The crux in problem finding:

Method & example from root cause investigation(s)

Claes Fredö

An approach that completes, not competes with condition monitoring

Ignore details – focus on the **Philosophy & 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

Instrument whatever is relevant for the problem at hand.

"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

Strange measurement data may contain the key to solving the riddle.

Do not shy away from such data.

QRING Approach: *The Canary Bird*

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

Is it a correct measurement? – No

Is it useful information? – Yes

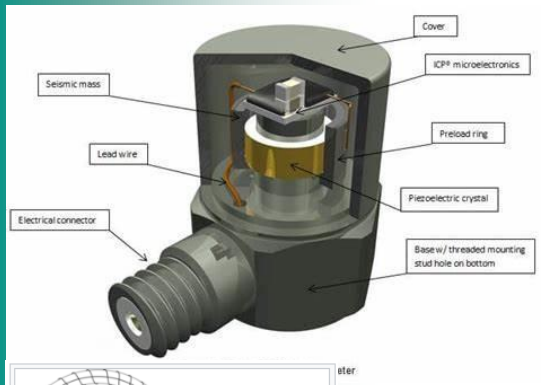
Should you discard the event? – No

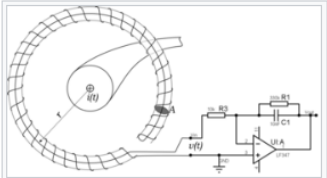
As Fermi shows us – it may very well hold the keys to new knowledge.

QRING Approach: *Avoid confirmation Bias*

- To capture the unknown
  – Use different kinds of sensors to improve observability.
  - Transducers of different type and manufactury, eg accelerometers, laser vibrometer, proximiter, etc.
- Collect & structure DATA
  - Log data 24/7 – measure it all – also to be able to exclude.
  - Automatic processing to handle large amounts of data
- Structured analysis process
  - Start with an overview (helicoptervy)
  - Do not dive into data without first formulating a theory, i.e a way of reasoning that can be falsified (proven wrong).
- Hug & squeeze *'errors'* for information
  - Ascertain that the transducer is in a working condition.
  - Next, ***explain why***, it may behave erroneously – such insights might solve the problem – ***cherish your Canary birds***

Approach: *MultiDisciplinary - Use Different Transducers*





A Rogowski coil is a toroid of wire used to measure an alternating current $I(t)$ through a cable encircled by the toroid. The picture shows a Rogowski coil encircling a current-carrying cable. The output of the coil, $v(t)$, is connected to a lossy integrator circuit to obtain a voltage $V_{out}(t)$ that is proportional to $I(t)$.

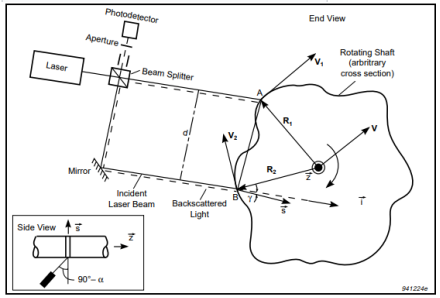


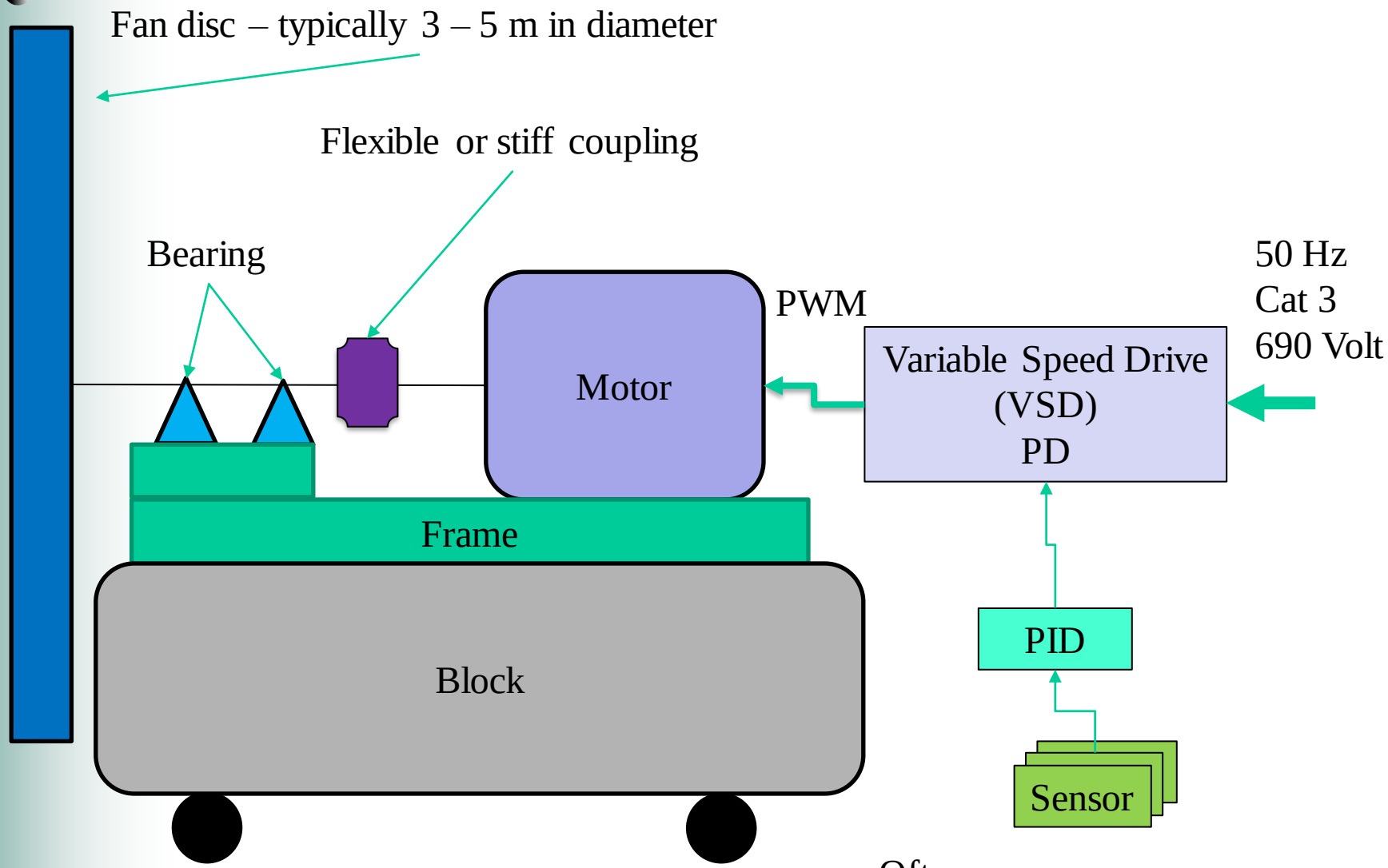
Fig.1 Optical geometry of the Torsional Vibration Meter Type 2523

- Accelerometer
  - Measures vibration from inertial load on piezoelektric cell in transducer.
  - Measures amplitude correct upp to ~1/3 of its internal mass-spring resonance frequency.
  - ICP accelerometers have built in electronics that can be *effected*.
  - Transducers differ in sensitivity to external *disturbance*.
- Electricity: Rogowskiscoil
  - Flexible core that encircles the wire and provides an output proportional to dI/dt, ie the electric current time derivative.
  - An integrator circuit provides a phase accurate AC current signal output.
  - Typical range is from a few Hz to a number of kHz. Versions that measure up to MHz are available.
- Torsionlaser
  - Two laser beams are reflected by special tape on the shaft to provide a signal proportional to the AC rotation velocity, ie the shaft rotation speed variation.

