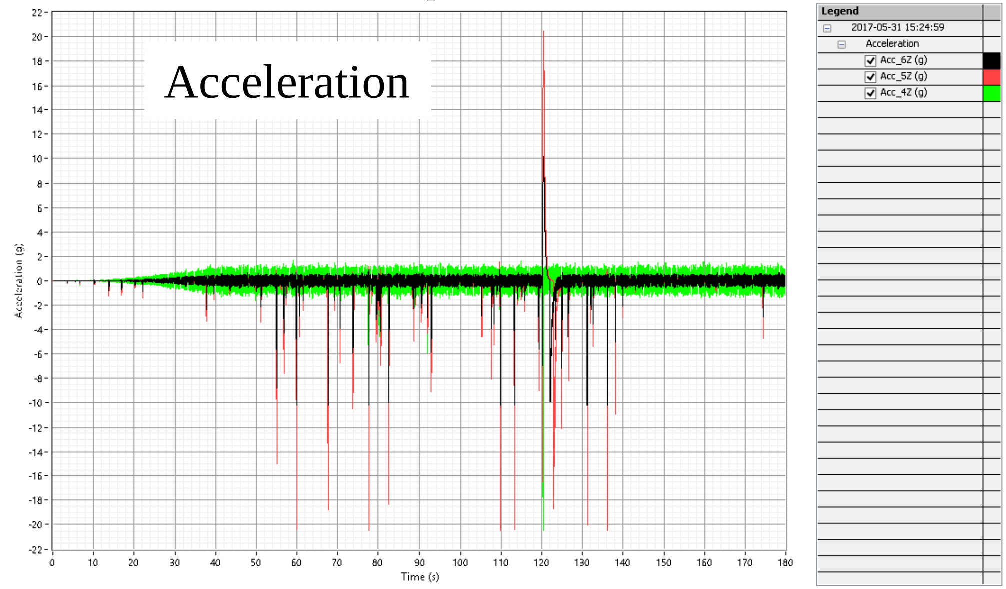
Problem & Measurement

- The machines work,
  - But, sometimes get stuck and refuse to start.
  - A hand push in the reverse rotation direction & it starts.
  - Bearing damage was suspected. Replacing the bearing is complicated.
- Measurement of
  - Vibration with accelerometers and laser vibrometer,
  - RPM with optical tacho,
  - AC current
  - Sound using microphone.
  - Voltage with 2-ch 40 MHz oscilloscope.
- Time signal, (ODS & Order) analysis

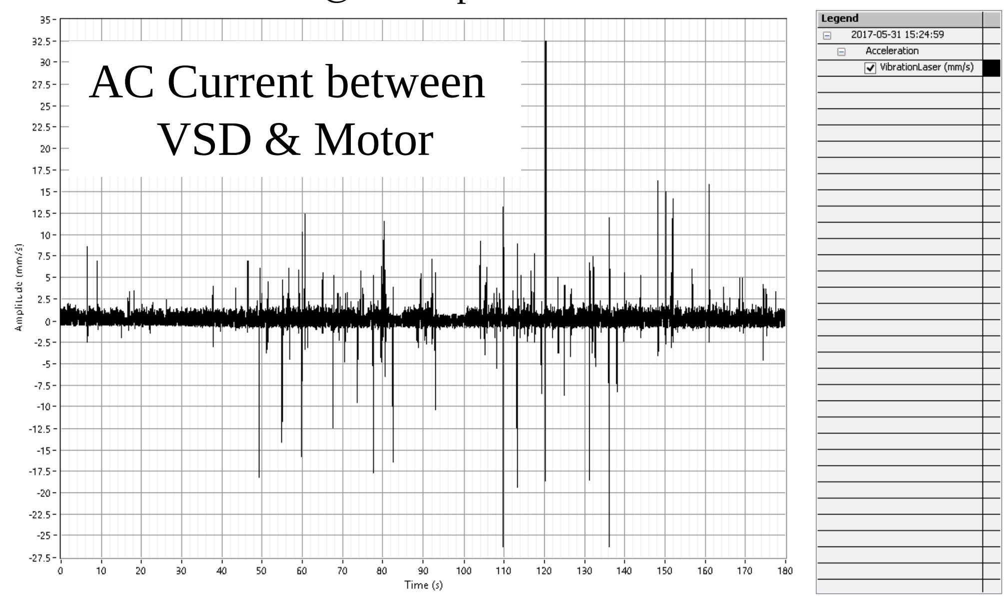
Run Up

Strange acceleration spikes appear during Run-Up for one of the machines.

