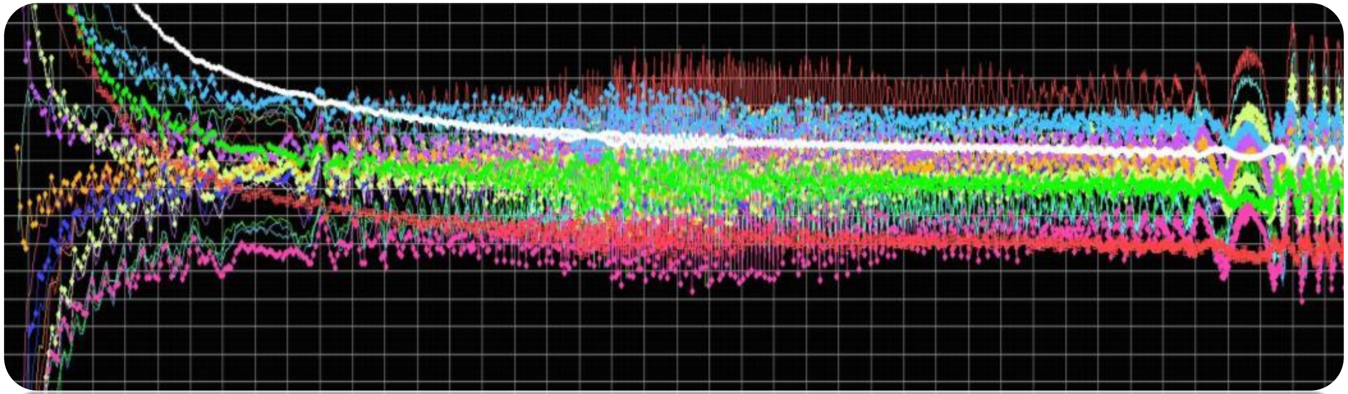
Vibration and clearance measurements using magnetoresistive sensors



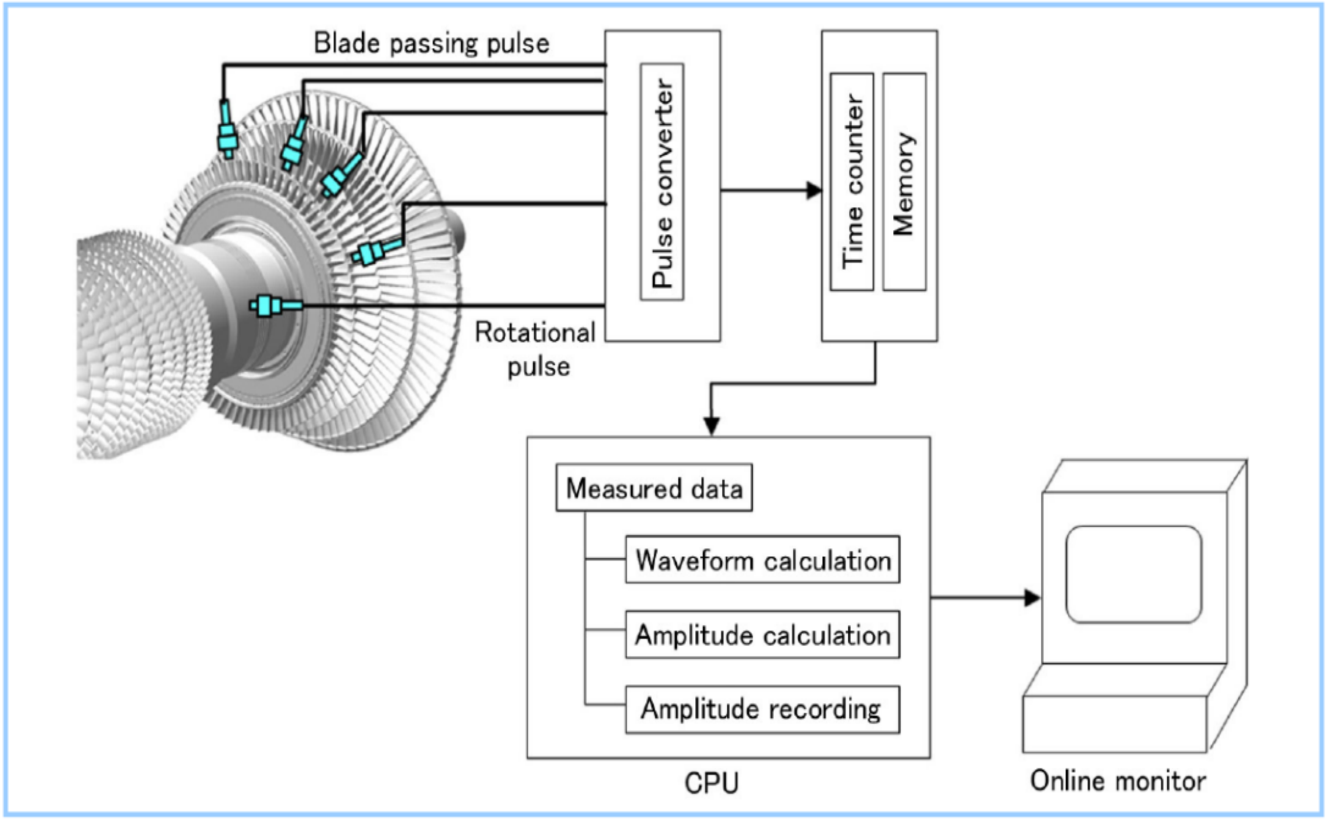
CISAS, 24 October 2016

PhD Candidate: **Roberto Tomassini**

Supervisor: Gianluca Rossi

von Karman Institute - University of Perugia - CISAS, Padova

BTT & BTC MEASUREMENT SYSTEMS



Contactless Measurement System of:

- The **gap** beetween the blade tip and the casing
- **Blade vibrations**

Sensors: Optical, Capacitive, Eddy current, Microwave, ...

OBJECTIVE

Objective of the PhD Project:

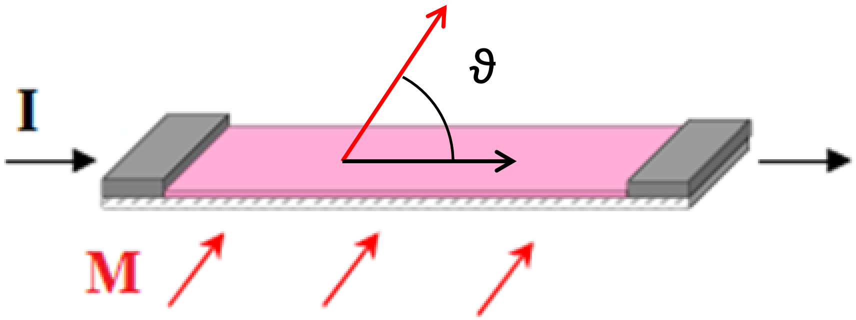
BTT & BTC measurement system based on magnetoresistive sensors

Starting from:

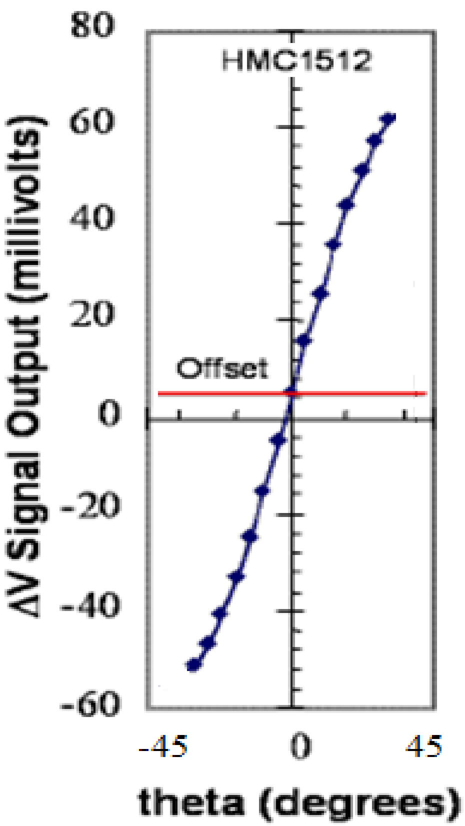
- **Marie Curie of Prof.G.Rossi**
- **VKI – Research Master of R.Tomassini**
- **(no strain gauge telemetry system, no commercial BTT & BTC system)**

INNOVATION: APPLICATION OF THE MAGNETORESISTIVE SENSOR IN TURBOMACHINERY TESTING

The sensing element: Permalloy thin film



Magnetoresistivity is the ability of a material (e.g. Permalloy) to change resistance under the influence of magnetic fields



$\Delta V = f(\vartheta)$

ΔV : Signal Output

M: Magnetic field

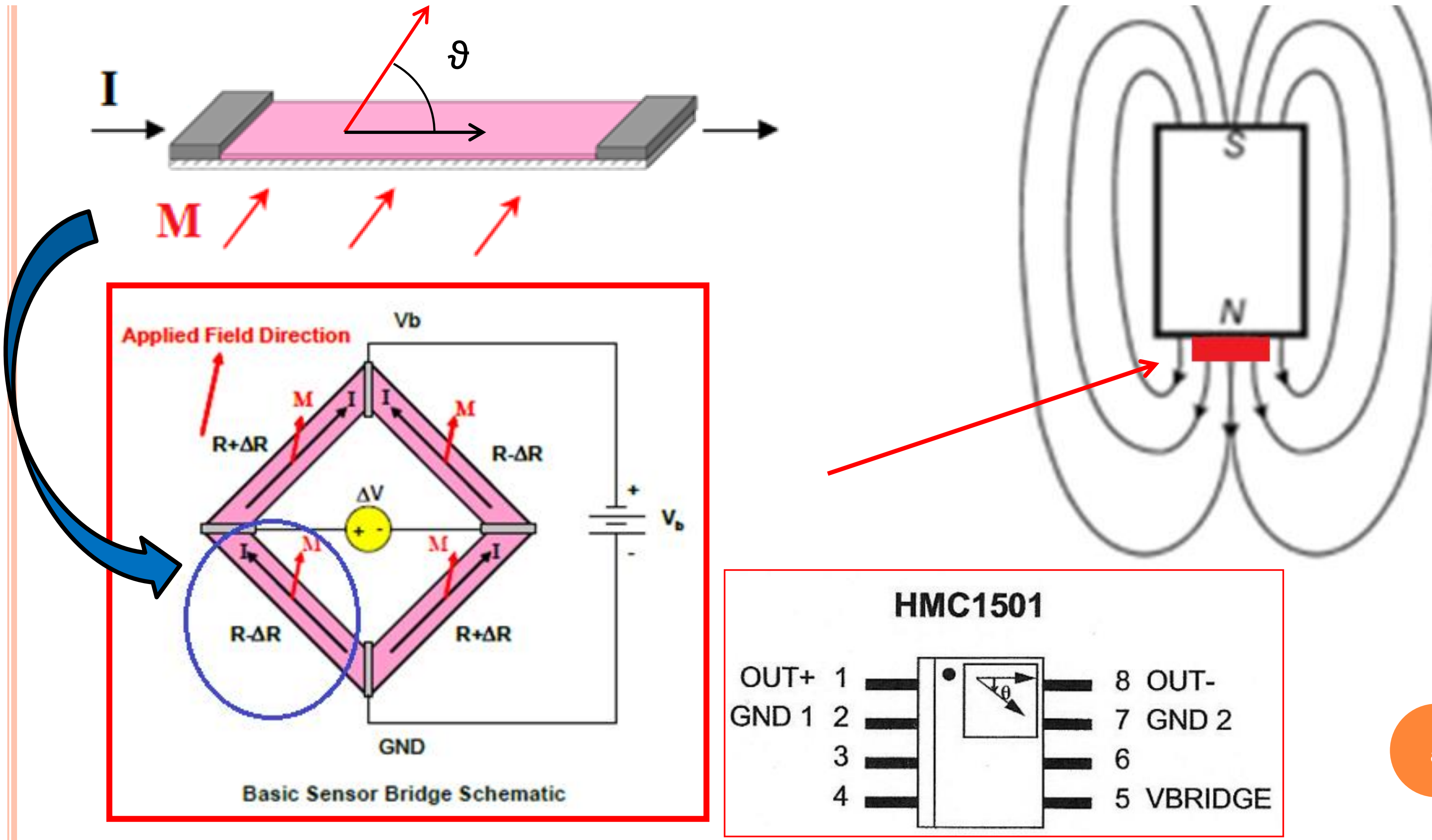
I: Current

ϑ: Angle between M and I vectors

$\boxed{\Delta\vartheta \rightarrow \text{Change resistance} \rightarrow \Delta V}$

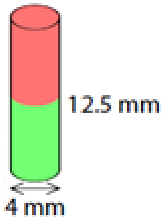
How to realize a sensor?