Approach: *Lots of data*

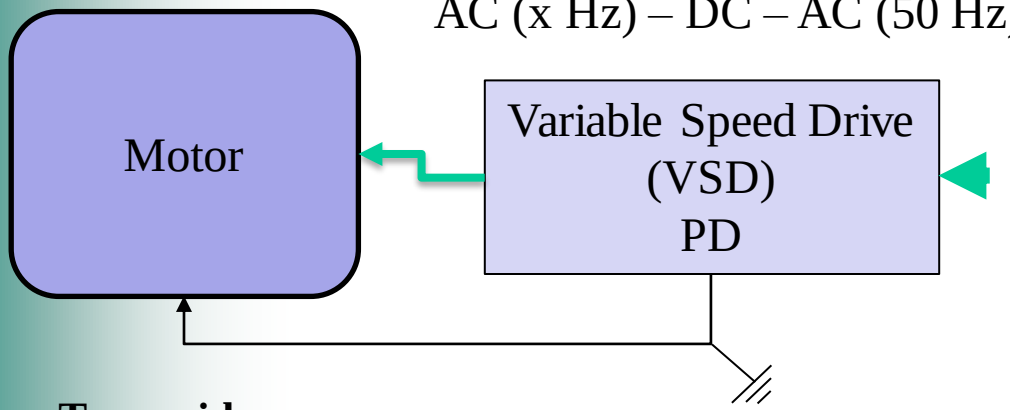
- Get the helicopter perspective you need.
- Find needles in haystack.
- Combine multiple views
- How?
  - Grab a big HDD – store all data
  - Use many channels
  - Grab whatever data you can – also from builtin transducers.
  - **Automate** the analysis: *Method* as analysis

Flue Gas Fan with Variable Speed Drive



Often one or more pressure transducers.

Pulse Width Modulation (PWM)



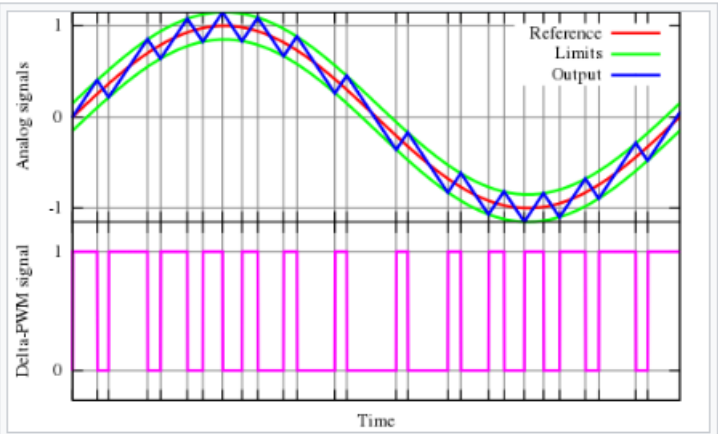


Fig. 3 : Principle of the delta PWM. The output signal (blue) is compared with the limits (green). These limits correspond to the reference signal (red), offset by a given value. Every time the output signal (blue) reaches one of the limits, the PWM signal changes state.

To consider

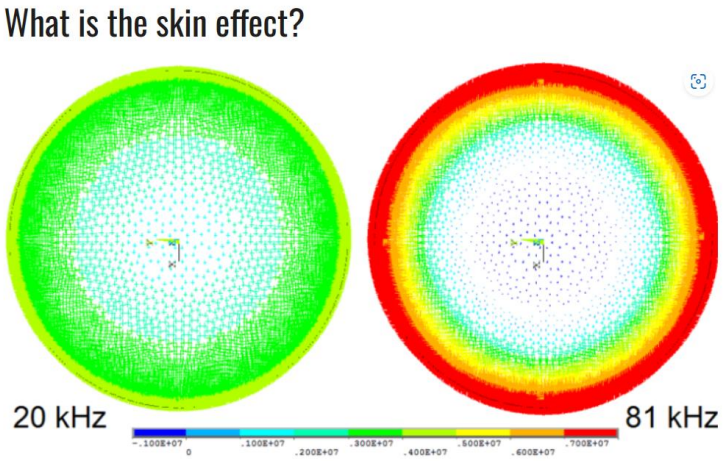
- Electromagnetic resonance
  - The electromagntic wavespeed in 3E8 m/s in vacuum, in a cable ~80%-50%. The rectangular pulse rise time excite up to ~5 MHz.
  - First cable resonance i.e cable is a quarter wave length => L = 1.5E8/5E6/4 = ~10 m
  - Long cables may increase the motor/cable peak voltage ~5x if pulses are not filtered.
- Electric potential
  - Skin effect
  - EDM (Electro Discharge Machining)
- VSD software
  - Motor model
  - S-ramp or Linear (Z-) ramp?

Electricity + Vibration:
a topic
with potential

Electric potential

A thick conductor concentrates
the current density to its surface
which increases its effective resistance.

Therefore, we use for grounding,
cable, harness (drain wire) & a thin screen.