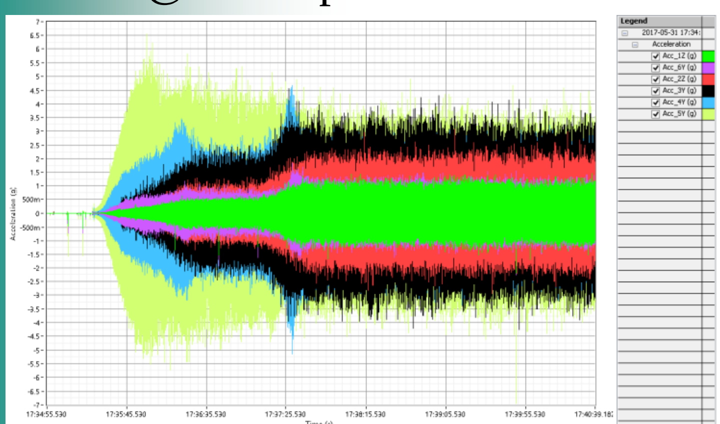
Acc@Run-Up for machine #1



Current@Run-Up for machine #1



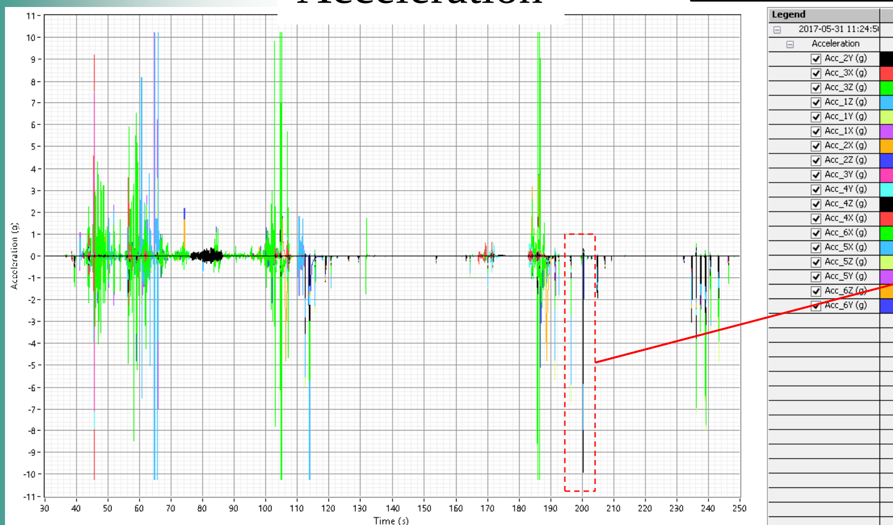
Acc@Run-Up for machine #2



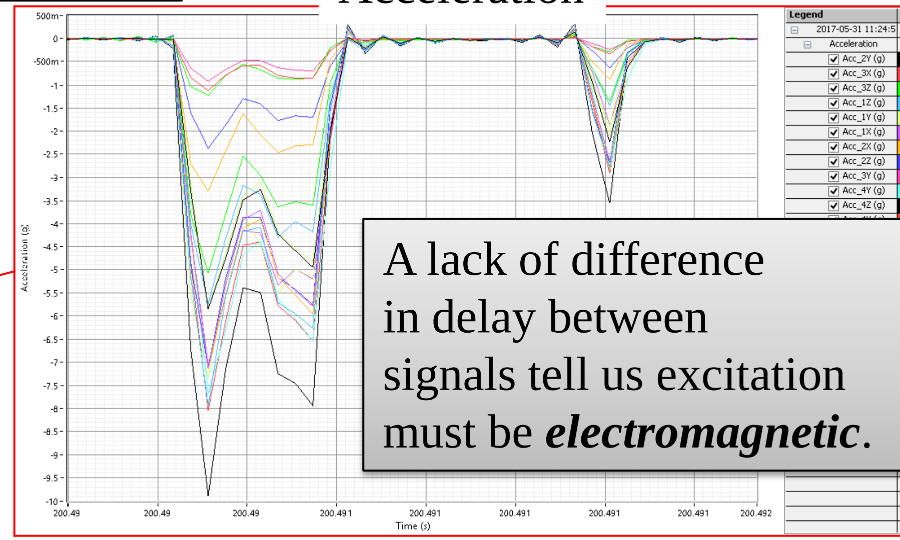
Example@Standstill, when powered

25,600 Samples/s

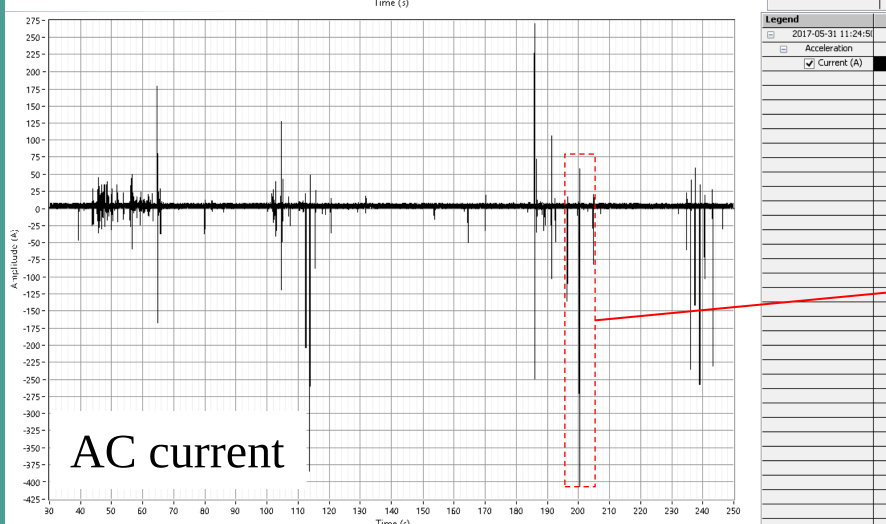
Acceleration



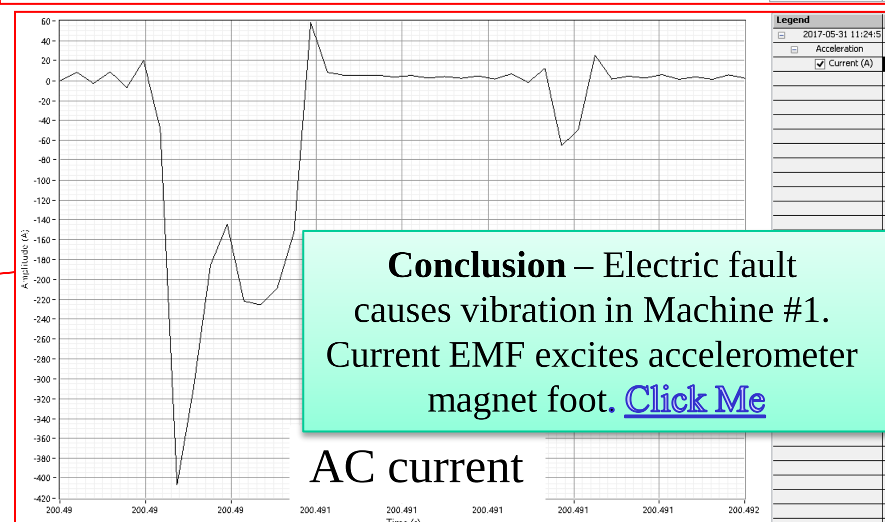
Acceleration



A lack of difference in delay between signals tell us excitation must be ***electromagnetic***.



AC current



AC current

Conclusion – Electric fault causes vibration in Machine #1. Current EMF excites accelerometer magnet foot. Click Me

Example:

Centrifugal Flue Gas Fan
&
Variable Speed Drive (VSD)

Importance of differences in knowledge basis,
logging data for a long time,

multi-sensors

&

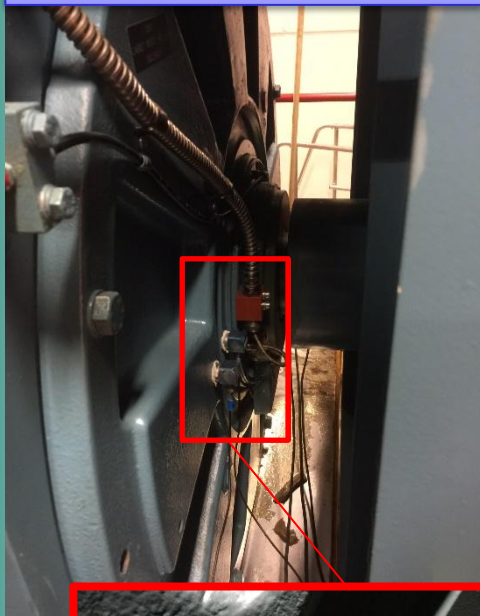
automating the processing

Problem

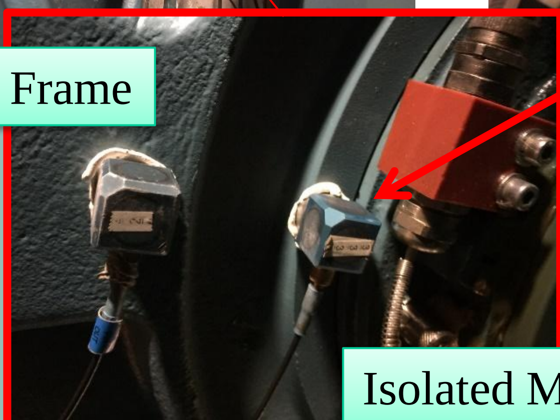
- A broken 1,7 MW flue gas fan
- Problem solving involved
  - Soft feet, alignment
  - Momentary strong axial vibration
  - Torsion vibration
  - Process control – PID regulator
  - High Frequency ground potential
  - VSD control software theory

Accelerometers

Acc Motor NDE



Motor Frame



Isolated Motor Bearing

Acc Motor DE

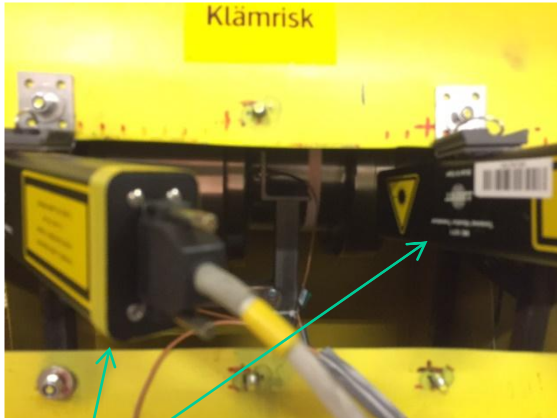
To be discussed

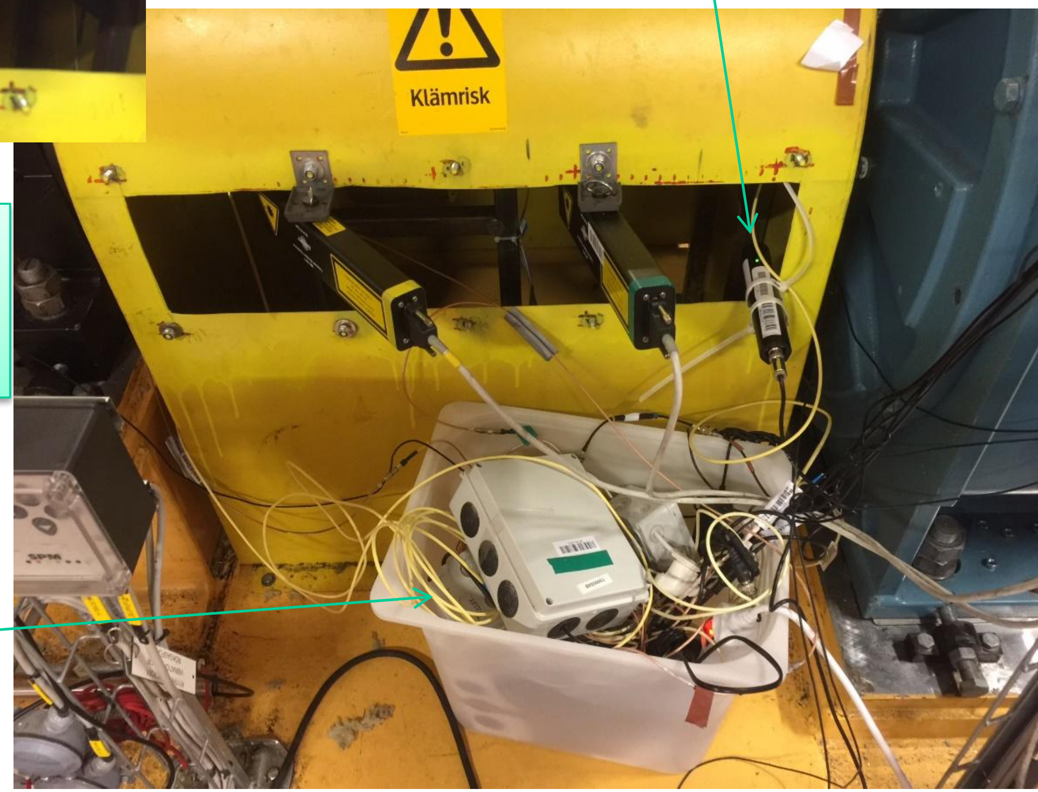
Accelerometer design is grounded. The setup uses epoxy to isolate magnet base, plus epoxy for gluing. A setup involing a large isolating pad was tested with the same end result.