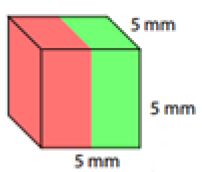
System sensitive to the variation of the magnetic field:



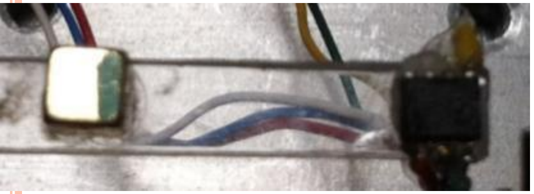
The magnetoresistive sensor

Cylindrical magnet



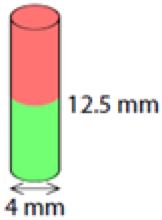


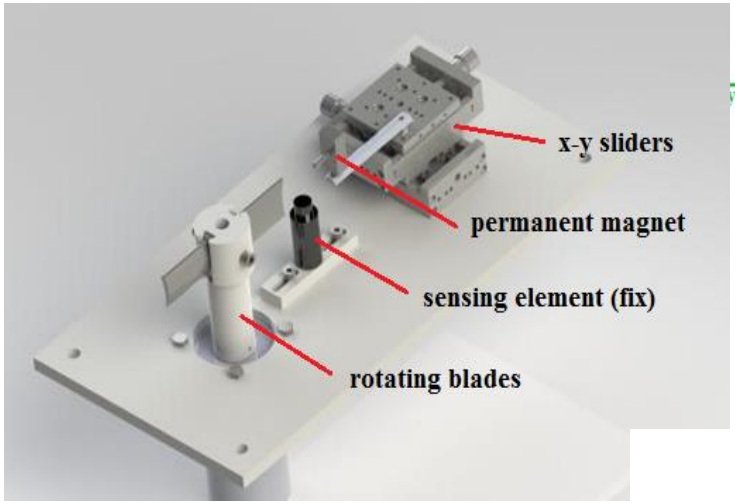
Cubic magnet

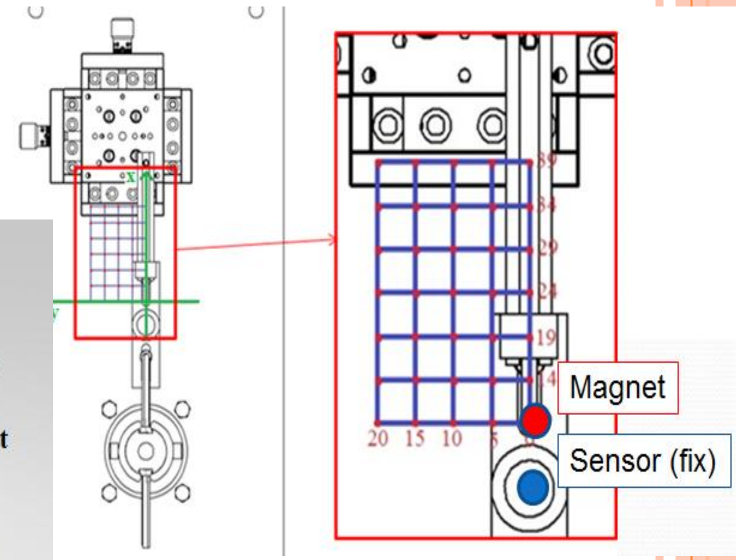


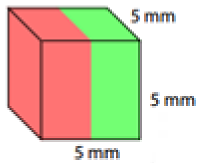
The magnetoresistive sensor

Cylindrical magnet

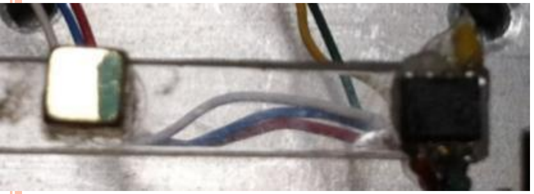




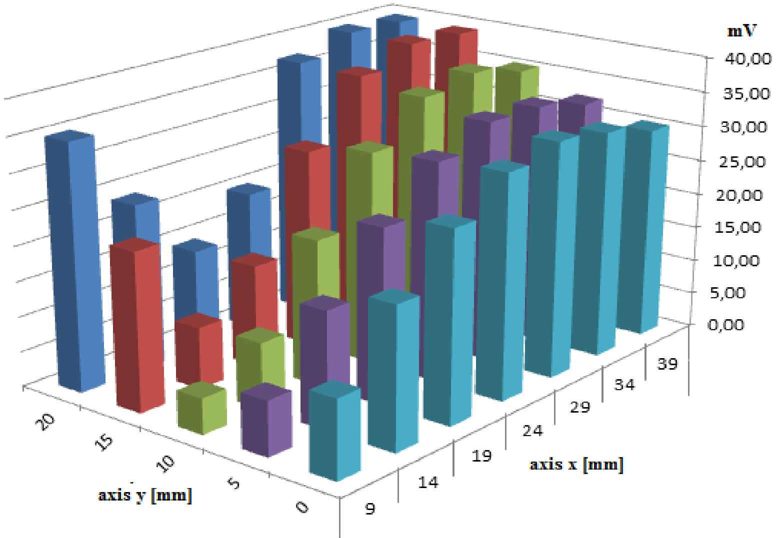