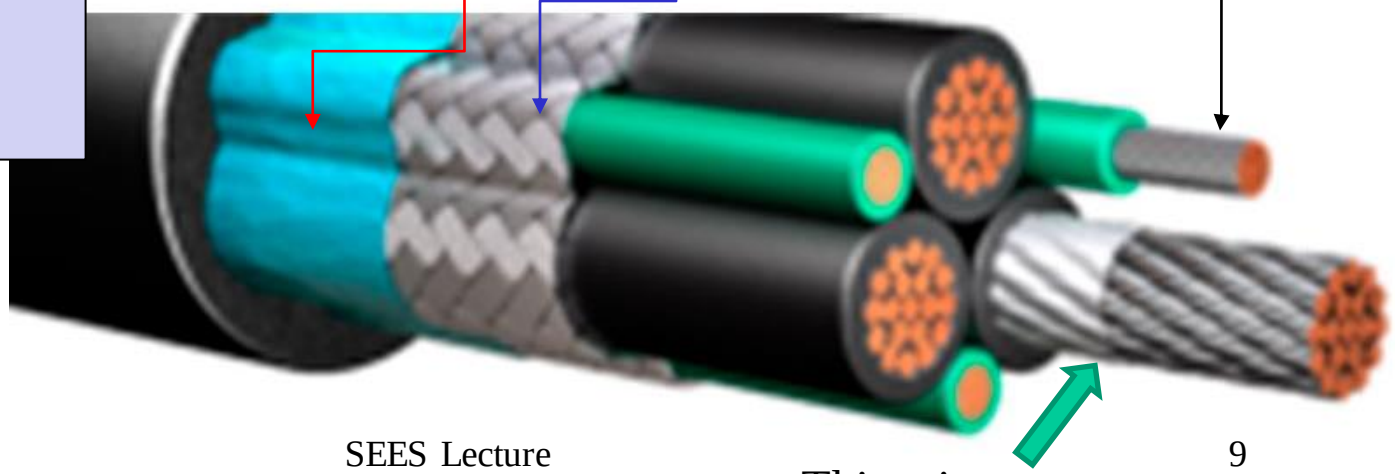


Grounding & EMF shielding

- 50 Hz cable
- Mid freguency harness
- High Frequency screen

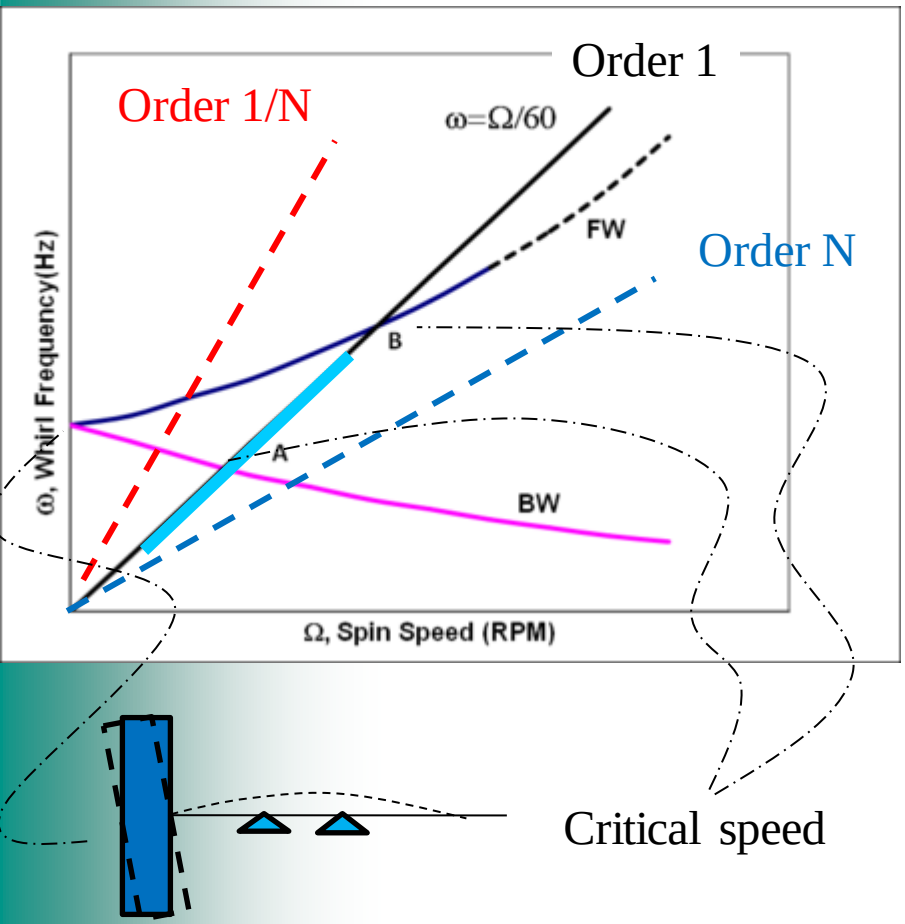
Use of VSD demands

- Motors with improved electric isolation.
- VSD Cable.



Rotordynamics

FW-/BW- rotating modes



Forward propagating (FW) modes form as waves travel with the rotation direction and hence, increase in frequency with the RPM.

Backward propagating (BW) modes fall in frequency with increasing RPM.

The Operable Speed Range (SR)

1) BW modes – tend to fall into the SR.
2) Order 1/N – uneven operation may interact with or instigate critical speeds.
3) Fan operation involves high flow speeds, which cause wide band excitation, ie such excitation may drive whatever resonance there is in the system.

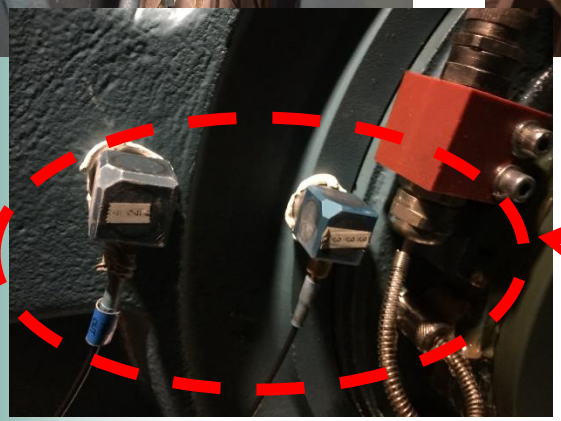
Example: VSD controlled flue gas fan

Large generators and wind mills may experience similar physical phenomena.

Accelerometers

Acc Motor NDE

Acc Motor DE



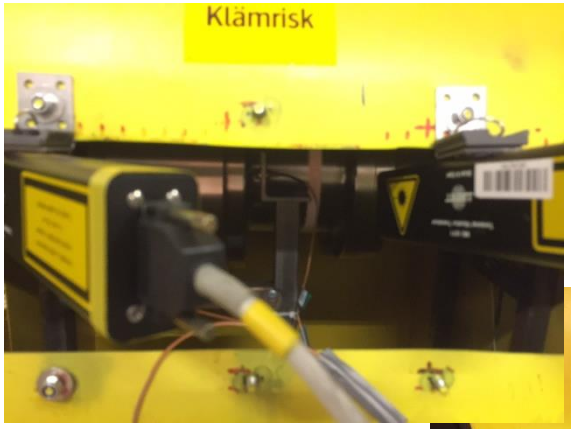
Discussed

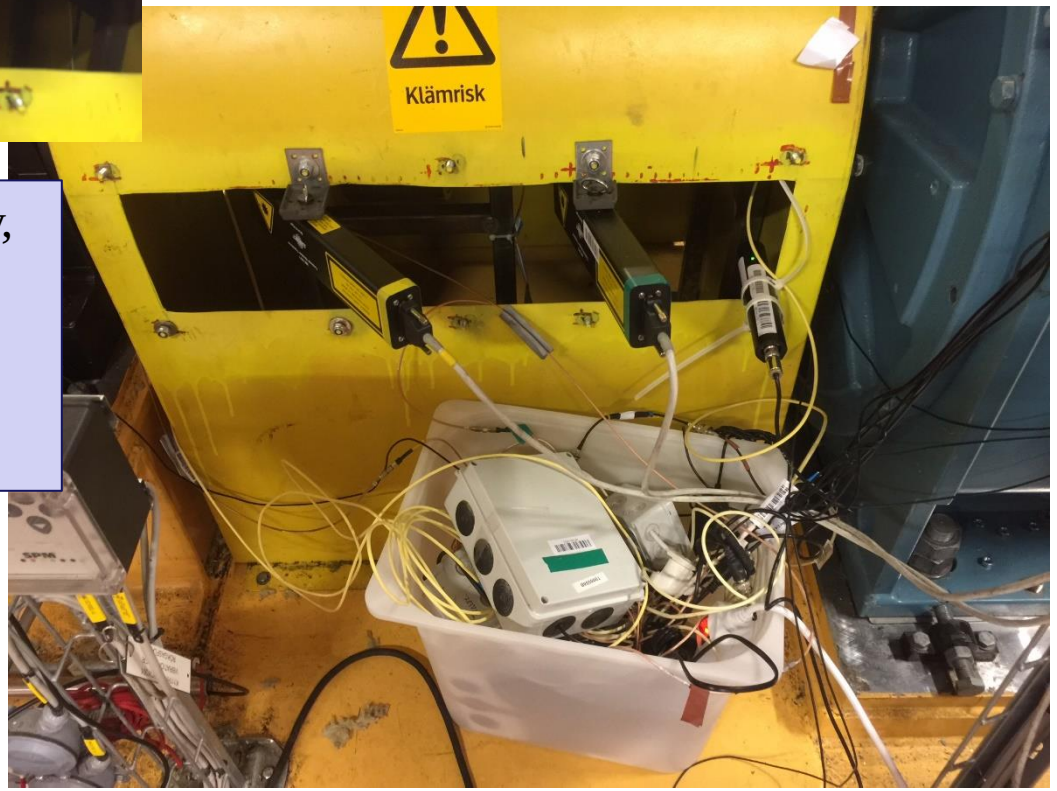
Acc Bearing Fan DE

Acc Floor

We instrument also to allow things to be ruled out

Torsionslasers, Tacho & Proximiter Sensors inside the Cover





A torsionslaser measures rotation velocity, ie the RPM AC komponent.

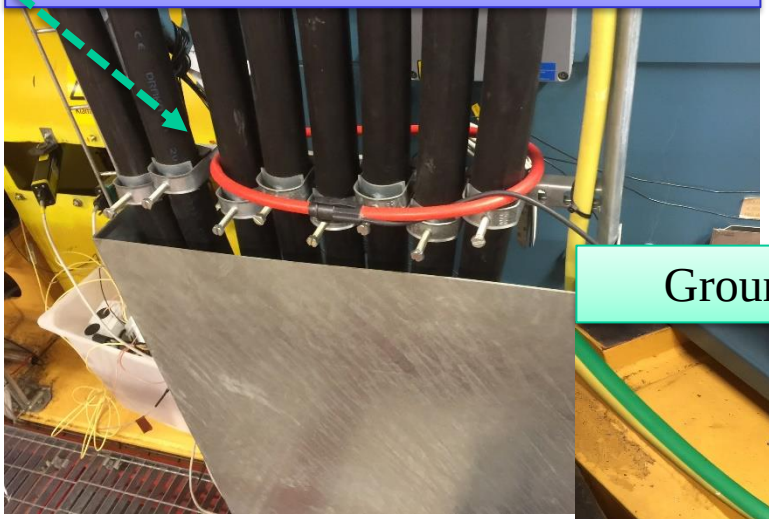
Proximeters measure the relative support-shaft distance.