Acc Fan DE Bearing

Acc Floor

Lasers, Tacho & Proximeters inside cover





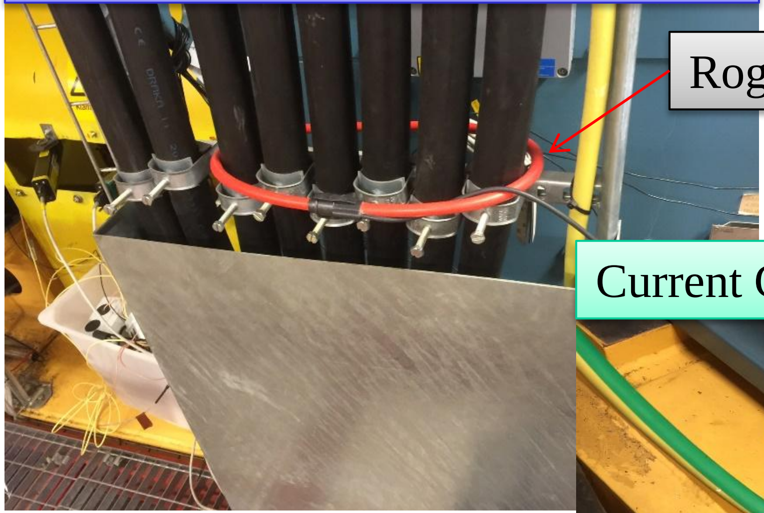
Tacho

2xTorsion lasers as there is a flexible coupling between the fan Drive End and the motor DE.

Proximiter probes to measure support-shaft motion.

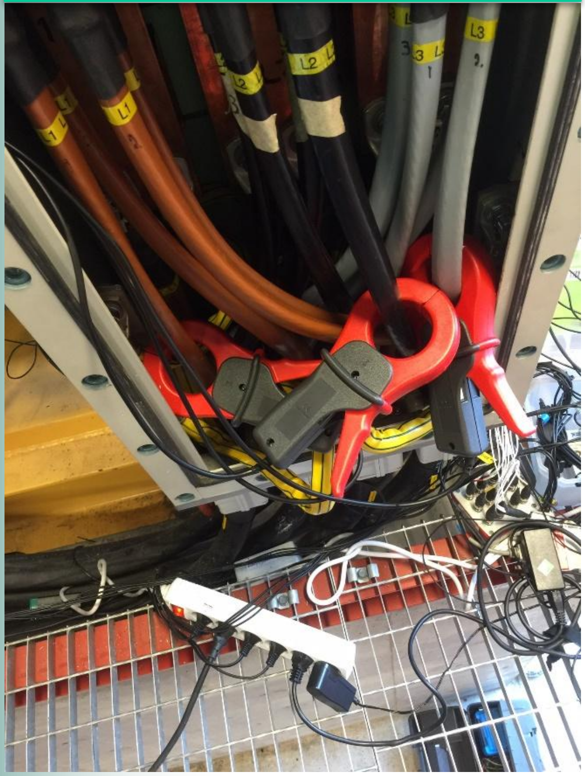
Current

Summed Current@Motor
(L1+L2+L3+N+Gnd)