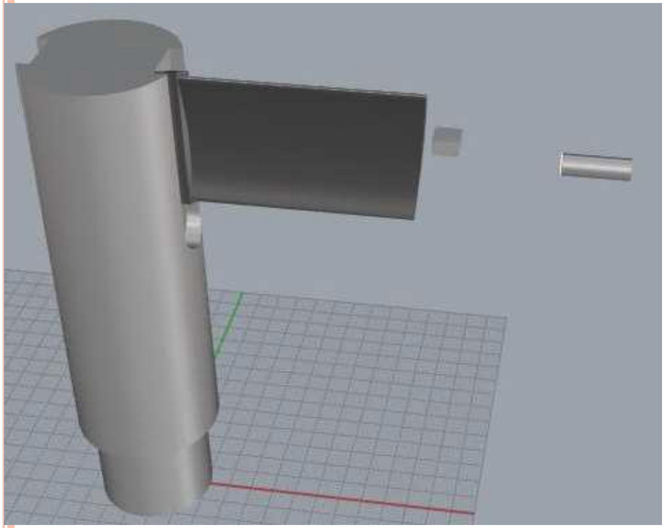
Cubic magnet

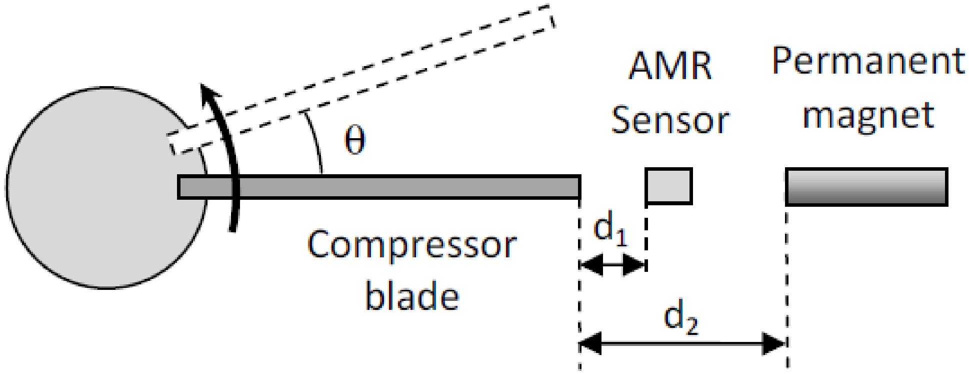


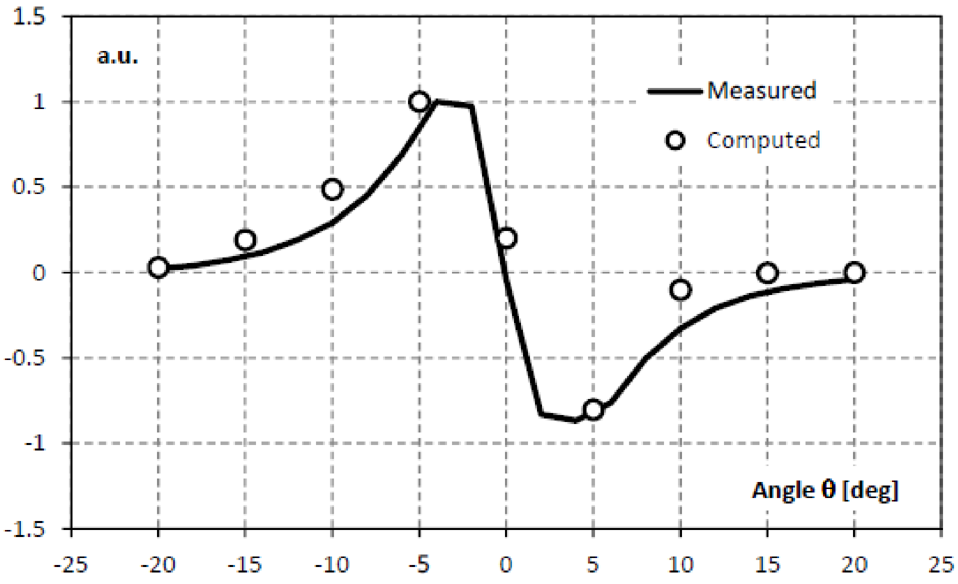
ΔV at the blade passage

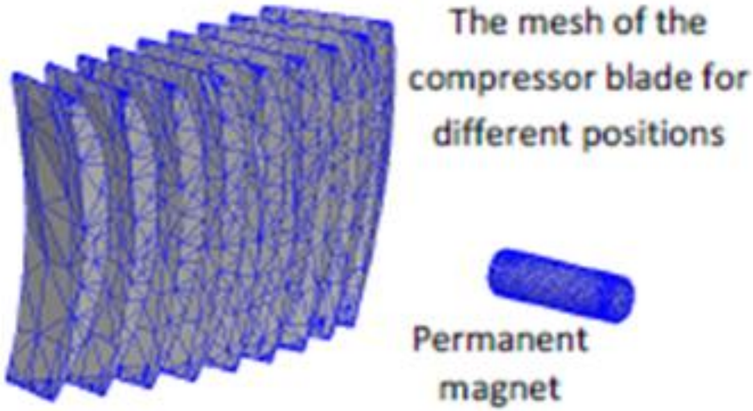


The FEM Model

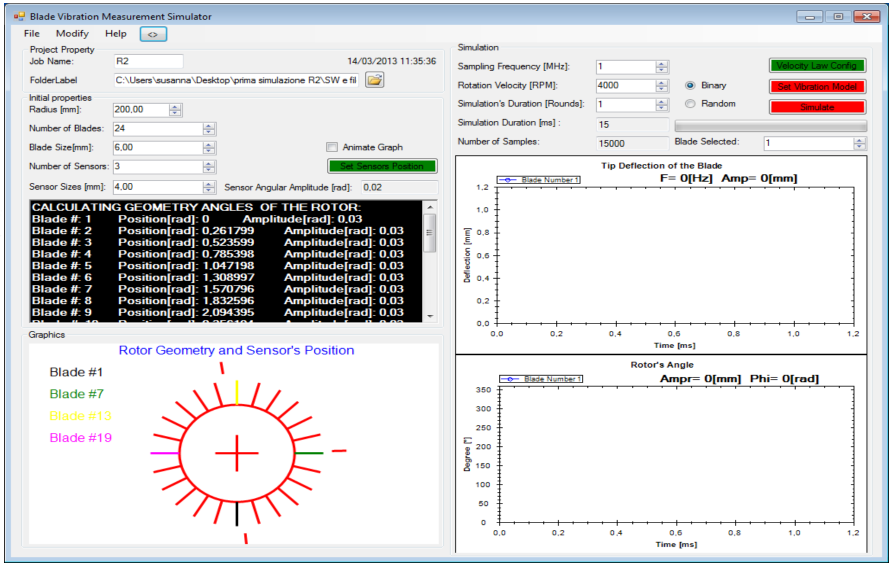


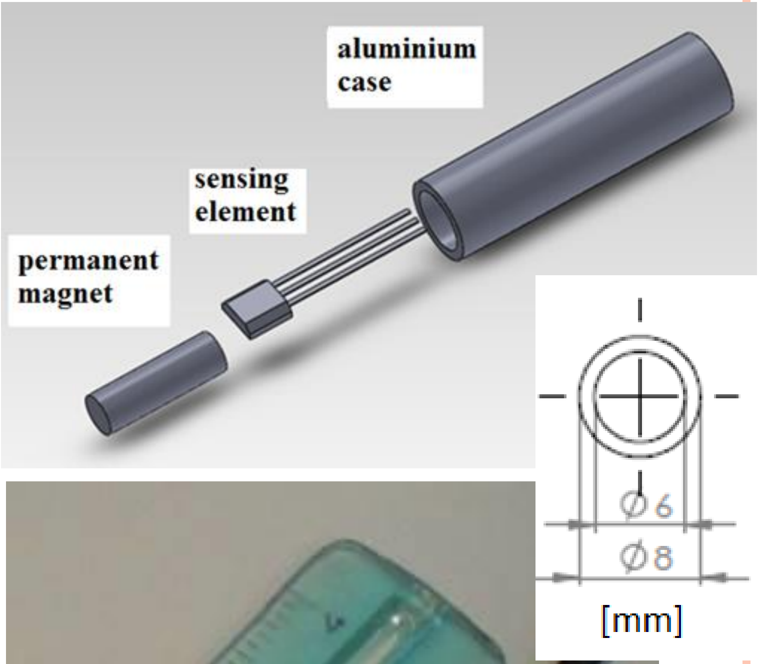


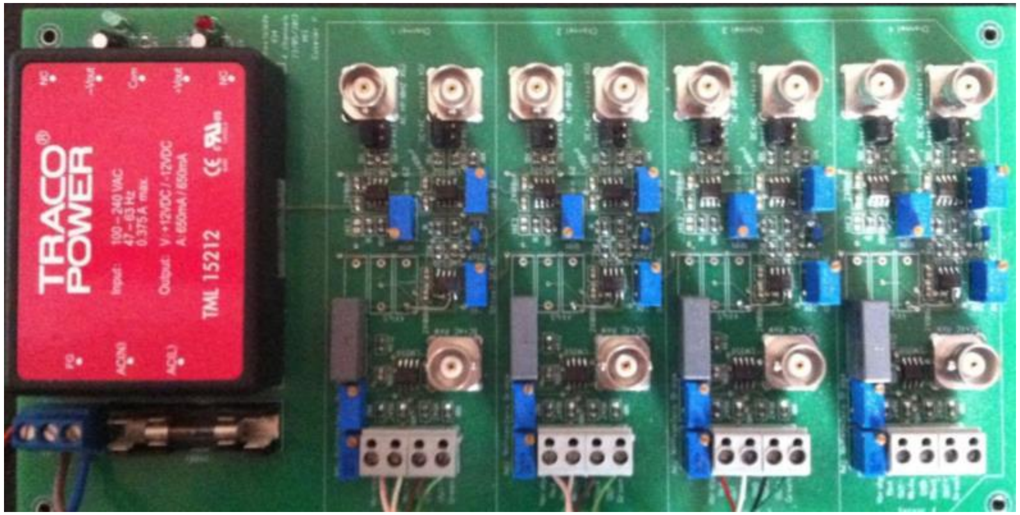




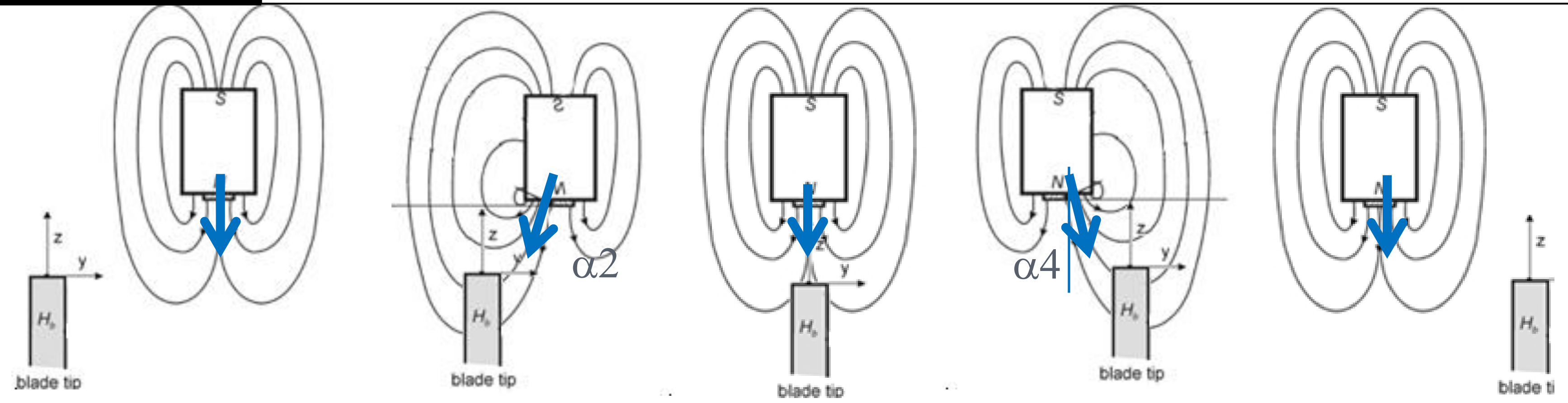
The measurement chain

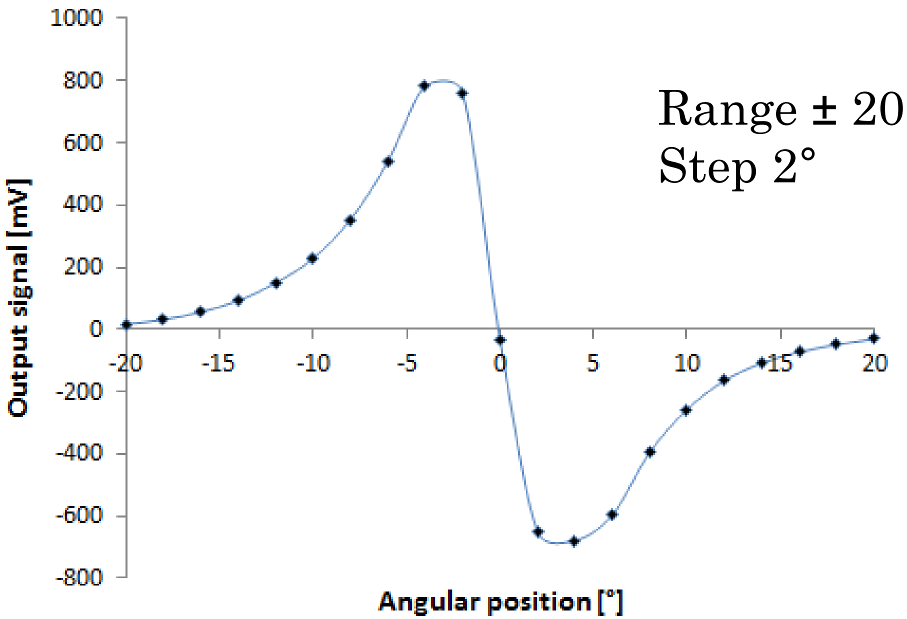






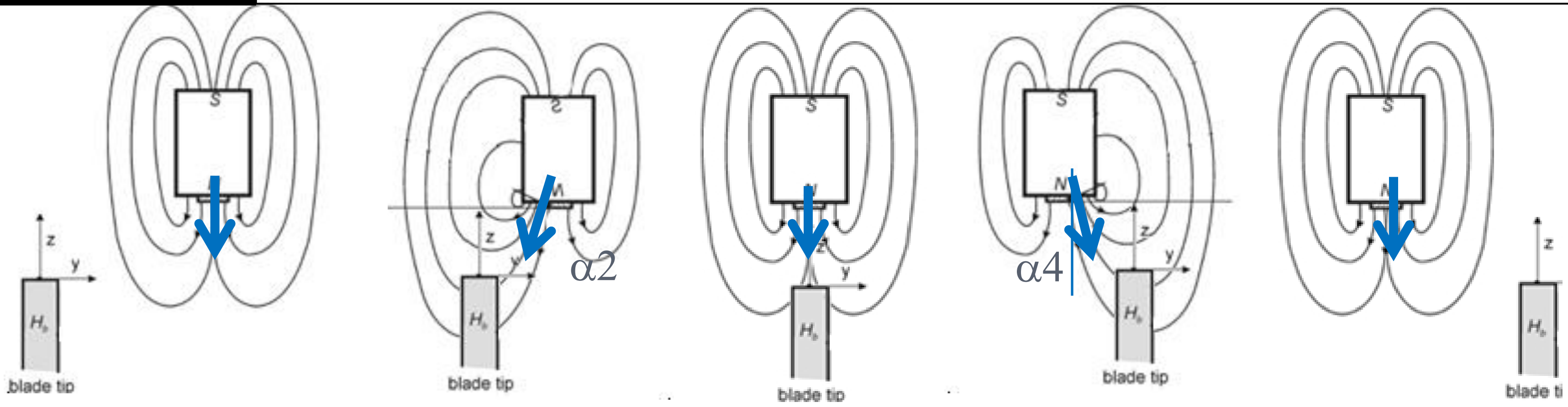