Current

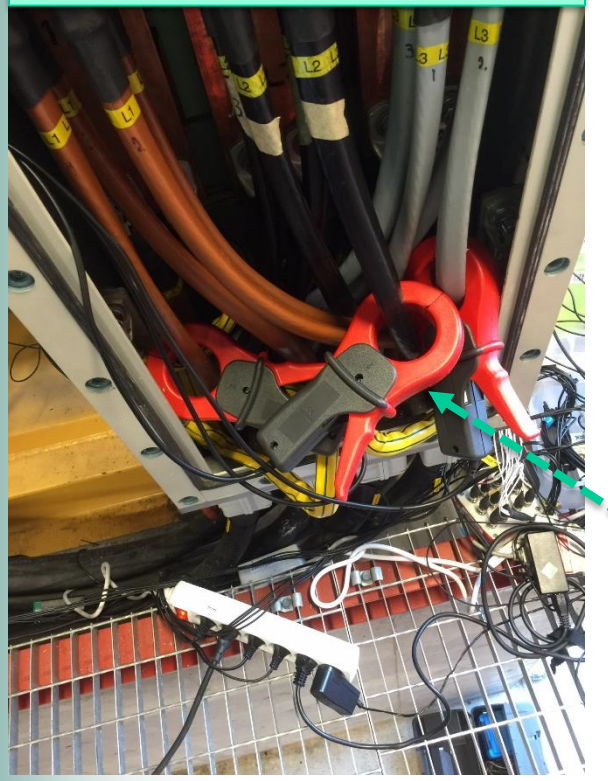
Electricians tend to doubt its use.

Rogowskicoil

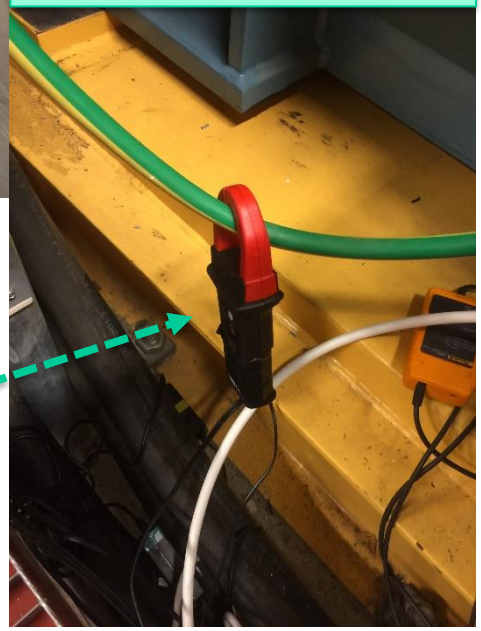
Summed current@Motor
(L1+L2+L3+N+Gnd)



L1-L3 Motor current

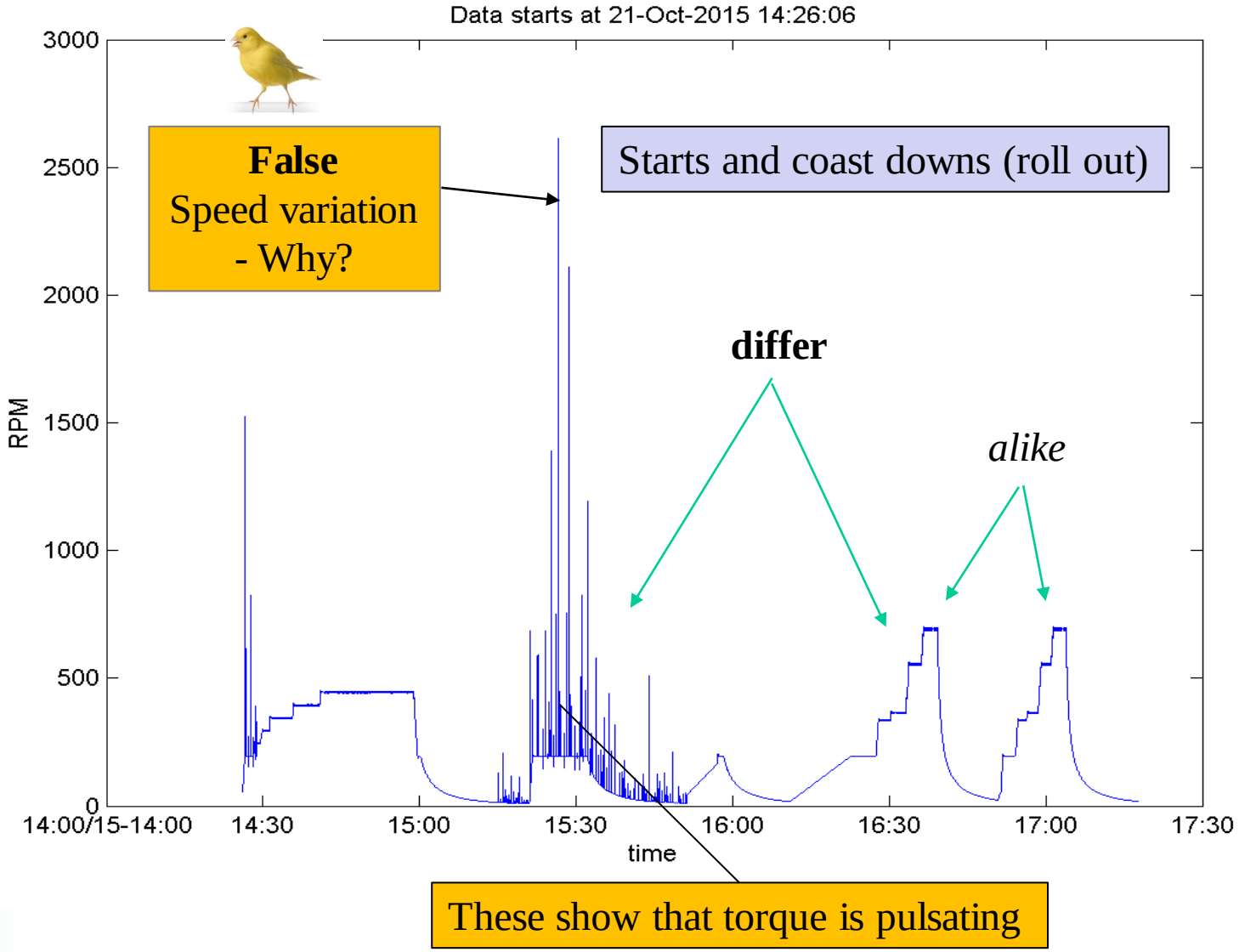


Ground current



Current clamp
(transformer)