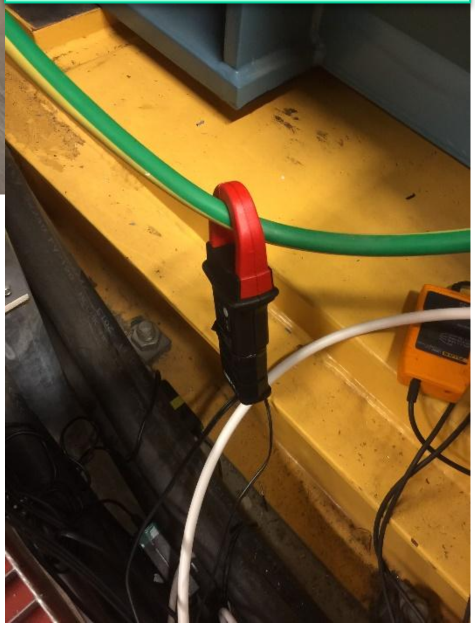


Rogowski Coil

L1-L3 Motor Current



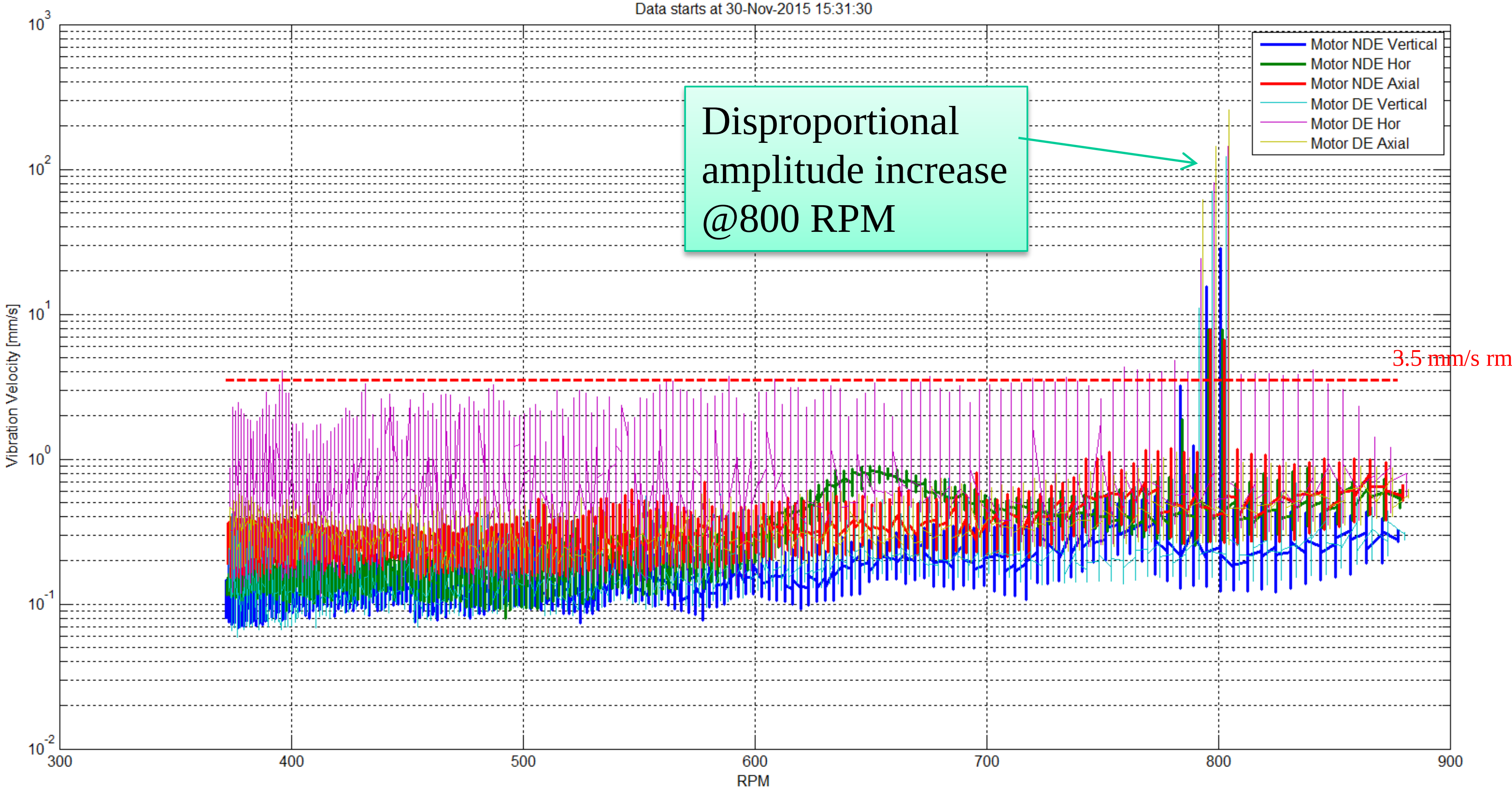
Current Ground



Also,
Summed Current@Network
was measured using a
Rogowski Coil

Motor Bearing

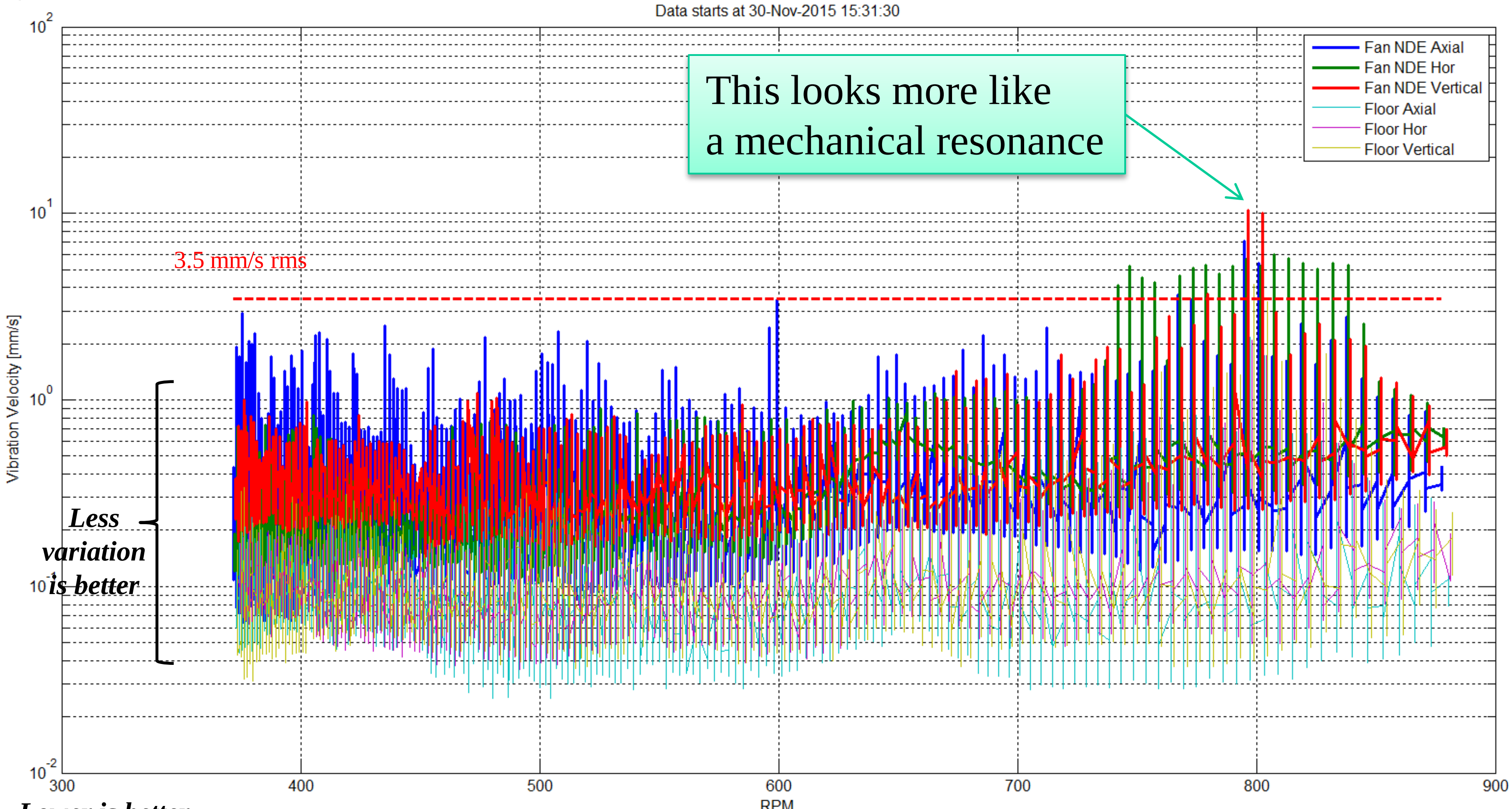
Data collected 24/7 for a few weeks to get full speed range.



Motor Supports and Floor

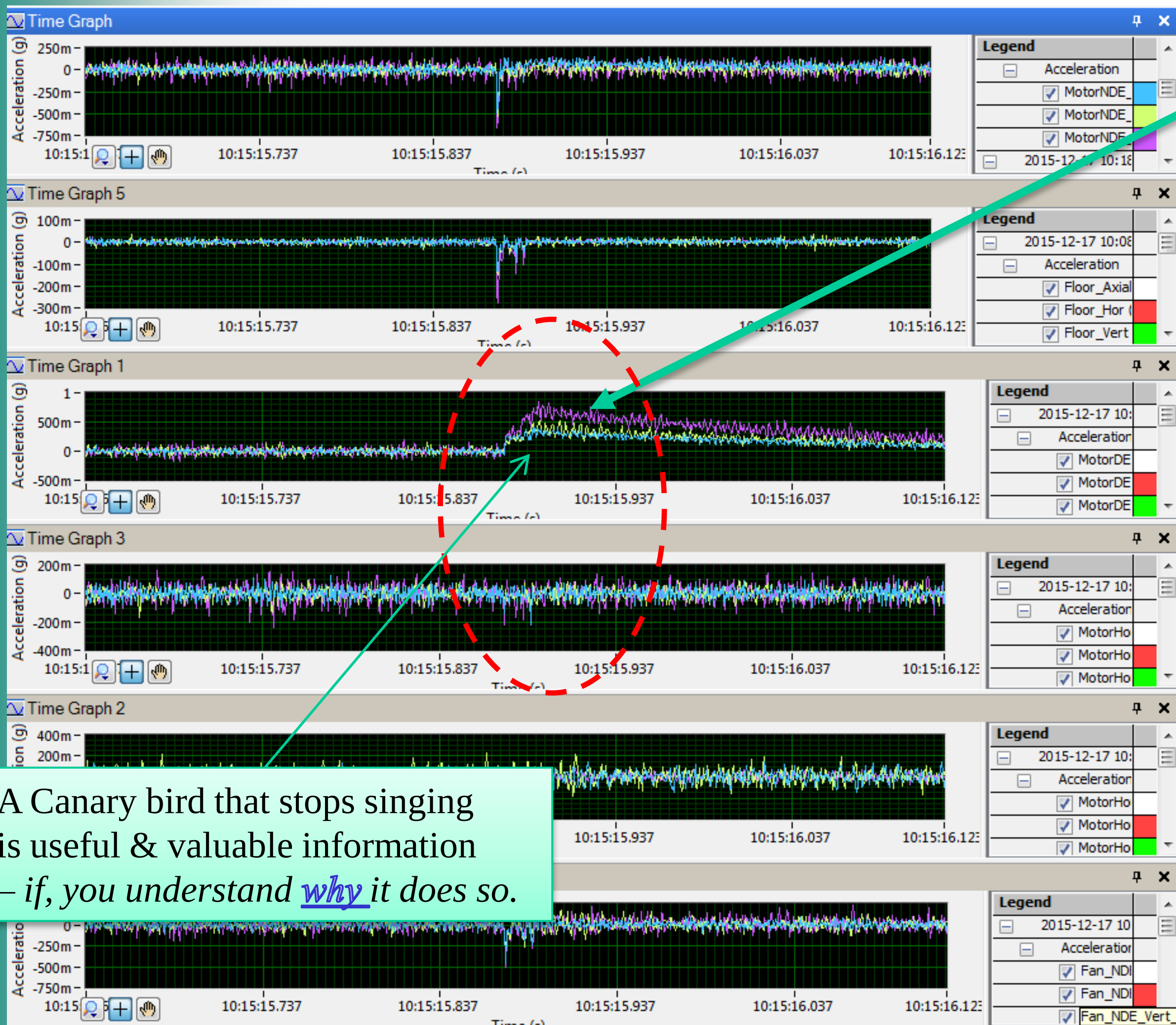
Data collected 24/7 for a few weeks to get full speed range.