The signal at the blade passage

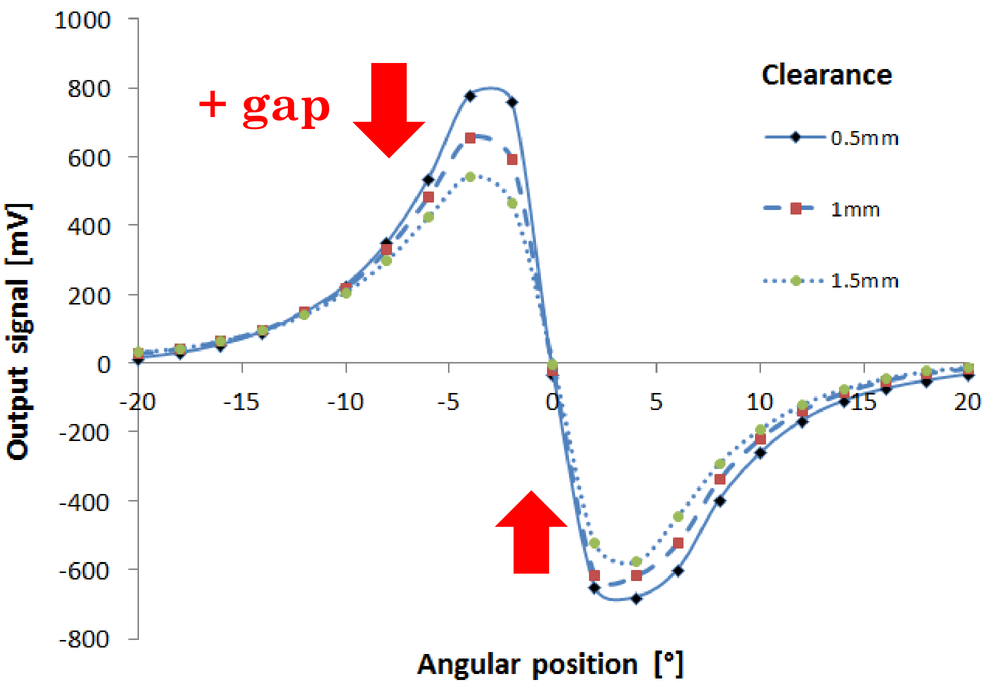




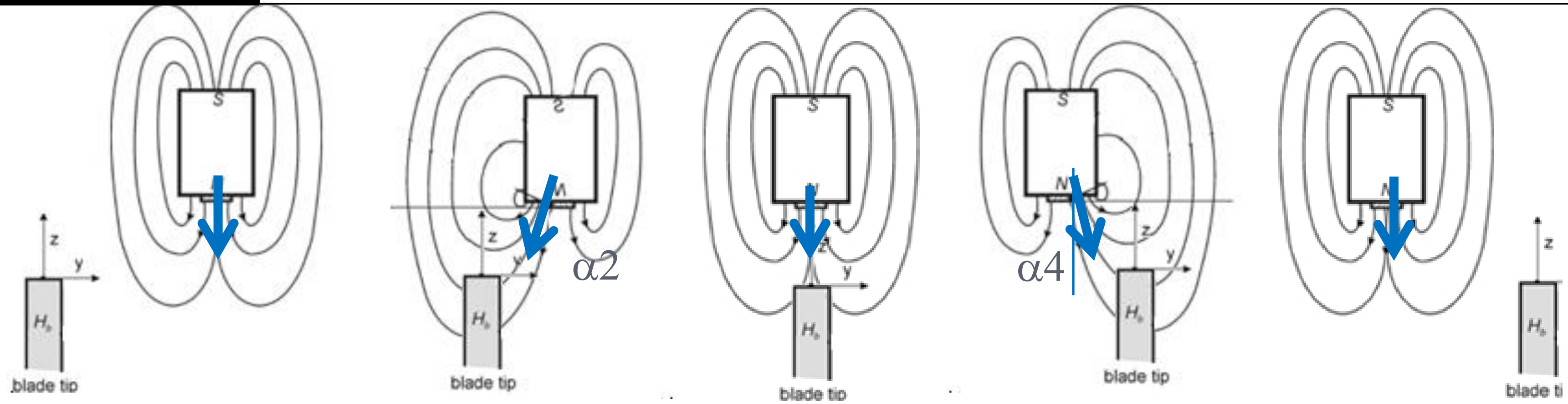
Range ± 20°
Step 2°

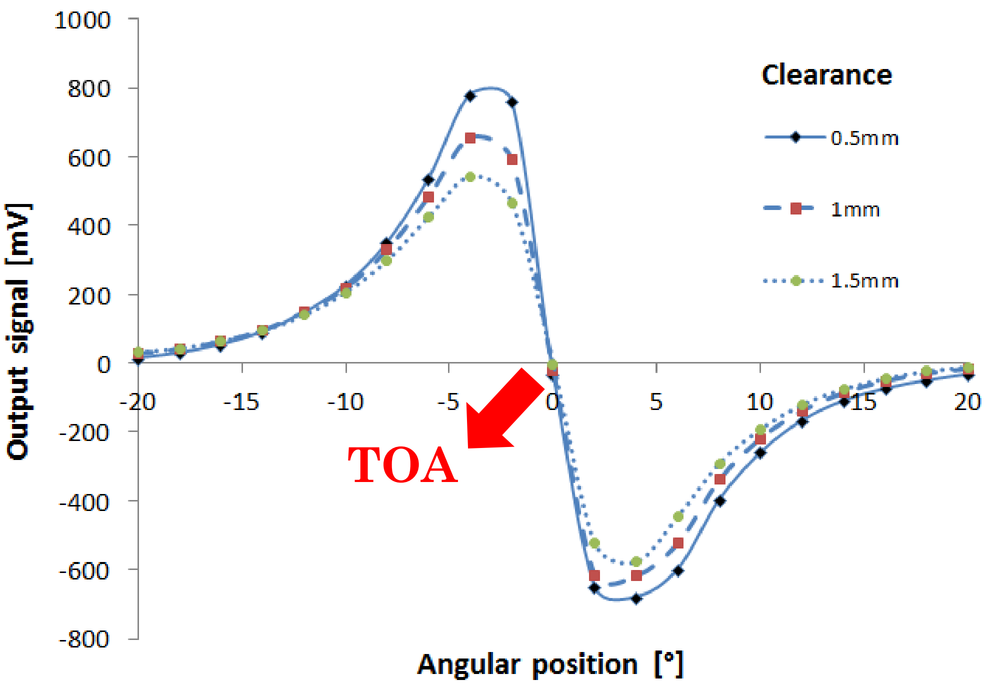
The signal at the blade passage



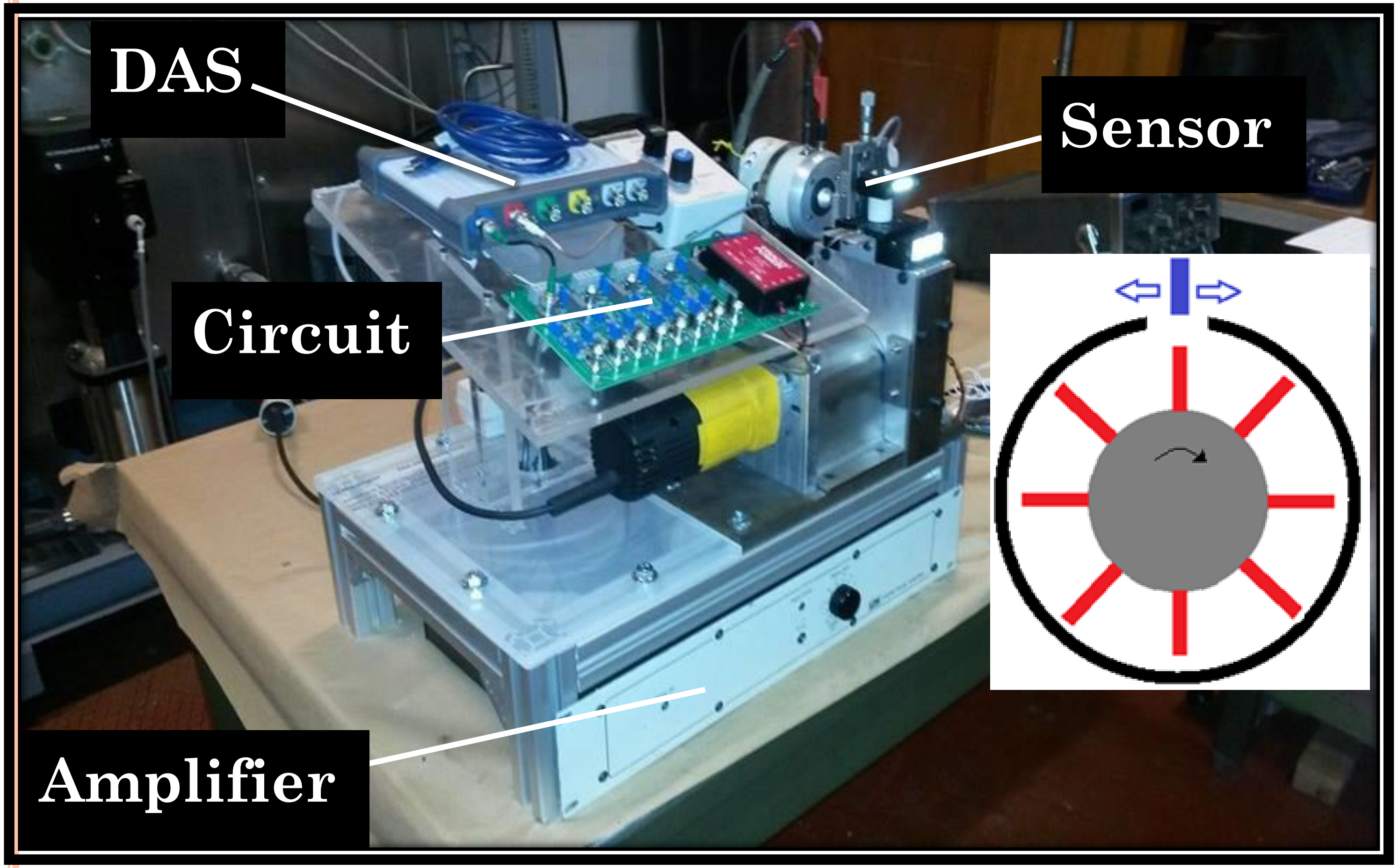


The signal at the blade passage





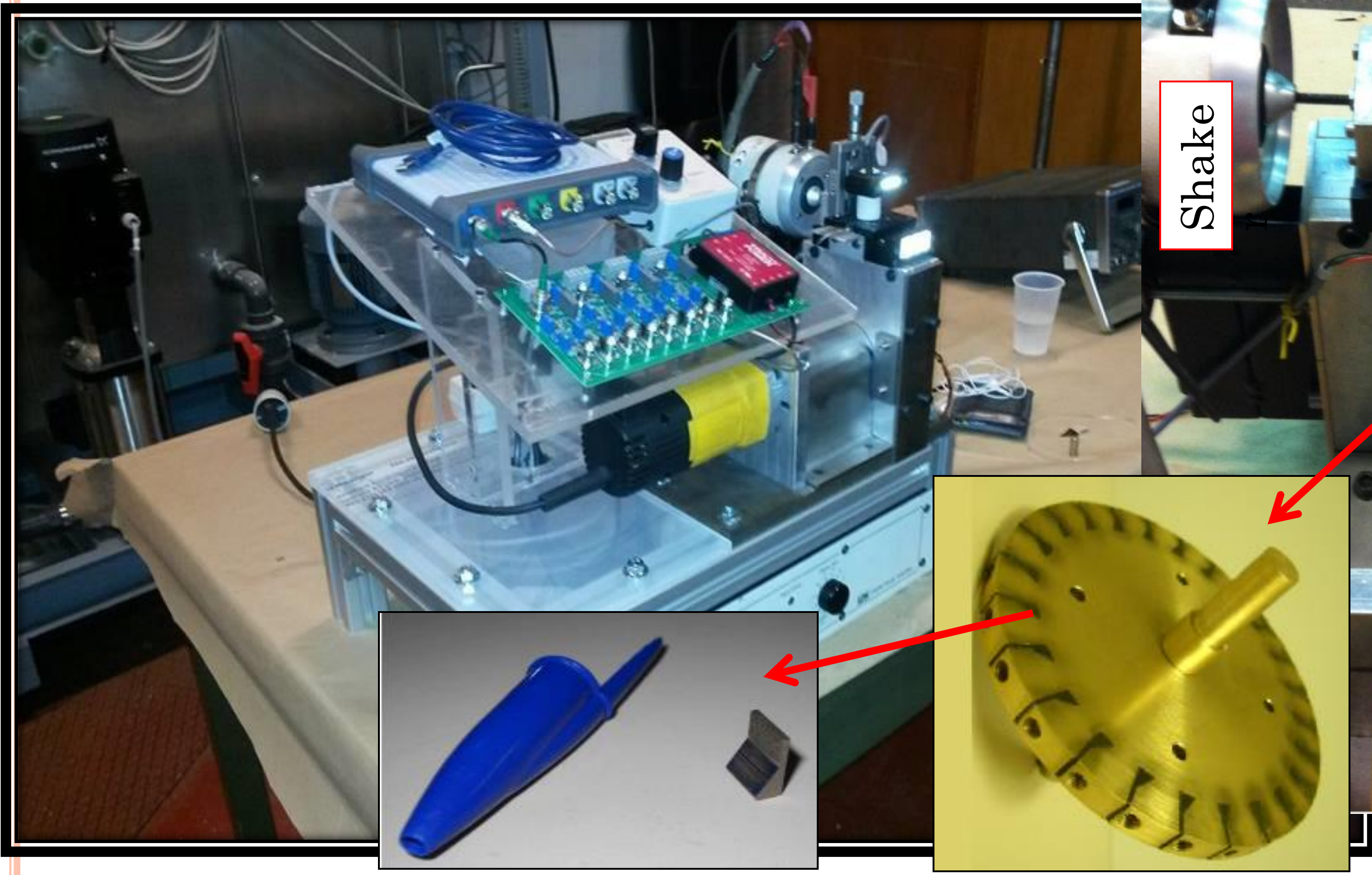
The BTT & BTC calibration bench

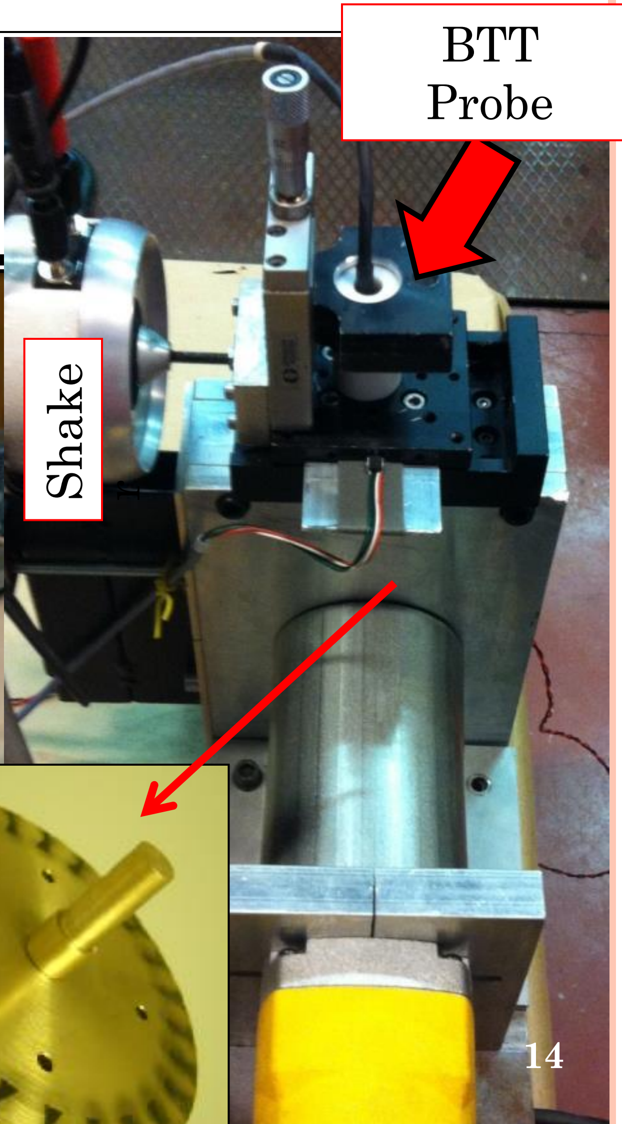


Blade
Motion
Decomposition

The BTT & BTC calibration bench

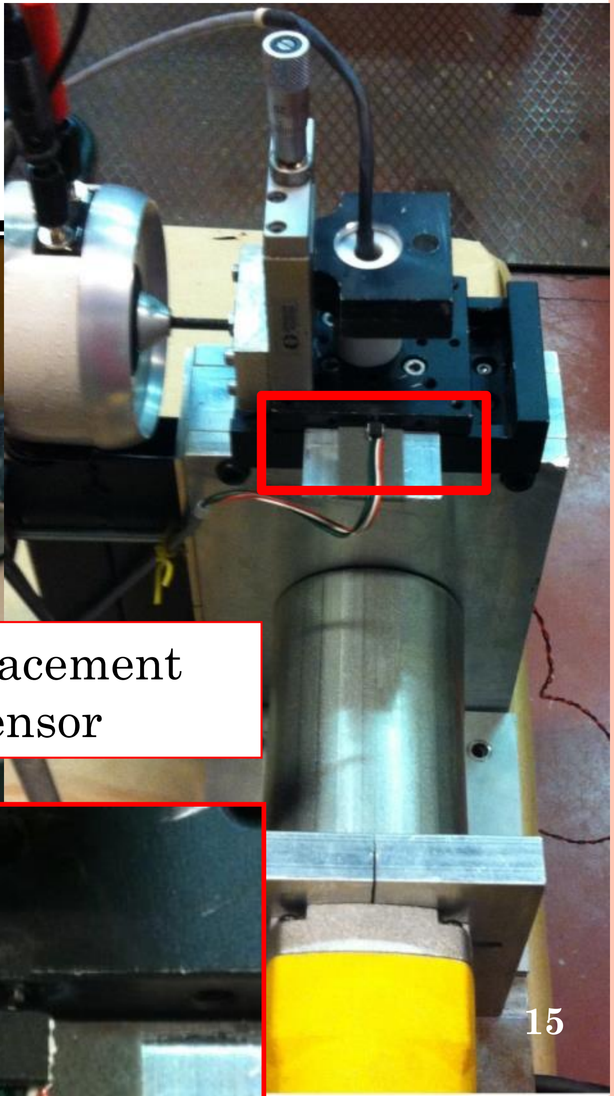