Cold Operation

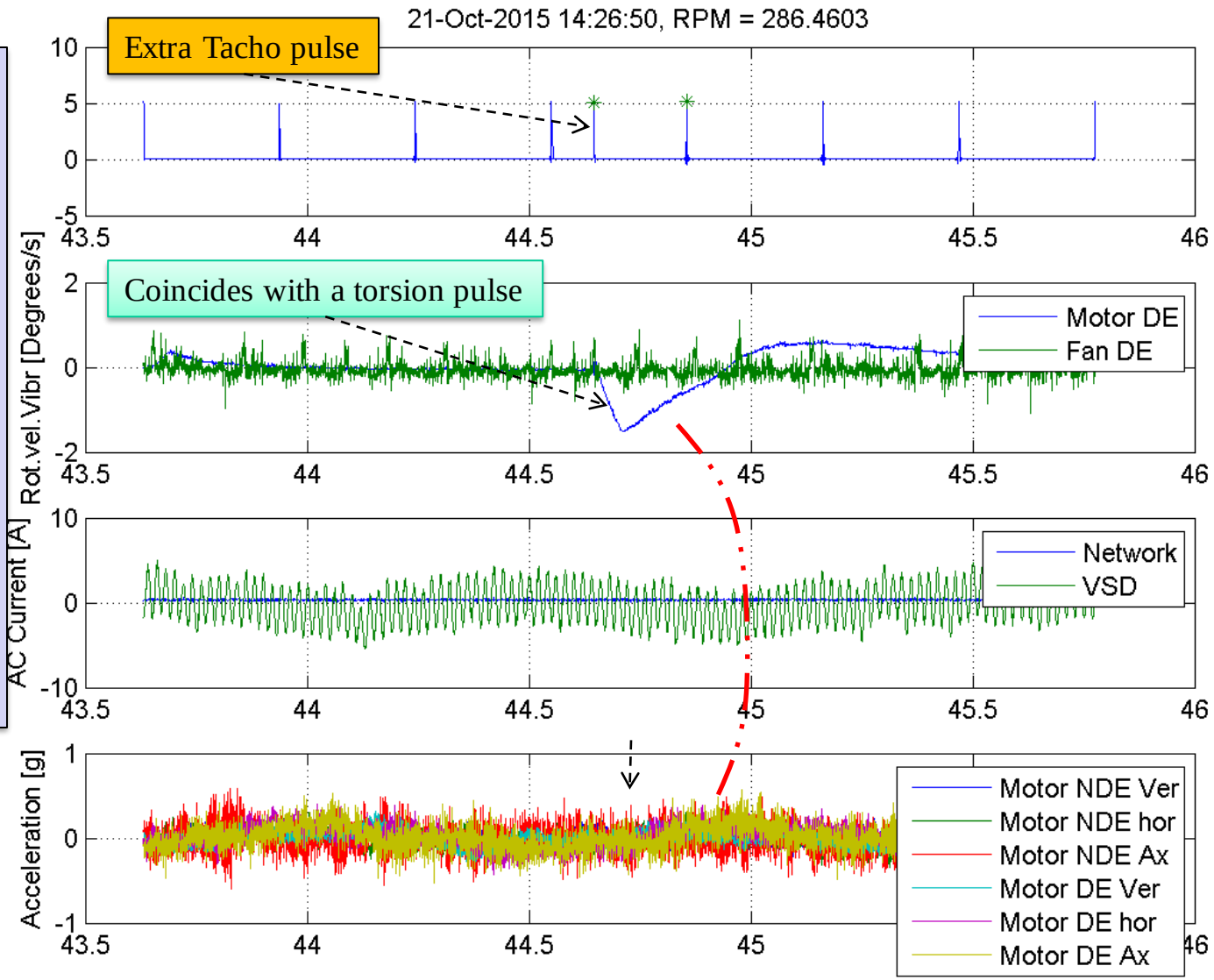


Cold Operation:

Speed Transients?

- *A torque pulse tensions the flexible coupling, which snaps back.*
- *The optic tacho on the motor shaft can then see the reflex tape multiple times per revolution.*
- *As the machine alignment is good, we do not see much linear vibration, ie not much acceleration.*

The VSD Z-ramp creates the pulse in the case shown - software

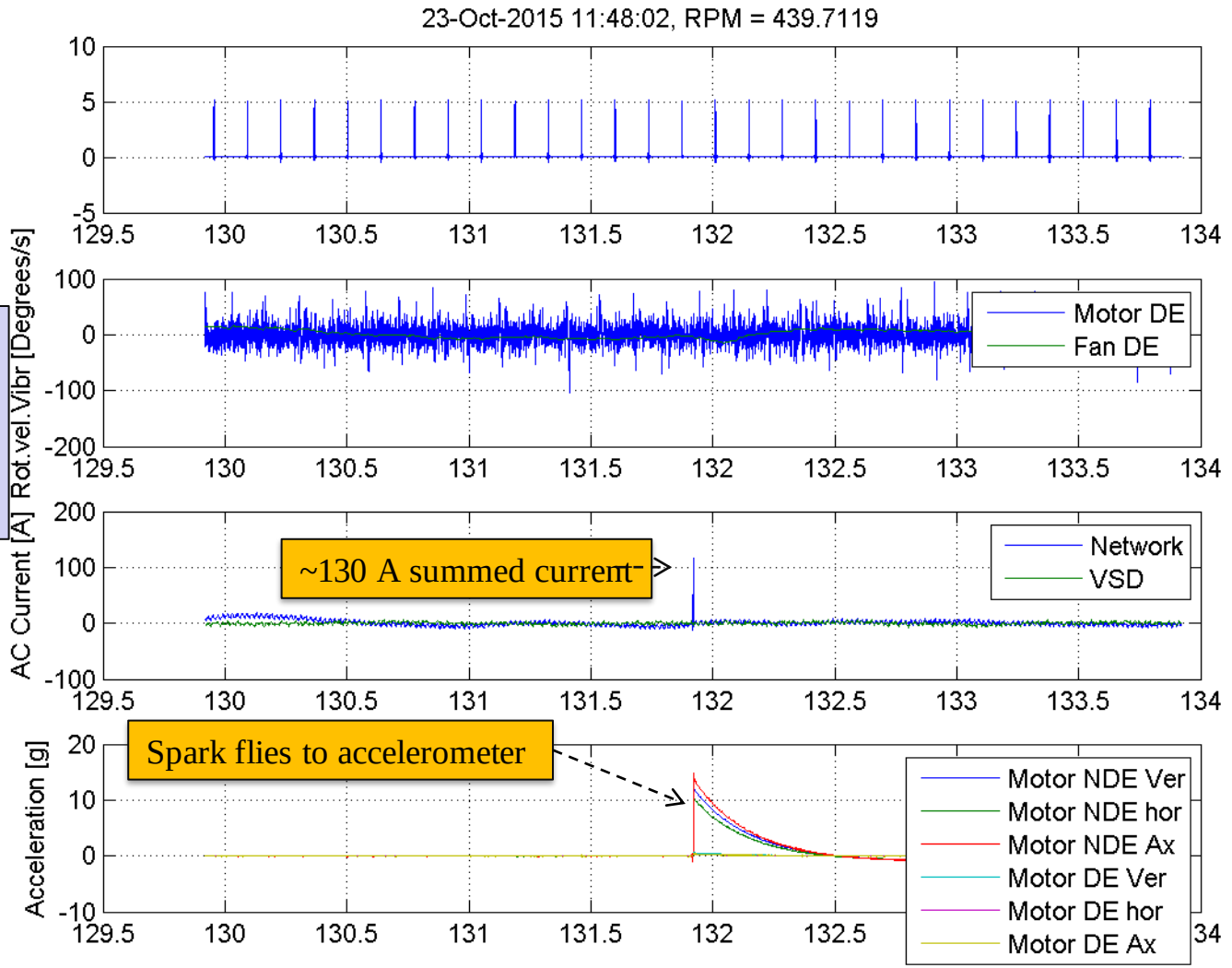


Cold Operation

Current can cause vibration

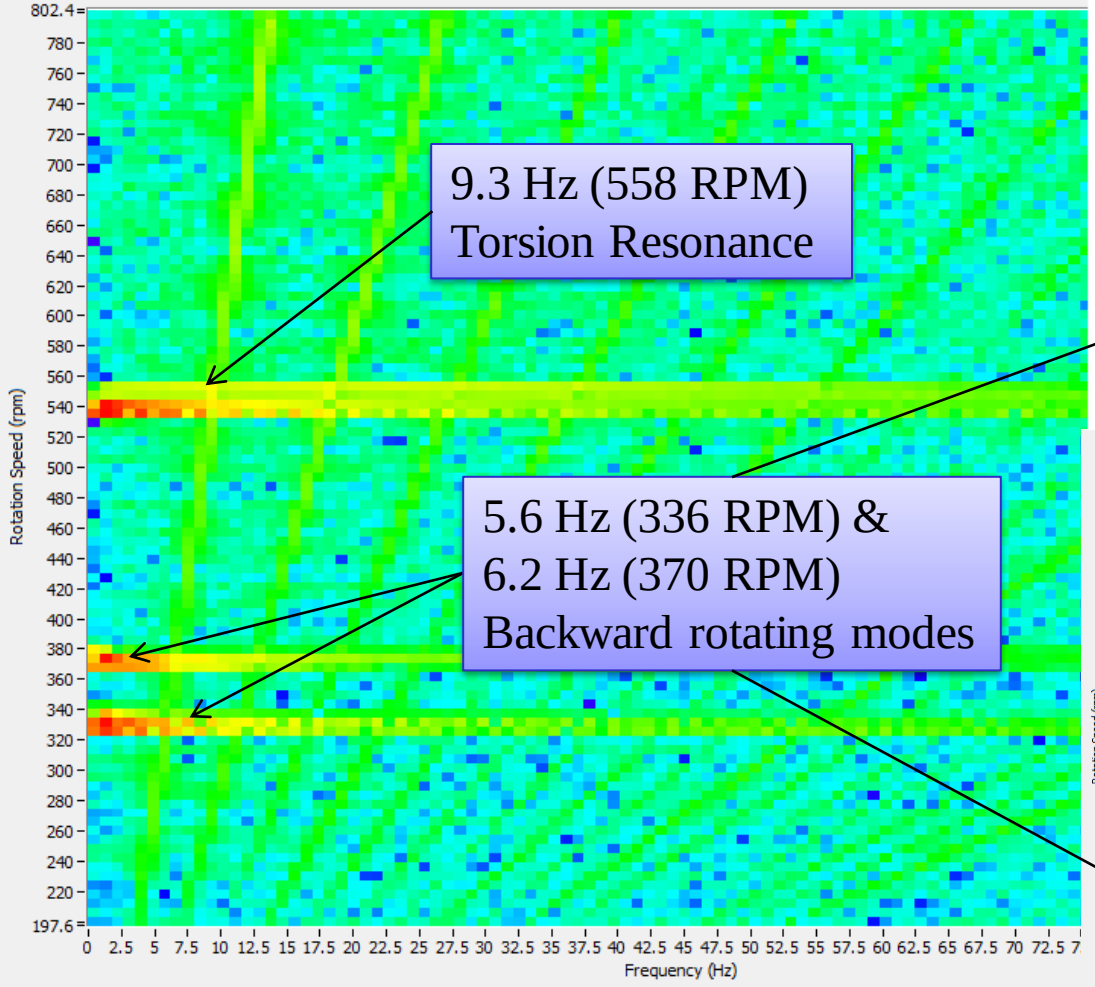
Does vibration/discharge cause current?