Higher is worse



Lower is better

Canary bird: Measurements?



The Acc signal suddenly DC shifts
Why? - *a high frequency induced ground potential becomes large enough for a spark to jump from bearing to acc ground.*

A Canary bird that stops singing is useful & valuable information – *if, you understand* ***why*** *it does so.*

SMARTNEWS *Keeping you current*

The Story of the Real Canary in the Coal Mine

Used until just 30 years ago, the humble canary was an important part of British mining history

Mining foreman R. Thornburg shows a small cage with a canary used for testing carbon monoxide gas in 1928. (George McCaa, U.S. Bureau of Mines)

By Kat Eschner
SMITHSONIAN.COM
DECEMBER 30, 2016

Multidisciplinary:

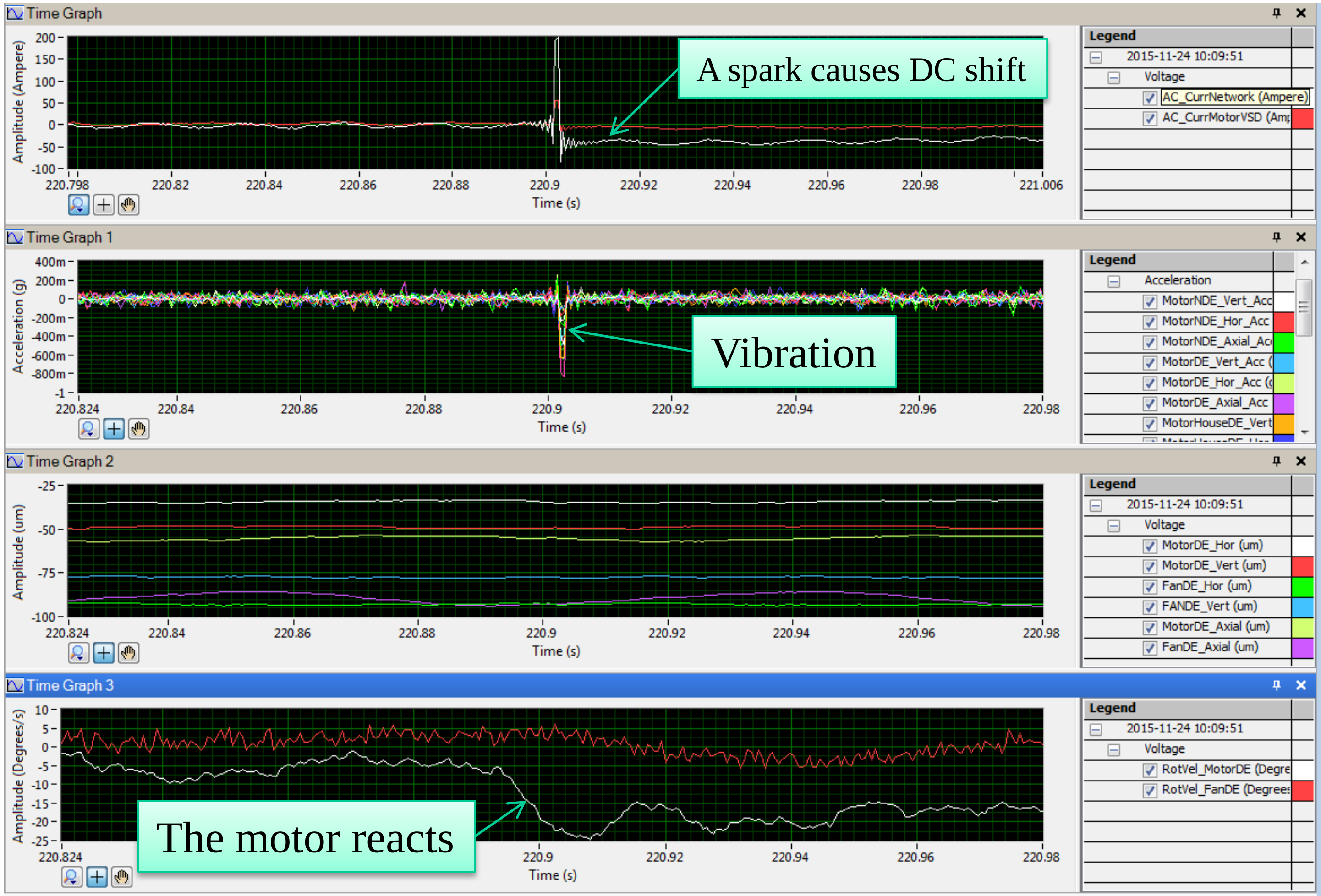
The VSD causes sudden jerks

AC current
(Rogowski Coils)

Vibration

Relative position
(prox)

Torsion
(a flexible coupling is located between fan & motor)



Automated processing was used to identify and analyze erratic behavior.

What it all boiled down to

- Axial vibration.
  - The ground floor triax showed 1000 mm/s which pointed out another fan, a few rooms away to be the culprit.
- Torsion
  - Showed the presence of two backward rotating modes that sometimes were excited.
- Voltage sparks.
  - The VSD 360^{o} grounding was incorrect & caused electric discharge (sparks).
- Variable Speed Drive (VSD) software theory
  - Only caters for RPM, *cannot use*
    - *Key phase (Tacho) information, i.e. is unable to sense if it is regluating too late.*
    - *Encoder A or B channel, but not both, i.e. is unable to sense jerks.*
  - Therefore, the VSD is fooled by BW rotating modes that phase shift key phase N·180 degrees - which also trigger sparks
- Solution
  - Trim down VSD PID settings and use S-ramp.
  - Reduce step size and avoid jumps in setpoint gradient

Example:

Axial Flue Gas Fan

Importance of differences in knowledge basis,
use of a multi disciplinary approach,
logging data for a long time,
use of built in sensors,
grabbing past/present control room data,

a recapture of prior knowledge

&

customized processing

Problem & Work

- The fan
  - had after many years of operation experienced two failures.
  - was suspended from rubber blocks who were believe to be faulty and one end had been fitted with metal blocks.
- Correlation vibration versus certain boiler MW ranges was known.
  - Otherwise hard to predict or understand the fan or what to do about it.
- Work:
  - EMA, Torsion vibration measurement at unexpected outage
  - 3 month operation 24/7 logging of
    - Vibration
    - AC summed & ground current
    - Oil pressure
    - Channel pressure
    - Blade Angle

Problems

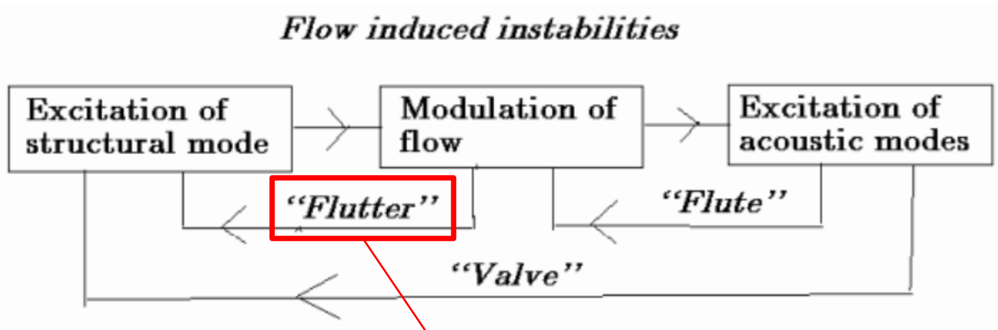
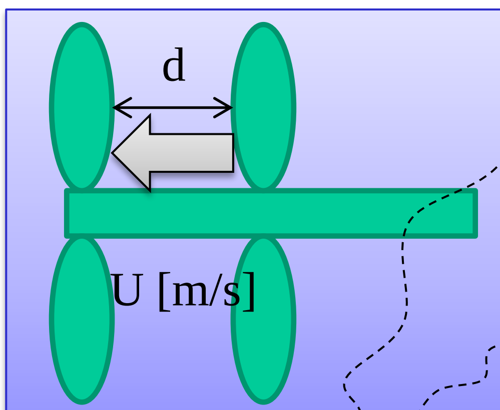