A **shaker moves the BTT probe** and a displacement sensor records the imposed vibration





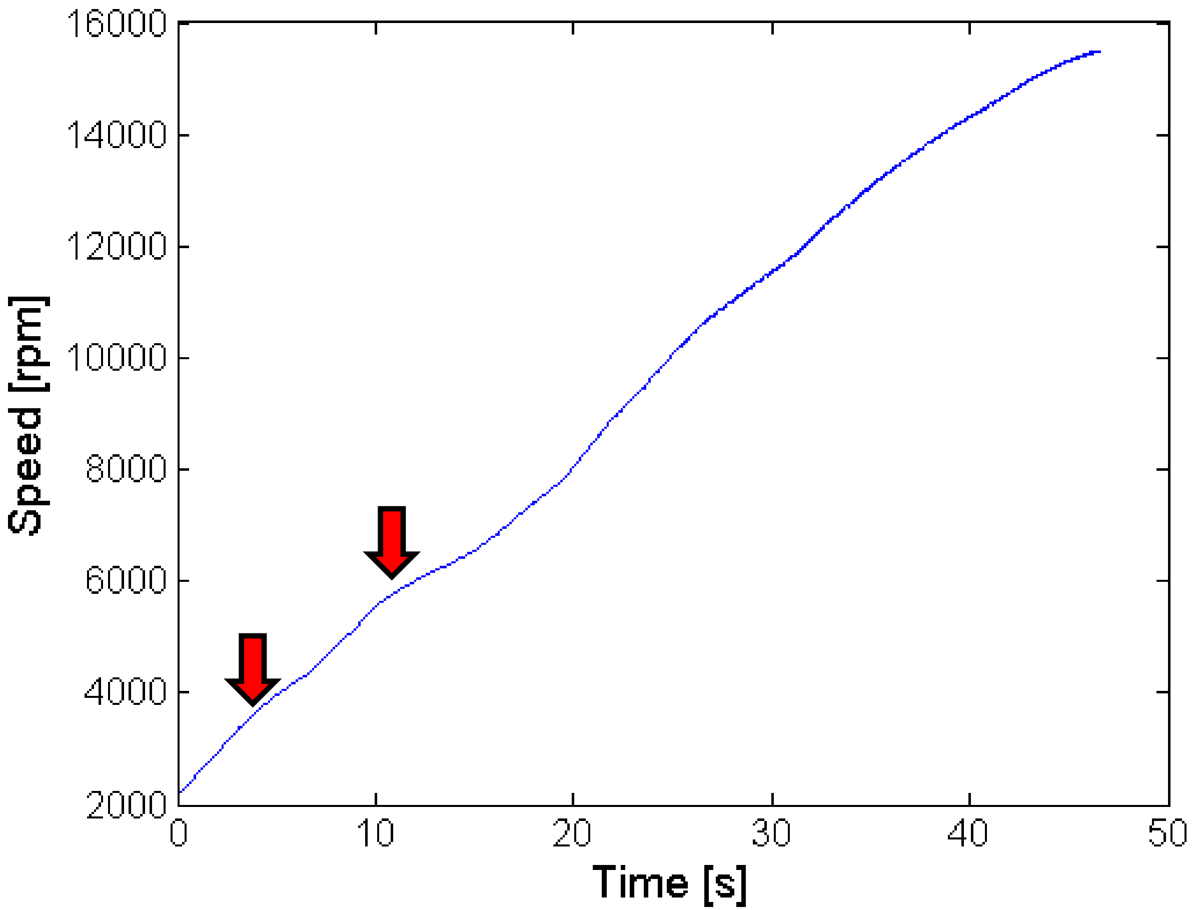
The BTT & BTC calibration bench

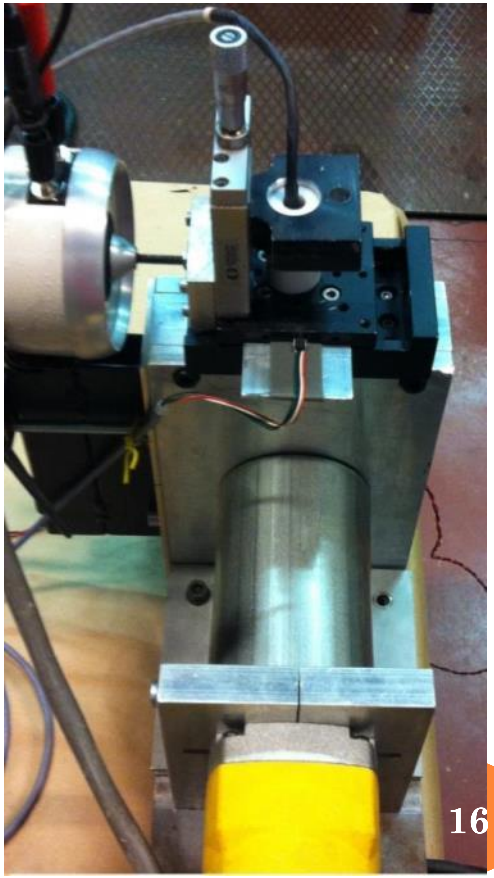
A **shaker moves the BTT probe** and a displacement sensor records the imposed vibration



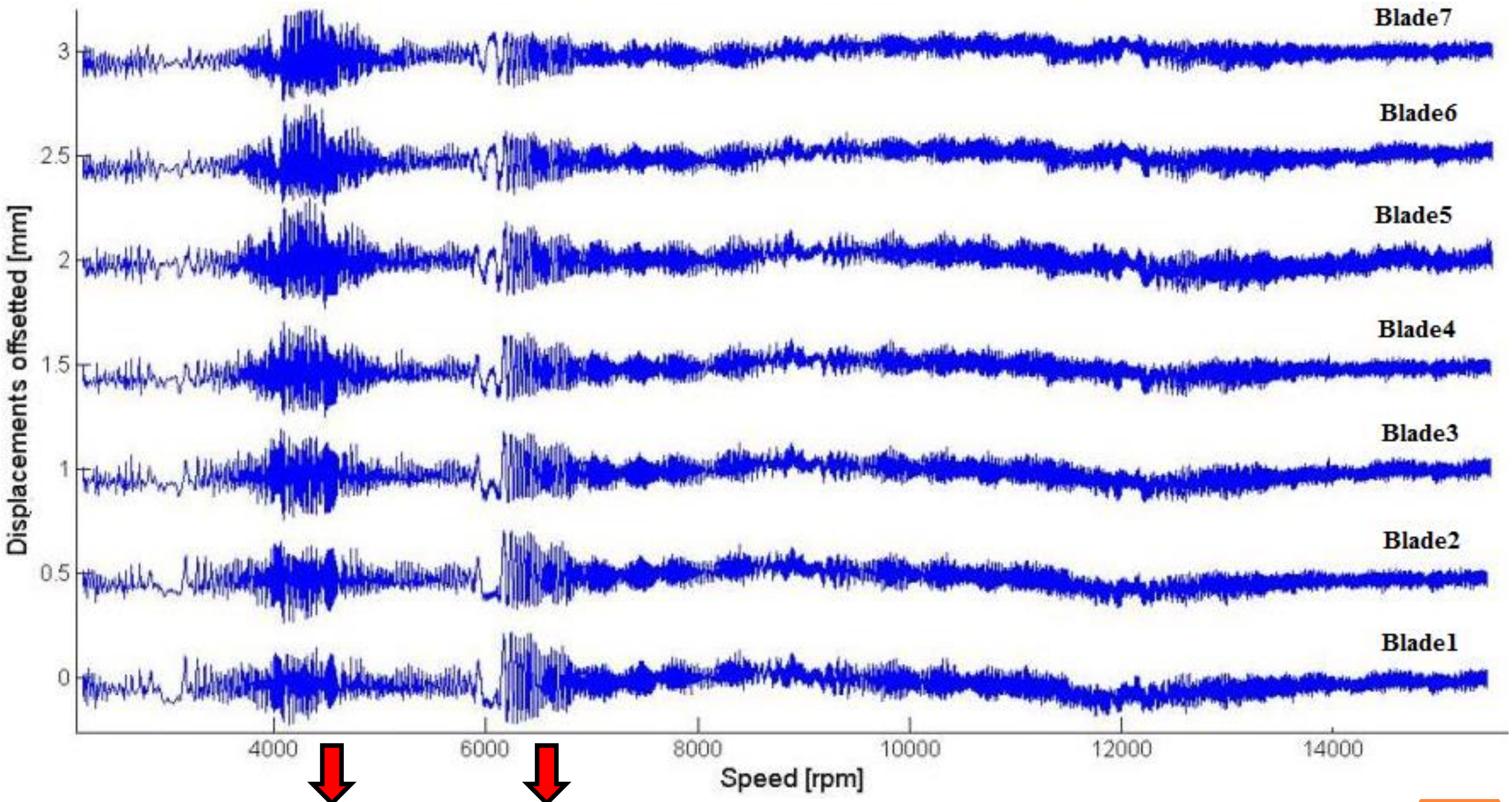
Vibration test

Imposed sensor vibration: 100Hz, Amplitude **A=0,1mm**, always present up to 13000rpm
Vibration peaks @ 4000 rpm (asynchronous) and @ 6000 rpm (synchronous), **A = 0,2mm**