Is there a fundamental reason for the problems we see?



Rotordynamics & Cold Operation

Torsionlaser on fan shaft



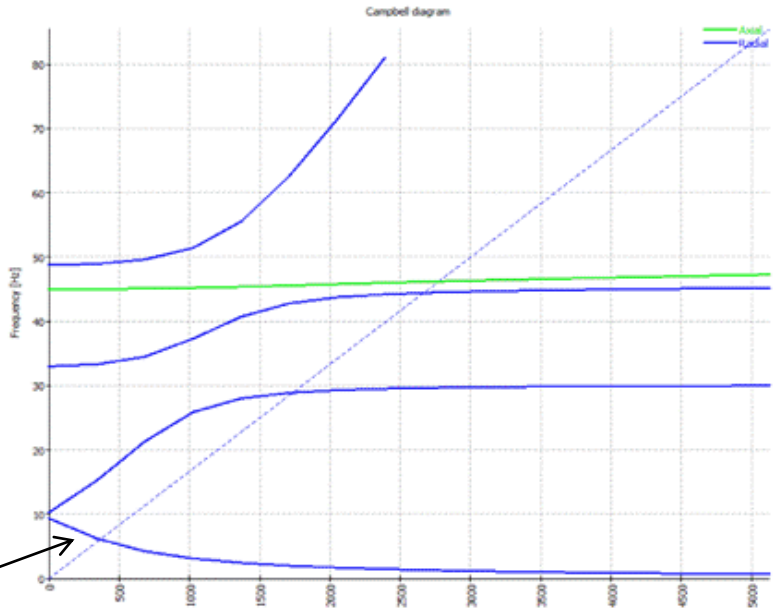
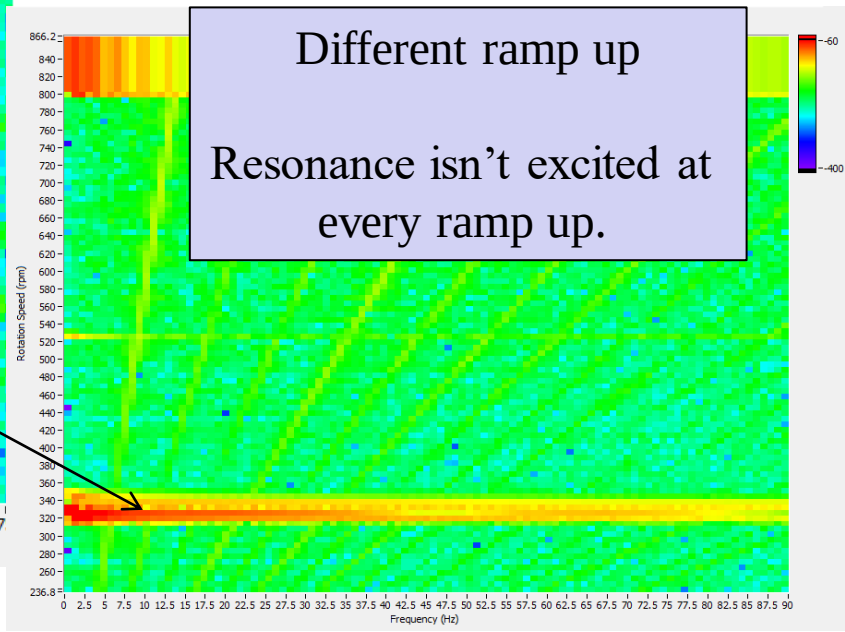


Figure 2: The Campbell diagram from MESYS

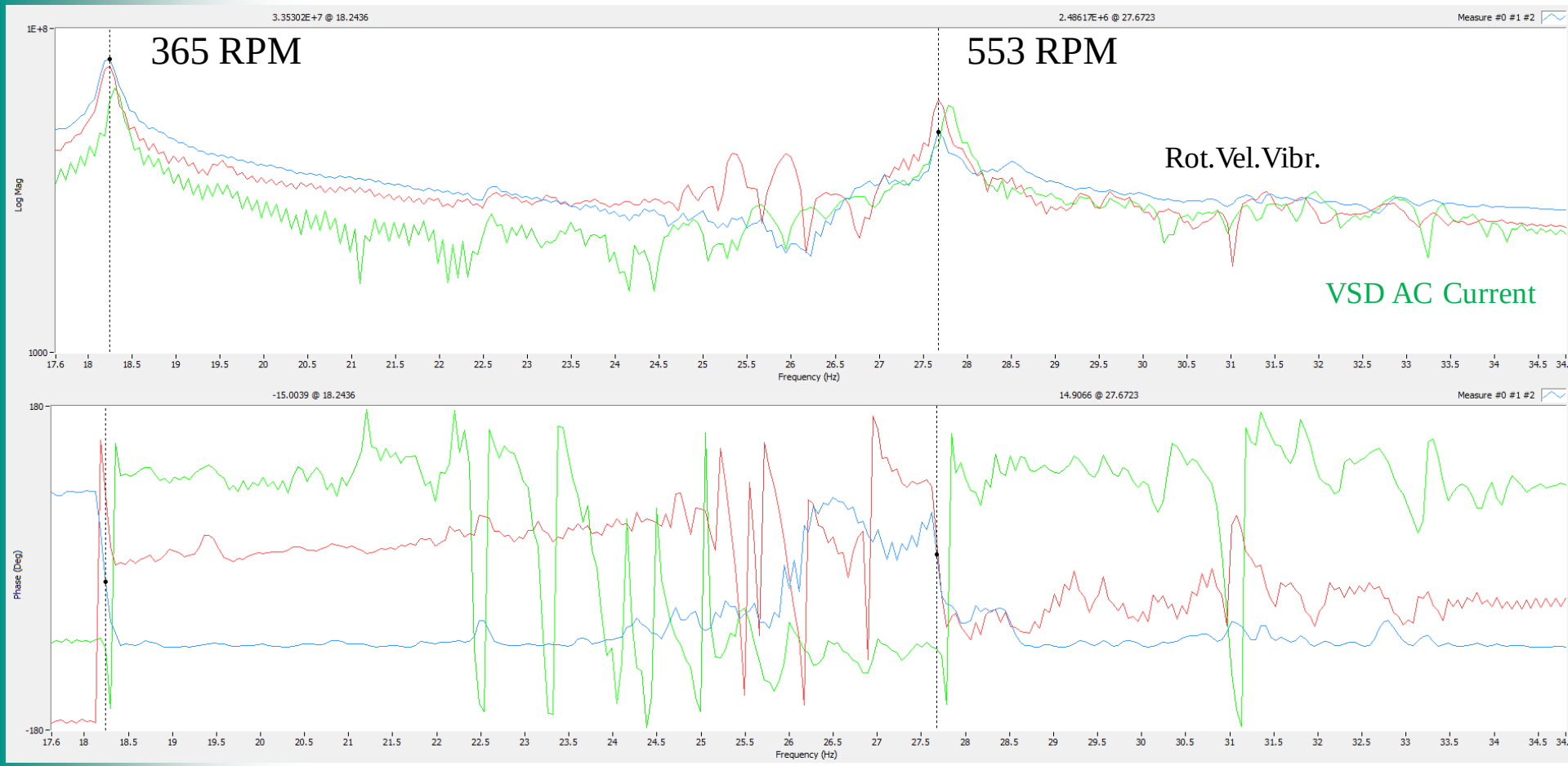


QRING Order FRF

Current phase shifts 180 degrees for each resonance that modulates the motorn speed, ie vibration modes turn the motor into a generator.