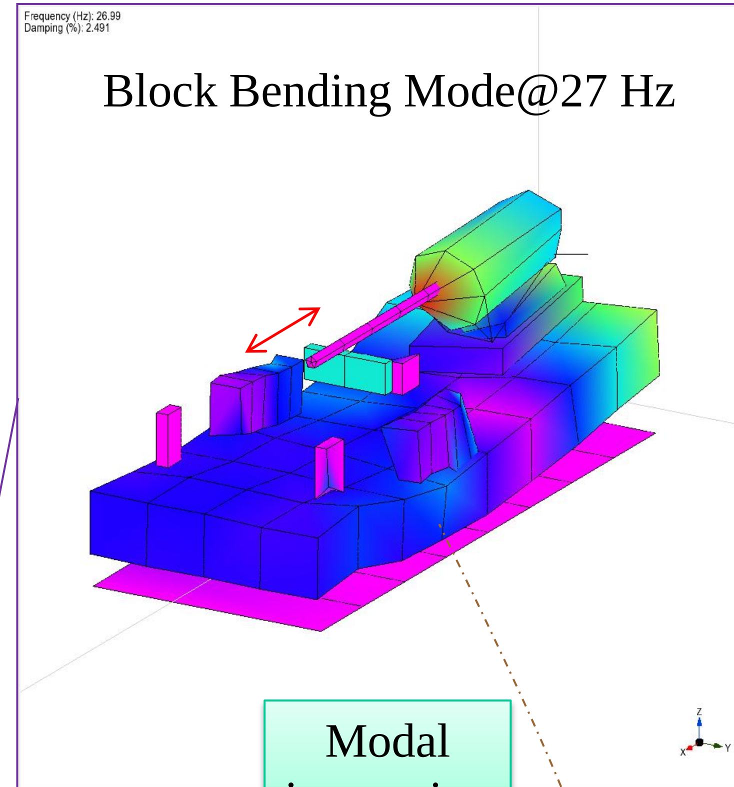
Figure 8.7: A classification of flow induced instabilities.

Axial flow frequency

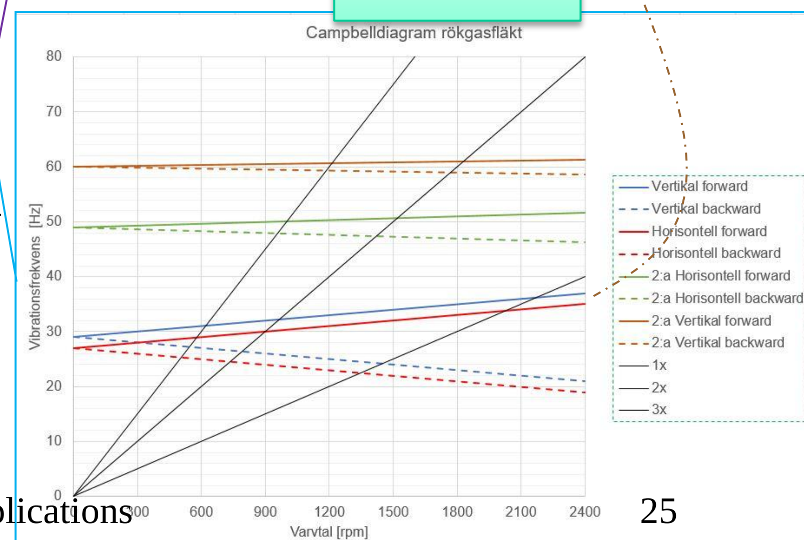
$f_{flow} = U/d$ [Hz]



Flutter



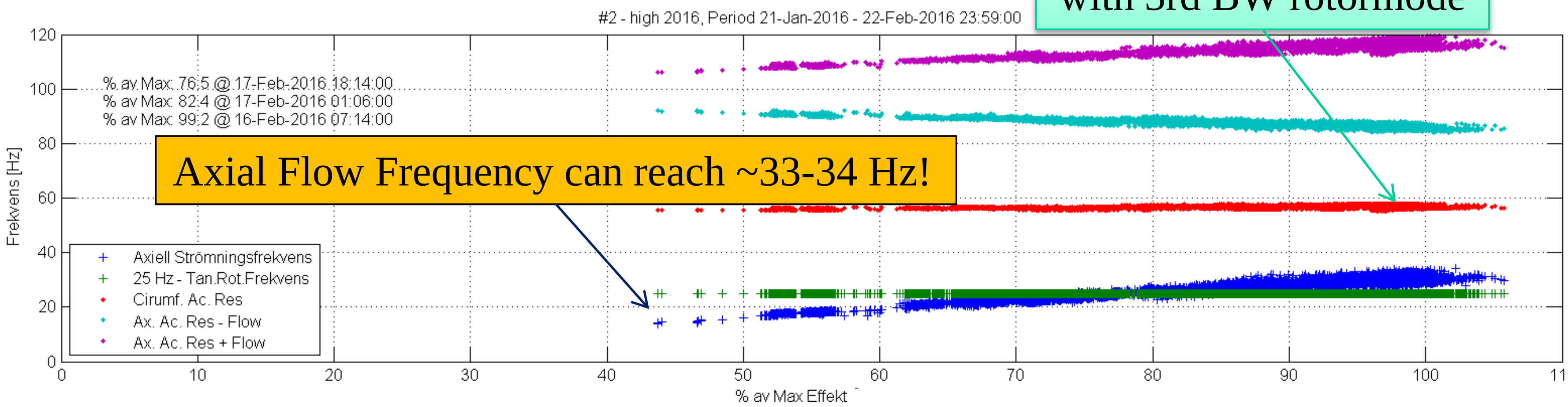
Modal interaction

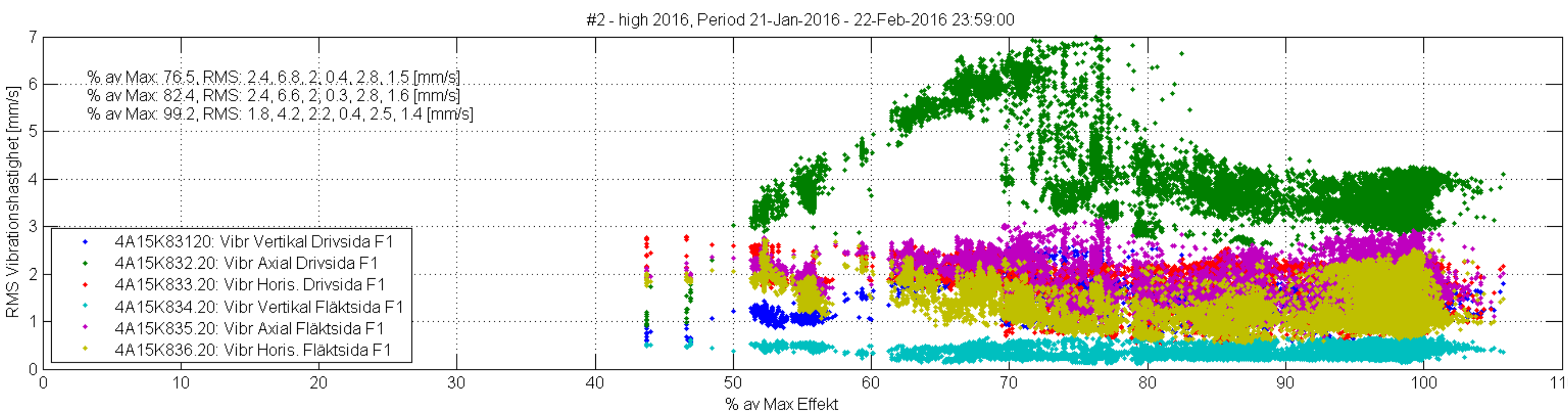


Process System Data Reinterpreted

Acoustics may interfere with 3rd BW rotormode

Axial Flow Frequency can reach ~33-34 Hz!