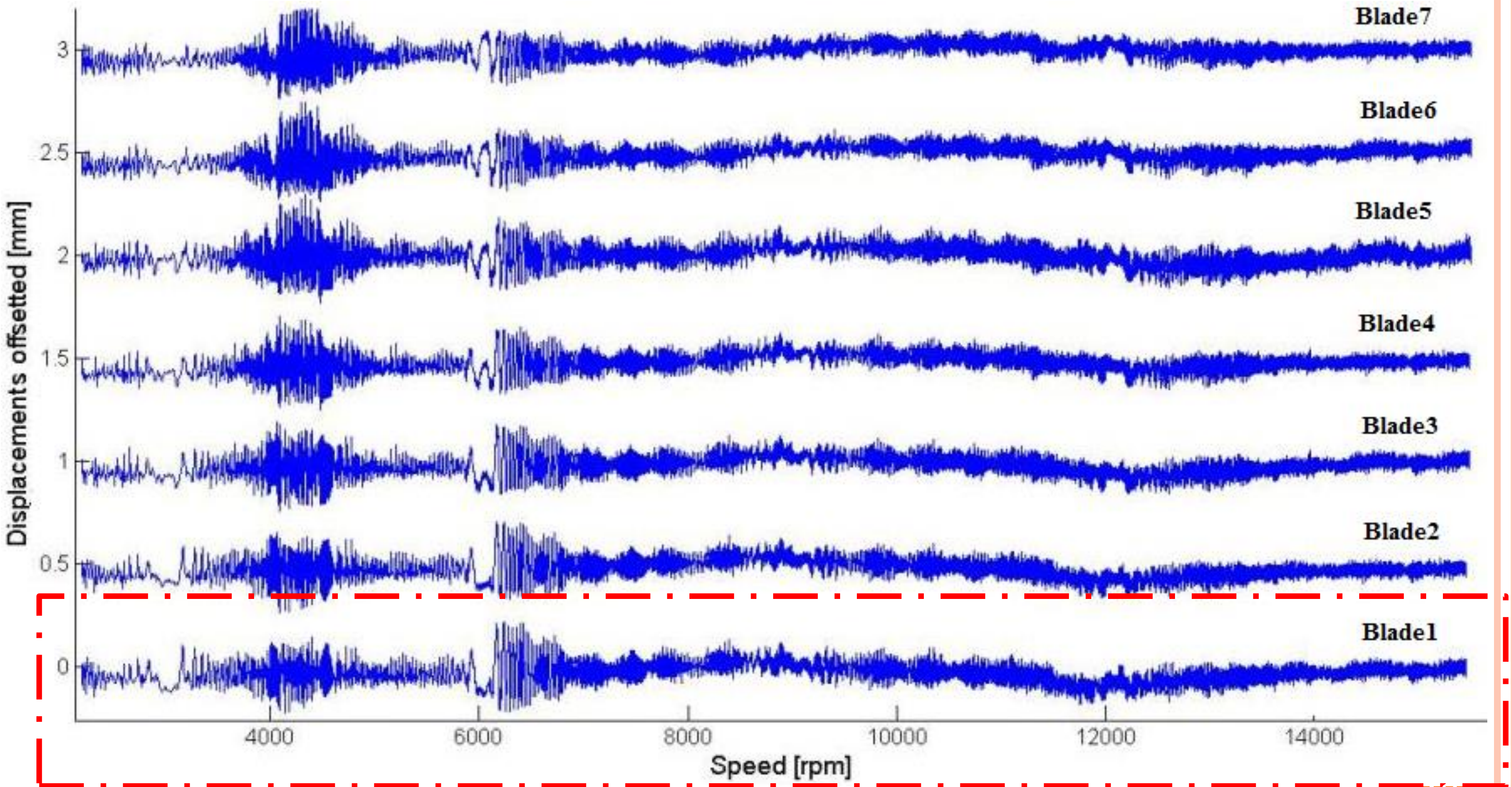


The waterfall of the measured displacements



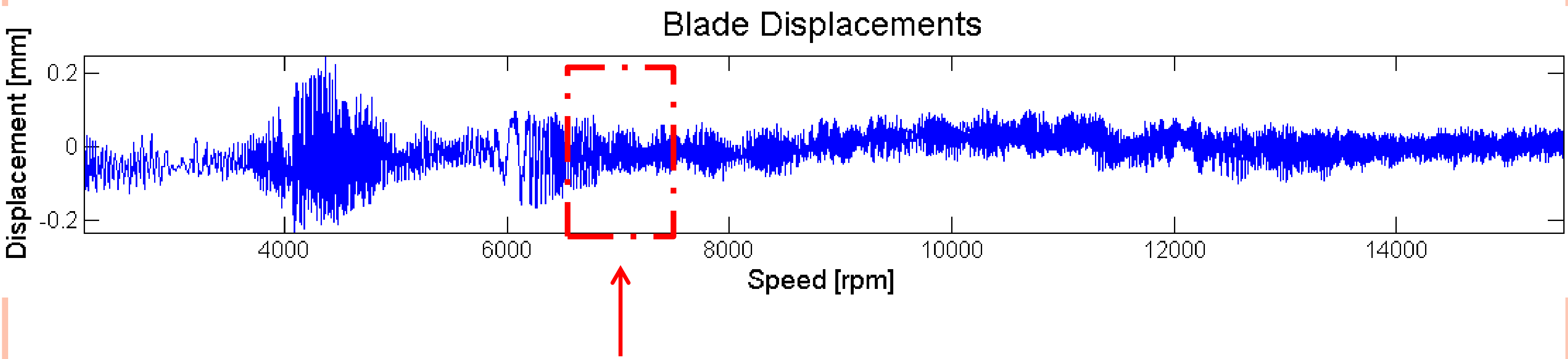
Simulated resonances @ 4000 and 6000 rpm

The waterfall of the measured displacements



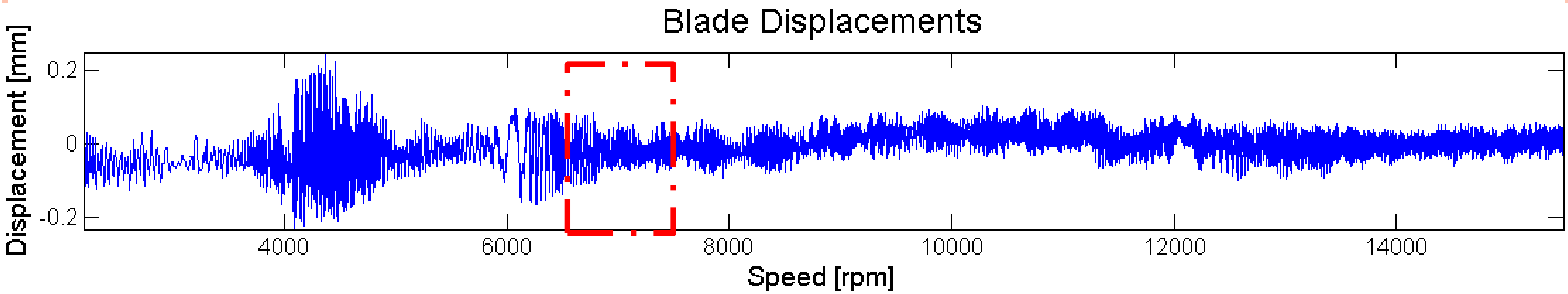
The individual blade spectrogram

Measured displacement of blade 1:



Processing method: window of N samples, successive FFTs

The individual blade spectrogram



Remarks:

One sensor: 1sample x blade x rev --> **Fs. = Frev.**

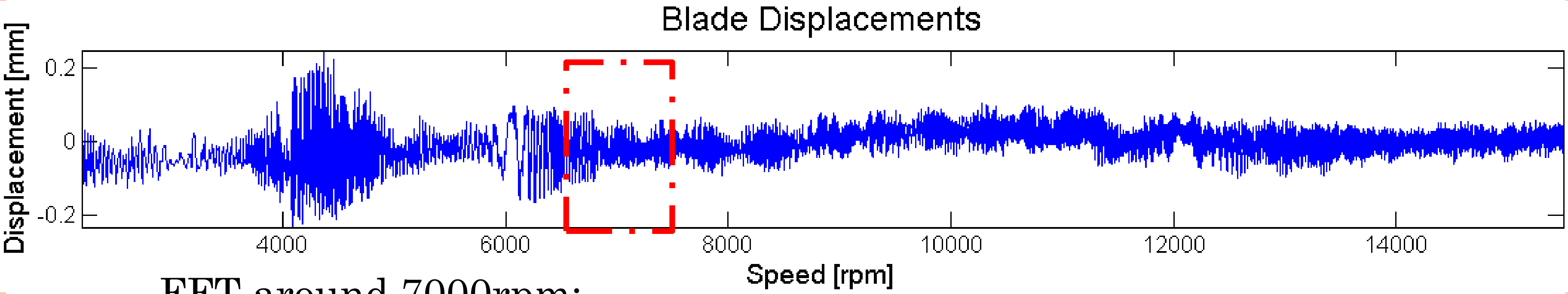
1) Speed change → Fs change

Frev. < Fvib.

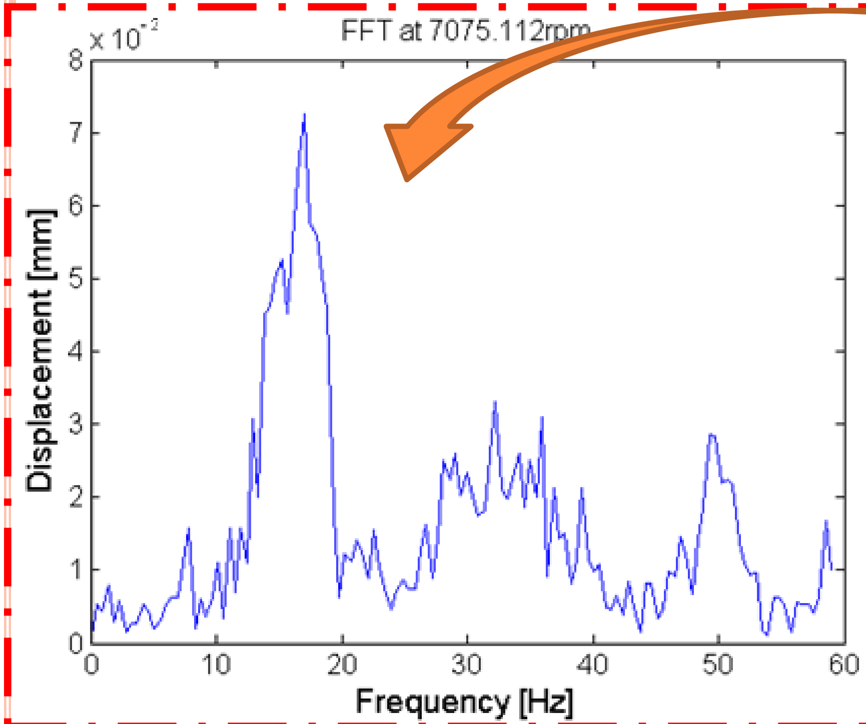
Aliasing:

2) FOLDED FREQUENCIES

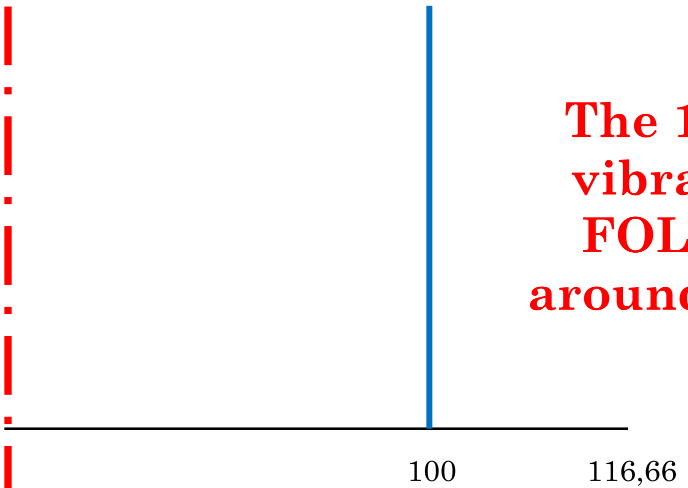
The individual blade spectrogram



FFT around 7000rpm:

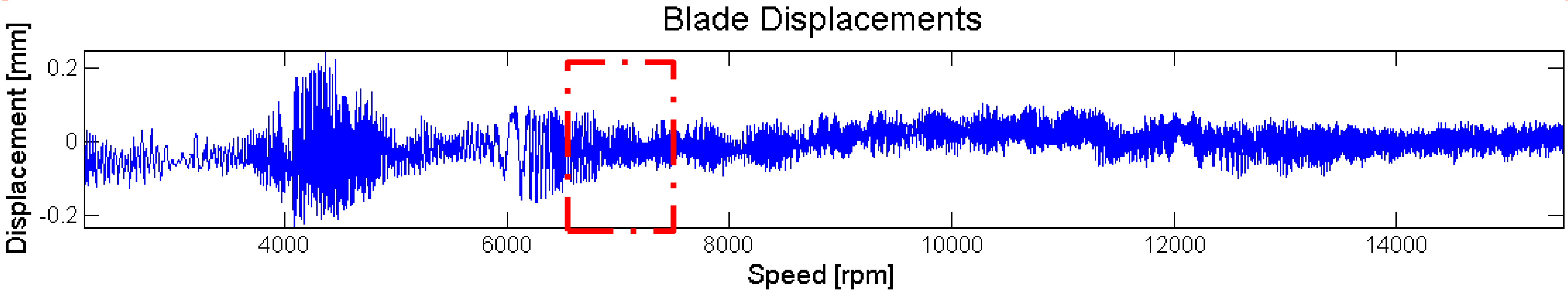


7000rpm
Frev=Fs=116,66 Hz
Fs/2 = 58,33 Hz

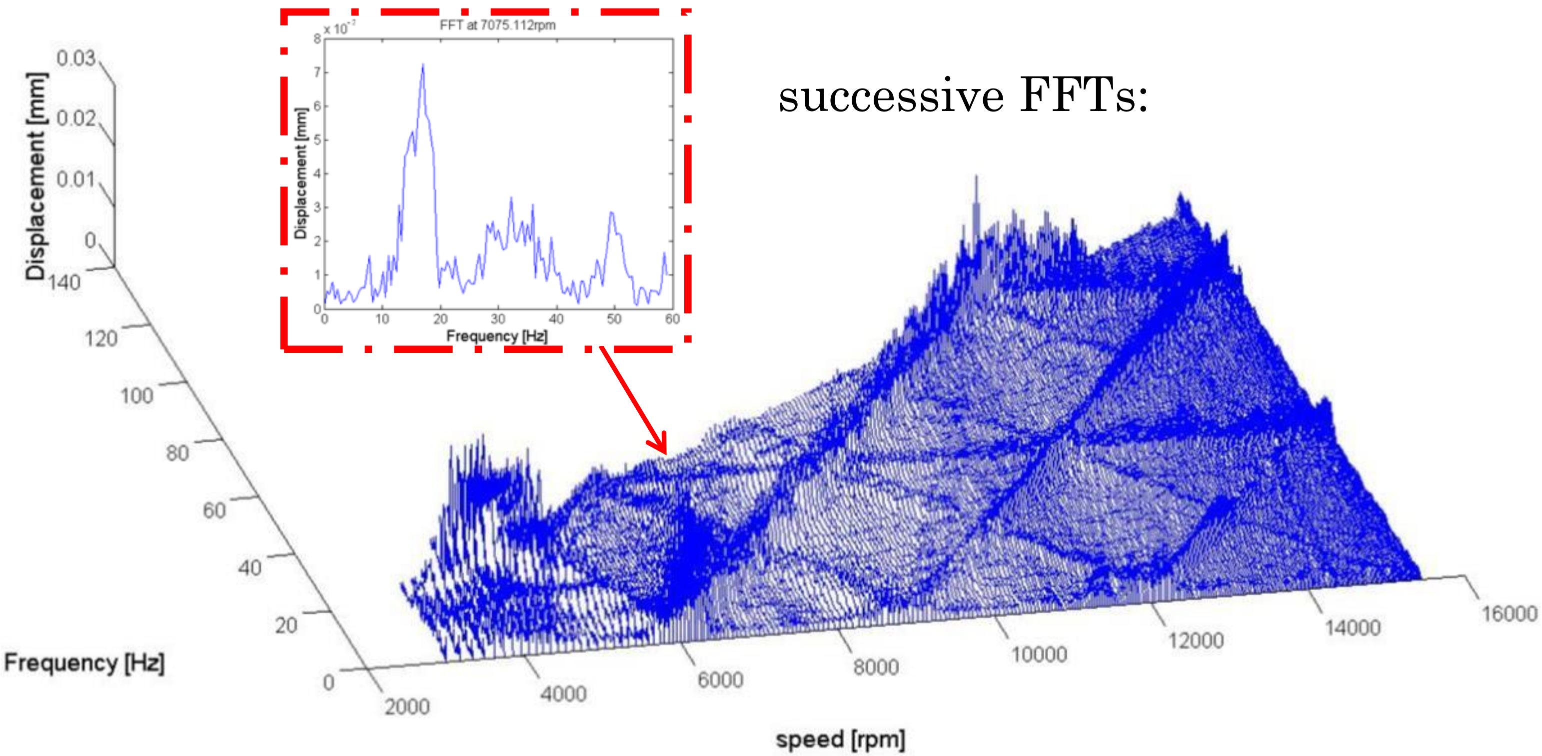


The 100Hz vibration: FOLDED around 17 Hz

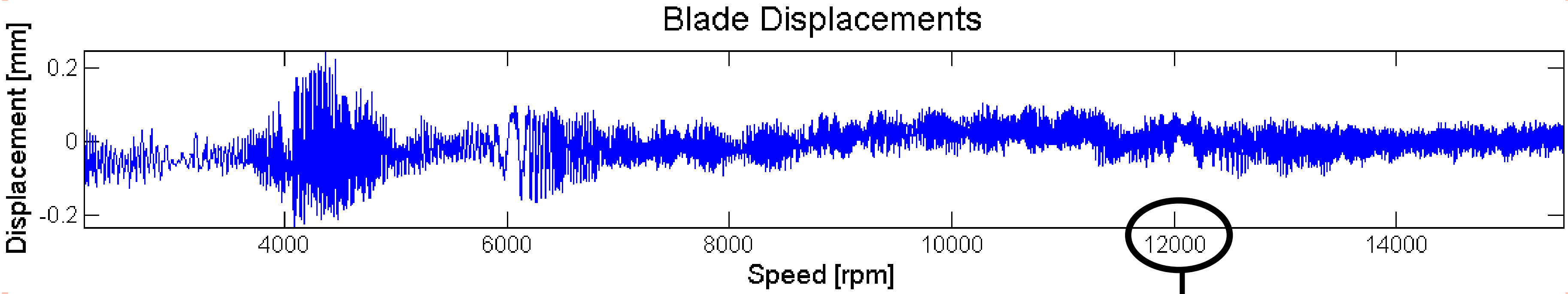
The individual blade spectrogram



successive FFTs:

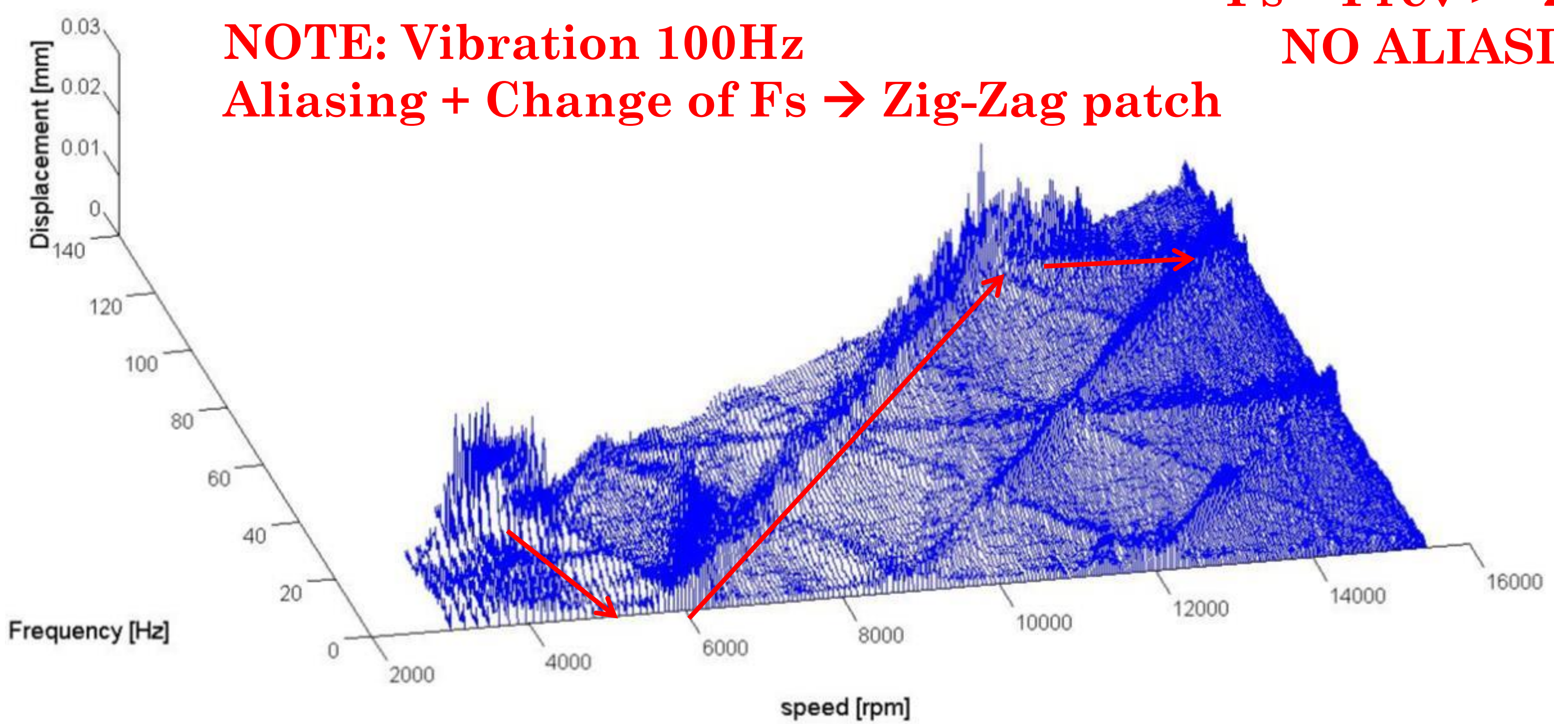


The individual blade spectrogram



Fs = Frev >= 200Hz
NO ALIASING

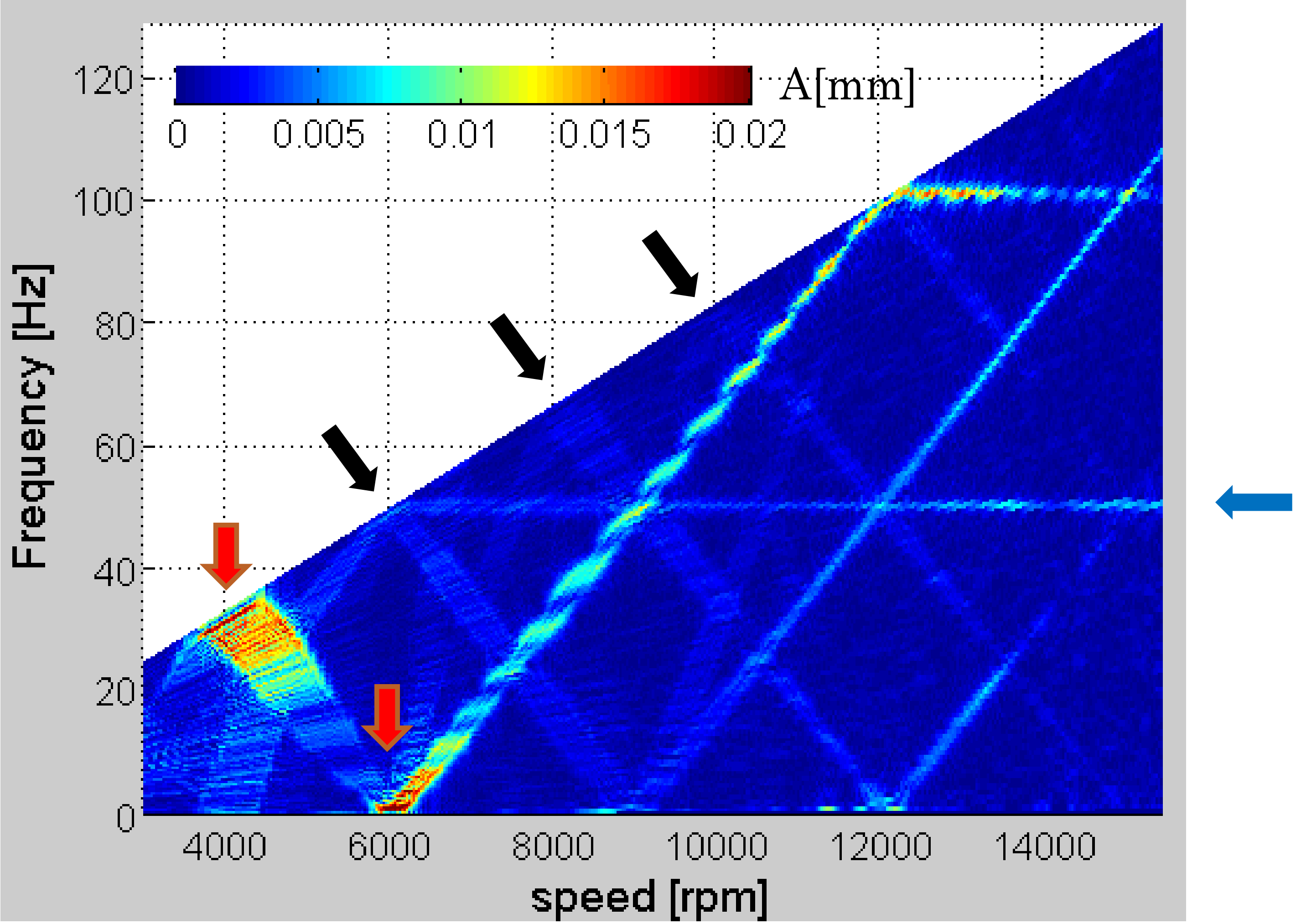
NOTE: Vibration 100Hz
Aliasing + Change of Fs → Zig-Zag patch