The Order FRF uses the motor shaft reflex tape as keyphasor.

=> The motormodel acts *N/2*-rotation too late when *N* modes are excited.



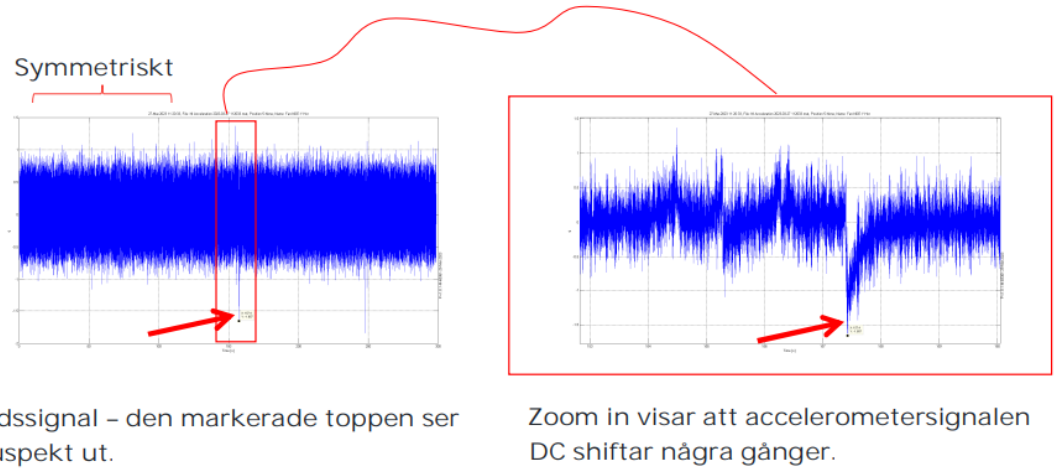
Aero Acoustics

Sound power scales with flow velocity, U m/s, as

- Flow across sharp edges $\sim U^6$
- Turbulence $\sim U^8$

Systems with high power and high flow can excite vibration up to very (100+ kHz) high freqency. Such excitation may excite sensor internal resonance(s) and saturate the built in electronics, which behaves poorly. The sensor may clip well below its amplitude range.

Example for a 50g accelerometer

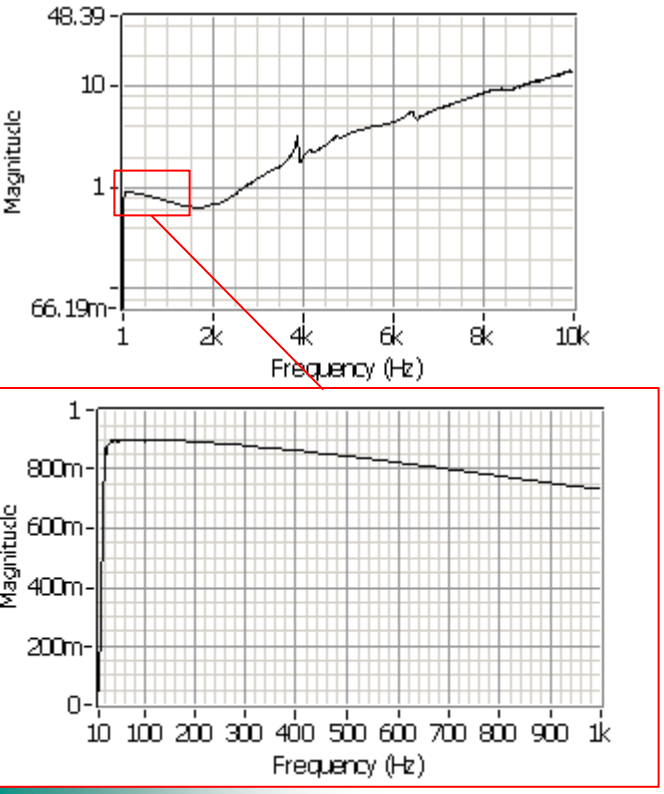


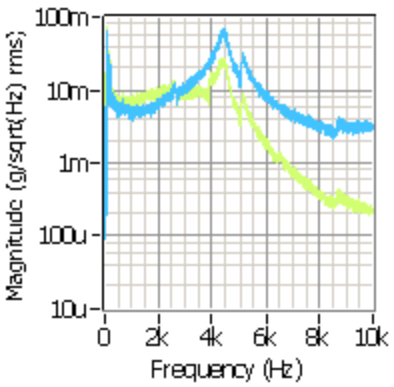
Tidssignal – den markerade toppen ser suspekt ut.

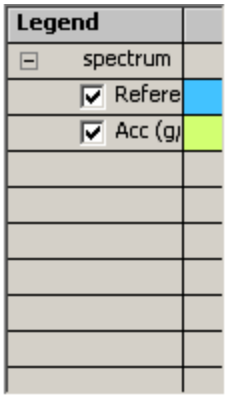
Zoom in visar att accelerometersignalen DC shiftar några gånger.

Sensor internal resonance & built in amplifier saturation

Mechanical filter







Exciter with calibrated reference accelerometer.

Example with typical ICP industrial accelerometer.

Industrial 4-20 mA accelerometrers typically operate up to ~1000 Hz and have sensor internal resonance at 25+ kHz.

This kind of sensor is amenable to mechanical filters.

Countermeasure

Mechanical filter (with pin for torqueing inserted)