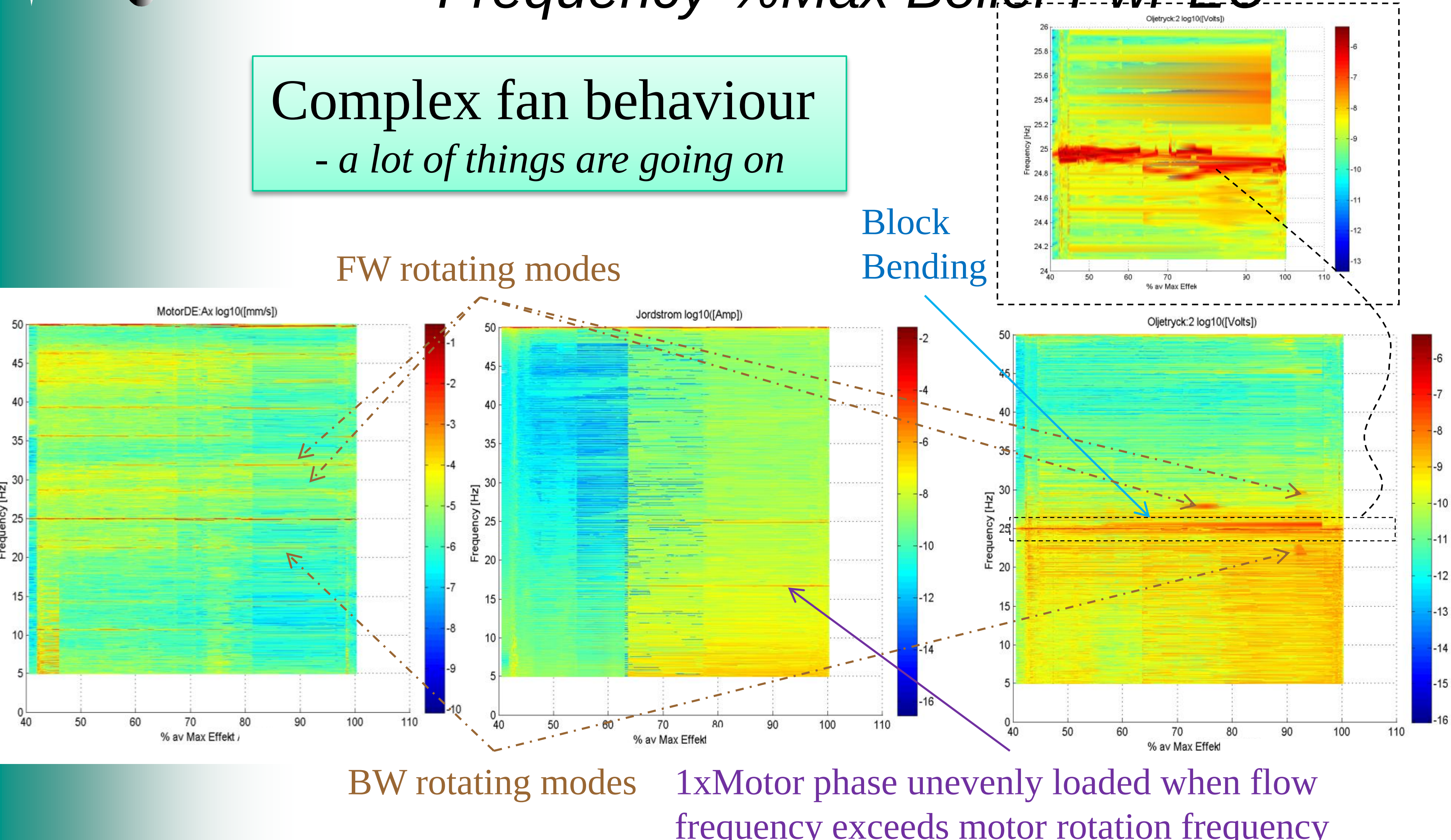




Bespoke Processing:
Frequency-%Max Boiler Pwr-EU

Complex fan behaviour

- a lot of things are going on



What it all Boiled down to

- Fan is costly to service
  - Therefore, is intended to be replaced by a more modern fan design in a few years time.
  - The fan was repaired with several new parts.
  - Faults from prior failure were corrected.
  - Motor was disassembled and a loose part found.
- The project work
  - Recaptured some old knowledge
  - Was used to guide and improve repair work.
  - Insights serve as a phenomenological map.
  - Provides operators with new avoidance recommendations that differ from one operating regime to the next.
    - What is a correct action in one regime is wrong in the next.

Example:

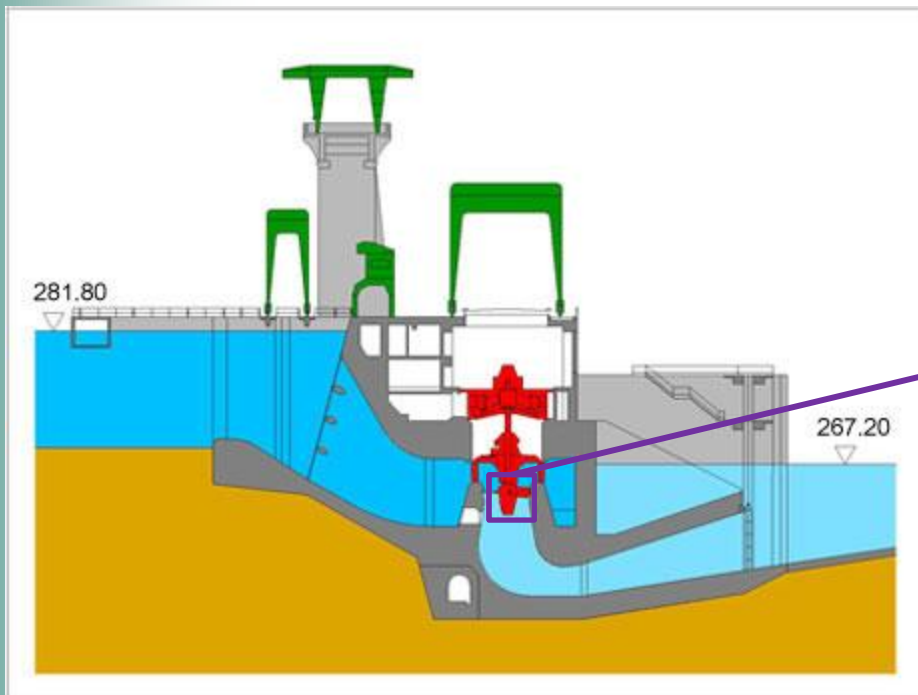
Hydropower Kaplan Turbine

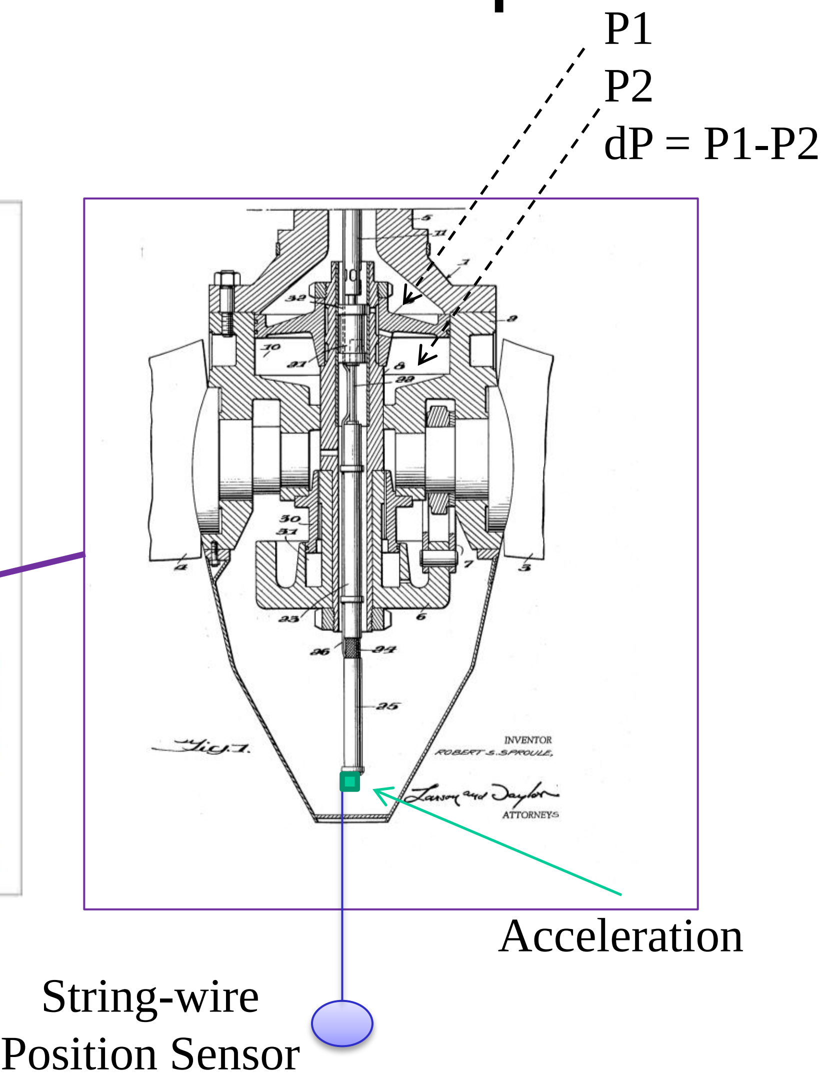
Importance of multi-sensors,
multiple dataviews
&
automated processing

Problem, Suspicion & Work

- Capacity
  - Hydraulic control consumed a large portion of the available pressure.
- Stick-slip
  - Suspected as control behaved erratic.
- Measurement
  - Acceleration
  - Position using string-wire gauge,
  - Pressure
  - Pulsation.
  - Orientation using inclinometer + Interial Measurement Unit *(3dof DC acc, 3 dof gyro + 3dof magnetometer)*

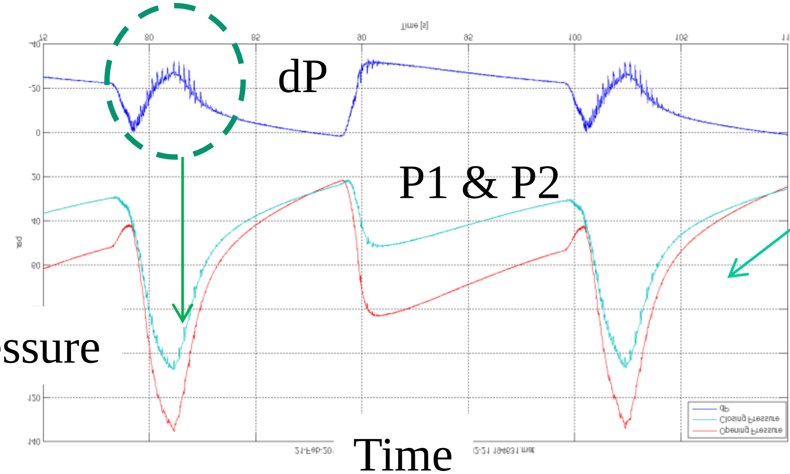
Measurement Setup

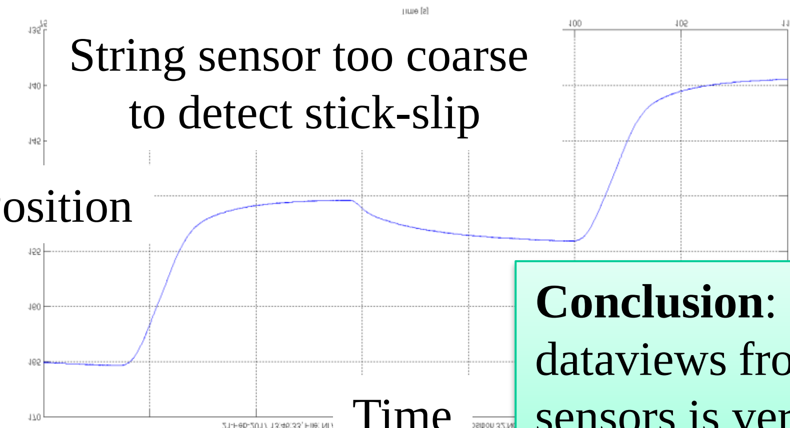


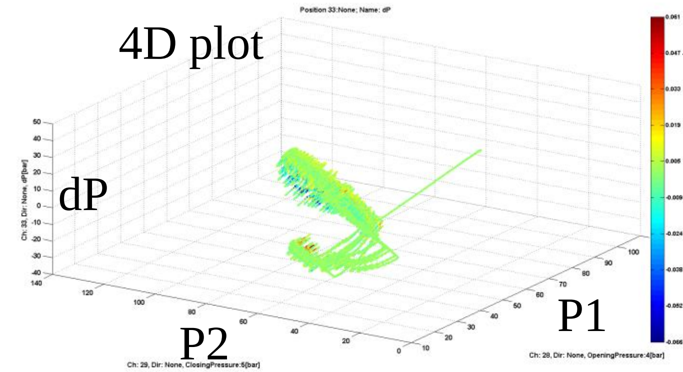


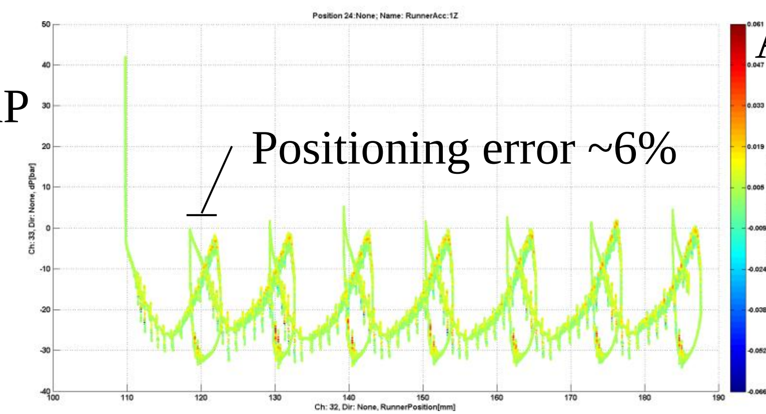
Data

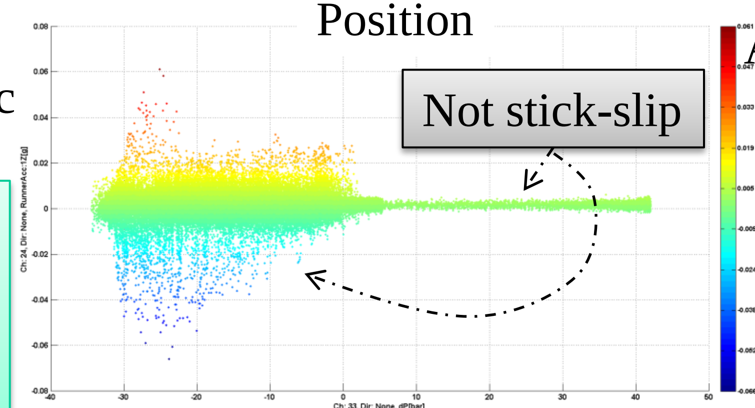
?











Conclusion: Multiple dataviews from varying sensors is very helpful in the analysis work.

What it boiled down to

- Stick-Slip
  - *Excluded* as it should be symmetric wrt to dP, predominant at low dP and as it does not explain the offset in both P1 & P2 regardless of direction.
- Explanation: Valve set points
  - Cause an offset in P1 & P2 and large hysteresis around zero dP.
    - One valve appears to stick.
    - Ajust valve set poínts.
- Consequence
  - A ~6% position error.
- Workaround
  - Adjust passive valve set points
  - Bypass arrangement until it works as intended.
- Data
  - Used for a variety of other, unintended, analyses, e.g. on mechnical tolerance, independent blade orientation measurement, etc.

Summary

- Use a **shotgun approach**
  - **Measurement is cheap** – as compared to having problems
    - Use as many channels/sensors as practical
    - Use signals from built in sensors.
  - **Accumulate** as much data as practical
    - Measure 24/7 as long as motivated.
    - Use control room data.
  - **Team** to use differences
    - Gain as many views as possible & avoid confirmation bias.
- **Programmatic** evaluation
  - Use computer for the tedious work.
  - Output many data views & use at convenience.
  - Put the real effort into the understanding of data
  - *Turn strange sensor behaviour into knowledge.*

"The unnatural, that too is natural."
Johann Wolfgang von Goethe