DIY Furniture pad

Lots of data: *1-month*

Events

Histo-gram

PSD

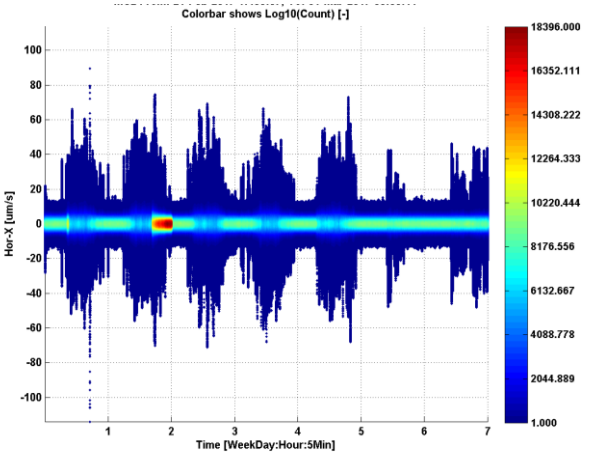
Event

Standard approach

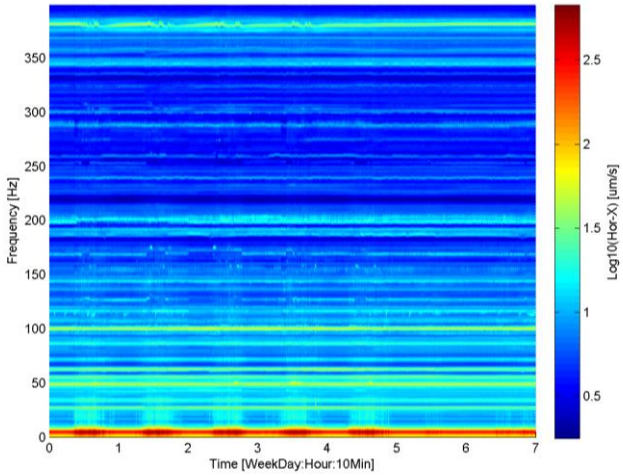
Reshuffle same data

Weektime 0 to 7 on X-axis

Histogram



Spectrogram



Lots of Data: *Realtime*

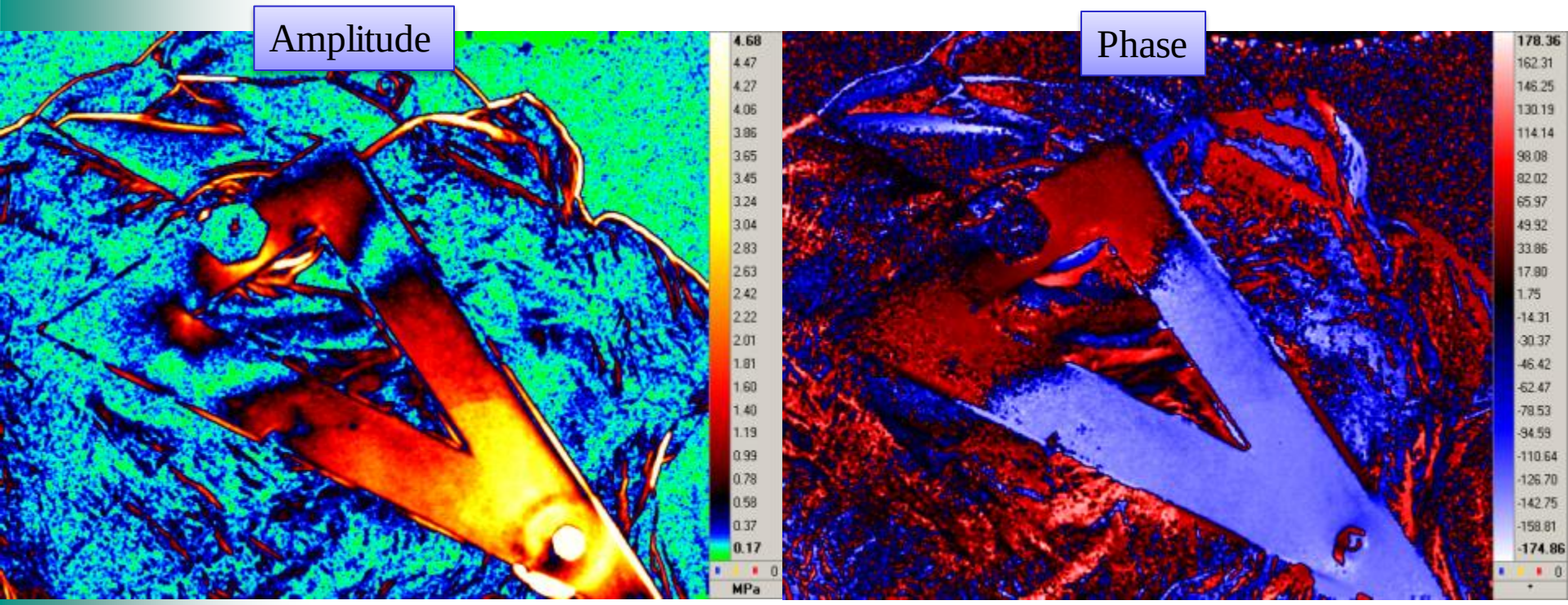
Time ODS: 128 ch

Troll Alpha
(gas platform)

Capacity test for new 2x40 MW Export Gas Compressor cooling water system
(blue line)

Lots of Data: *Full field*

Full field stress measurement using IR camera (TESA)



Other methods: DIC and Motion Amplification

However – *To see the light* – you do need full control of light with such approaches.

Conclusions

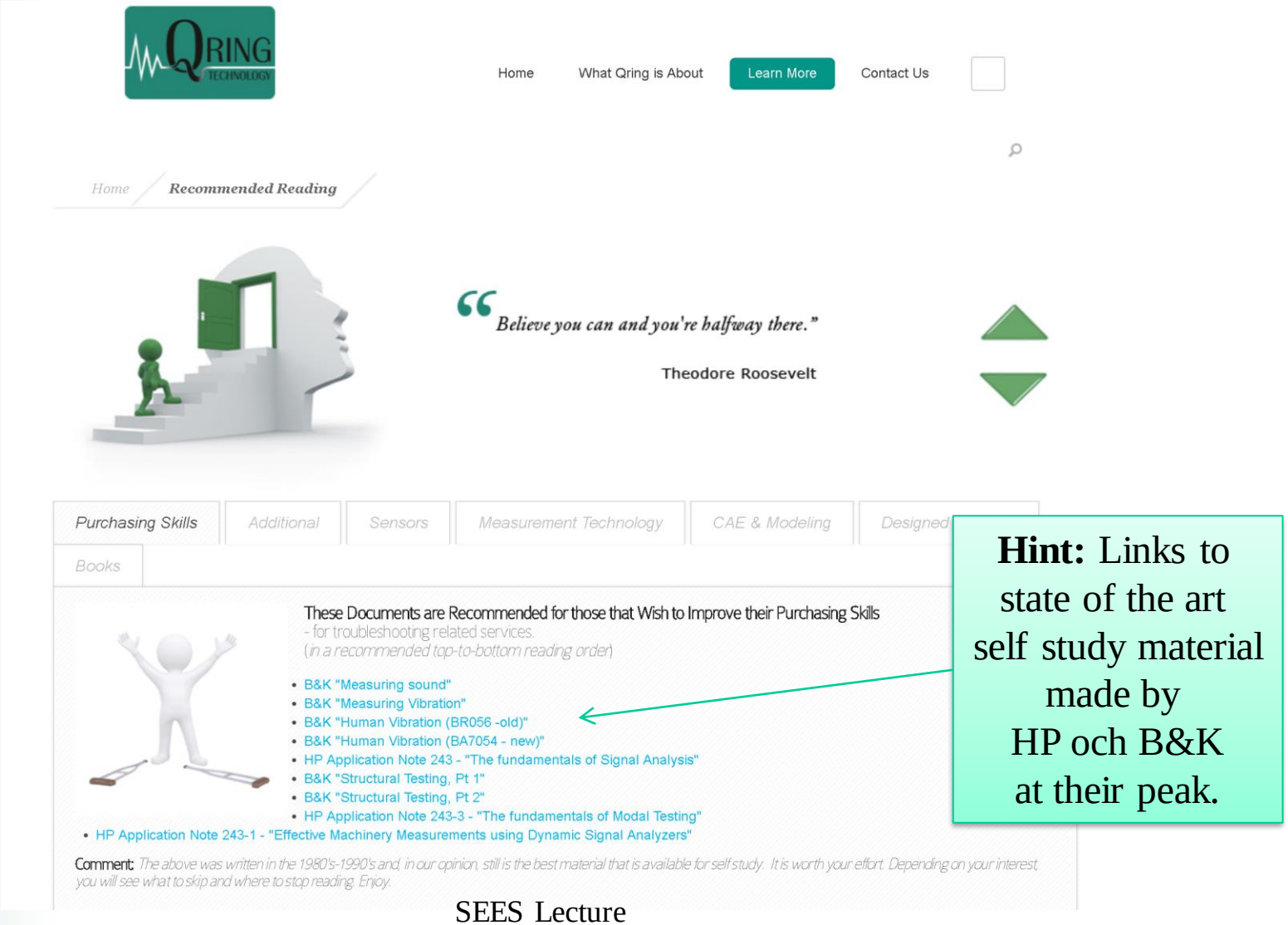
- Use a shotgun approach, i.e. high observability
  - Problems are costly as compared with measurement, i.e. **don't try to save on cost in the investigation**.
  - Use as many channels/transducers as practically reasonable.
  - Use existing signals from built in transducers, e.g pressure, etc.
  - Collect as much data as practical and for as long as practical to locate the needles in the haystack and/or be able to find trends.
  - Use control room data, figure out the machine's history & listen to every piece of information.

- Automatic evaluation
  - Evaluate, sort and filter information.
  - *Turn odd transducer behaviour to your advantage.*

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

Learn More: *Recommended Reading*

http://qringtech.com/learnmore/recommended-reading/



Hint: Links to state of the art self study material made by HP och B&K at their peak.