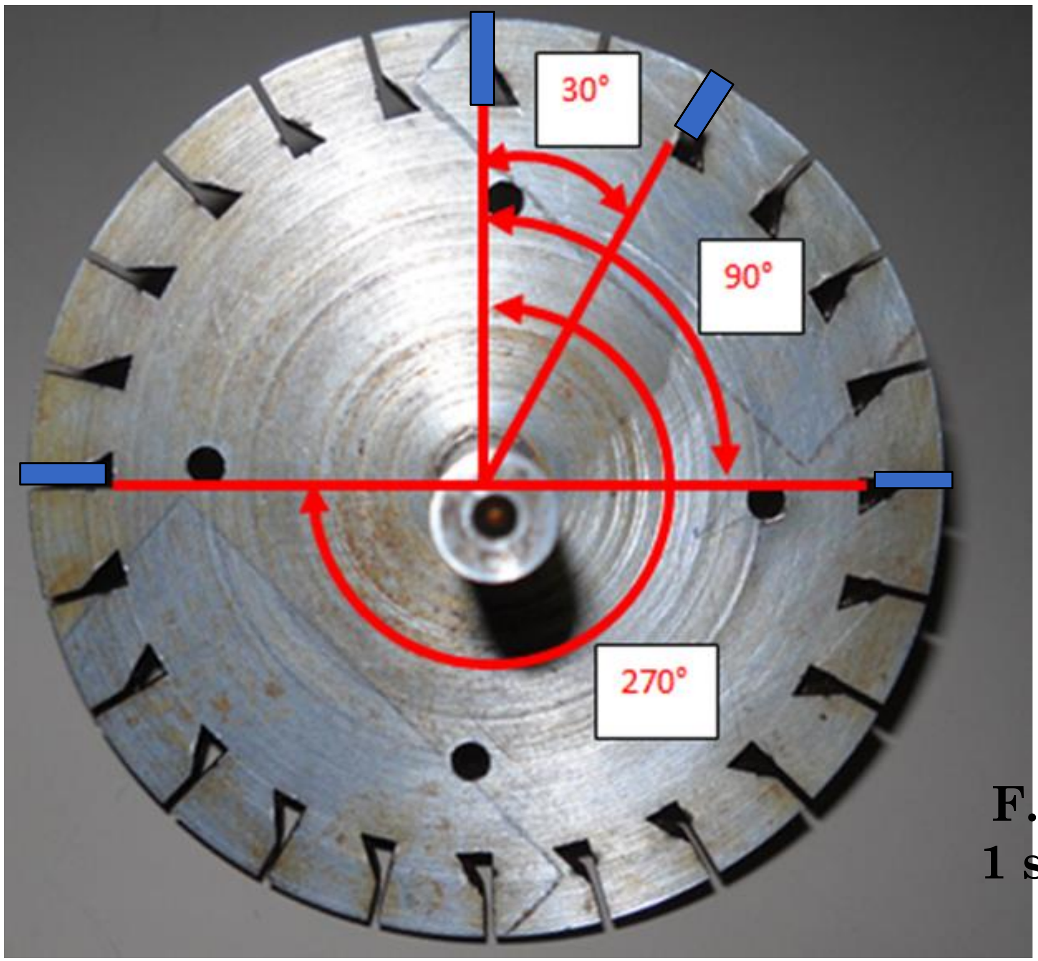
The individual blade spectrogram

100Hz vibration – folded up to 12000rpm → zig-zag patch (**Vib.peaks** + **Harmonics** + **Noise 50Hz**)

Remark: MEASURED DISPLACEMENTS NOT FILTERED



Vibration measurement at fixed speed



Working conditions:
The blade position simulates the sensor position

Rotor:
4 blades at [0,30,90,270]°

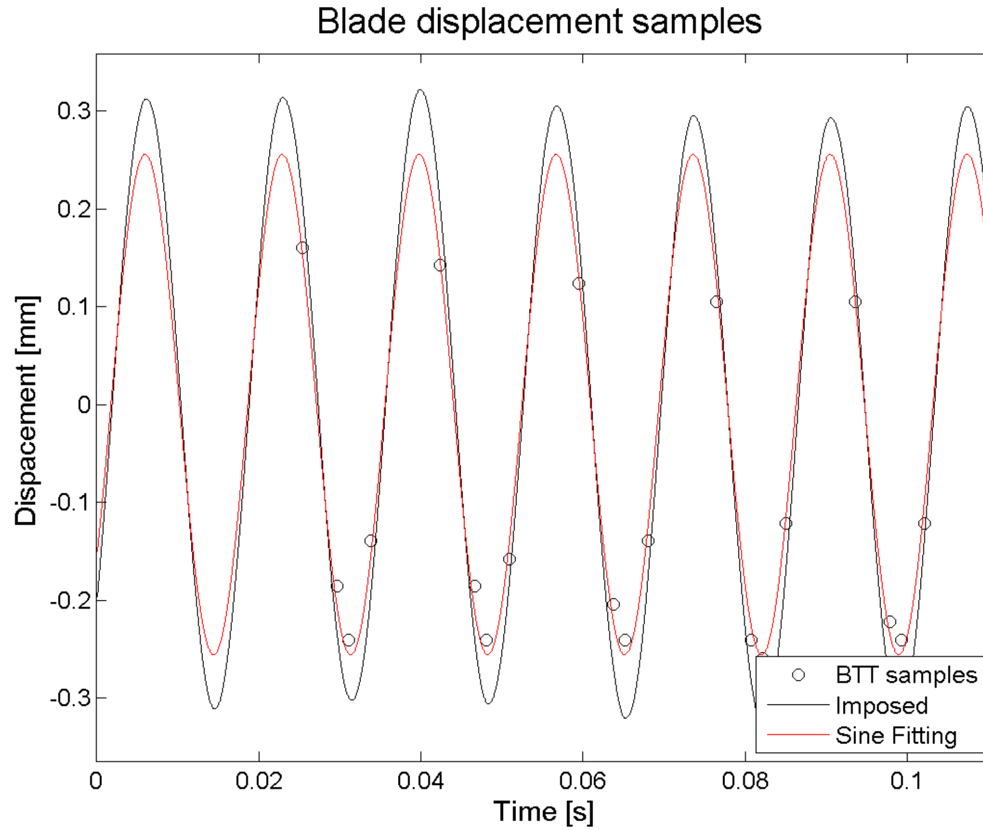
DAS: 12 bits, Fs 2MHz

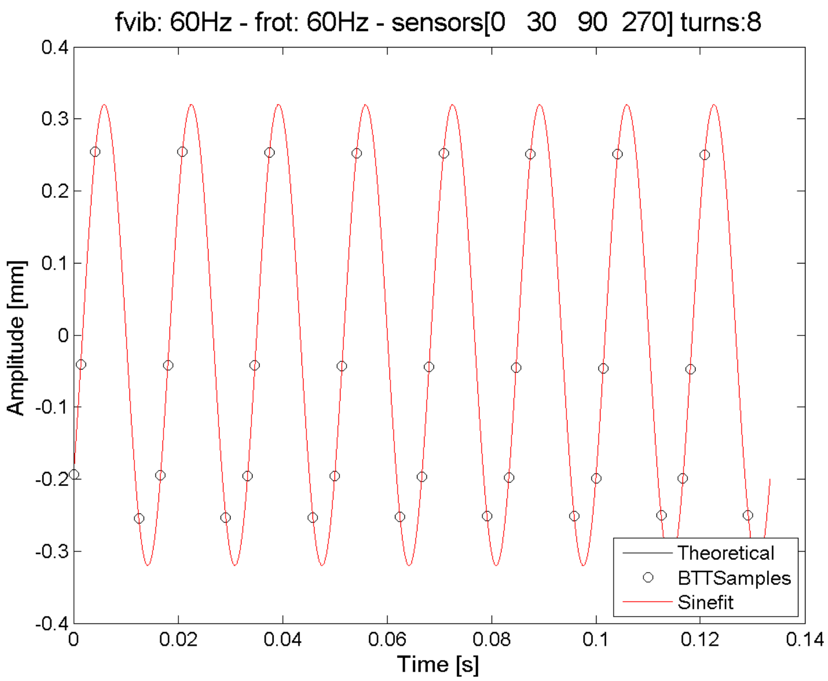
Test case:
F.vibration: **60Hz Amp: 0,3mm**
F.rotation: 60Hz (3600 rpm)

F.vibration: 60 Hz = F.rotation
1 sensor and 4 samples per rev:
NO ALIASING

Measured vibration amplitude

Experimental results →

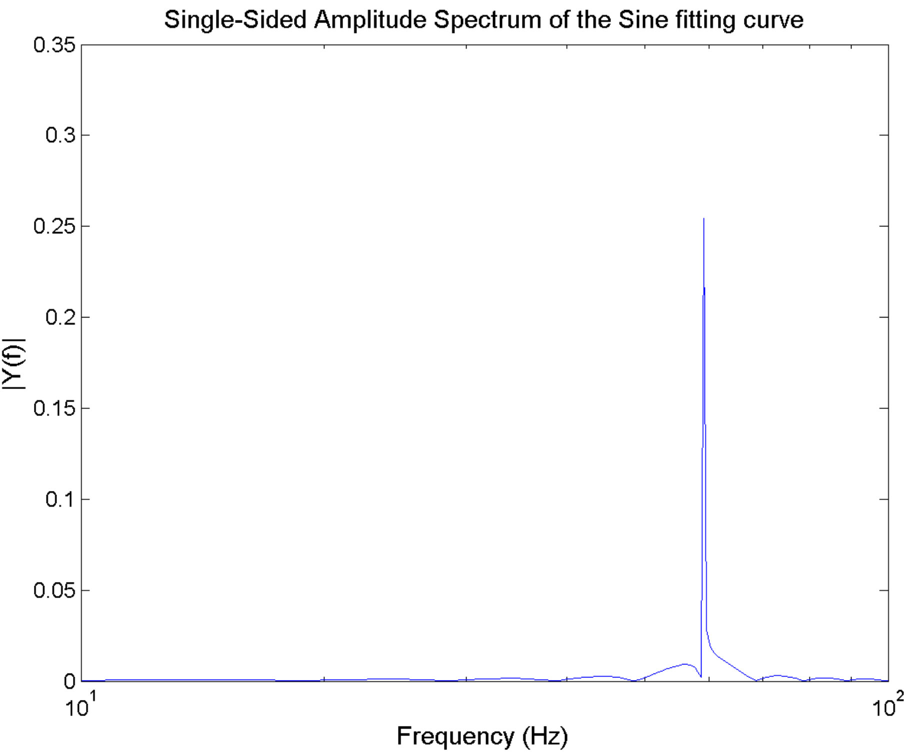




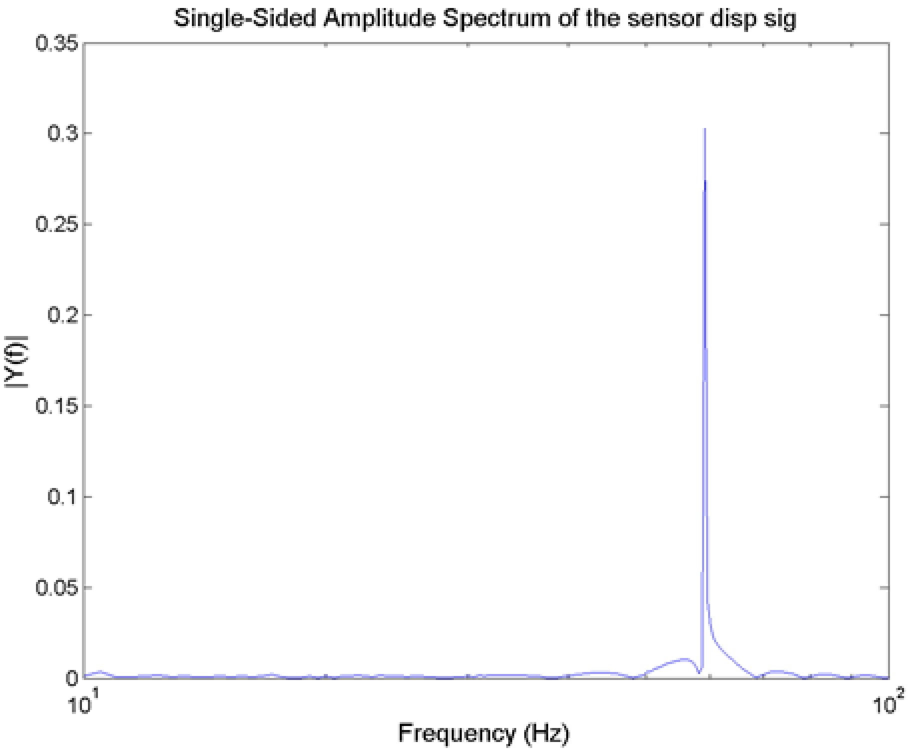
Numerical prediction with the
BTT simulation software
(EU Project BTTMON)

Measured frequency

Spectrum of the **measured** vibration



Spectrum of the **imposed** vibration

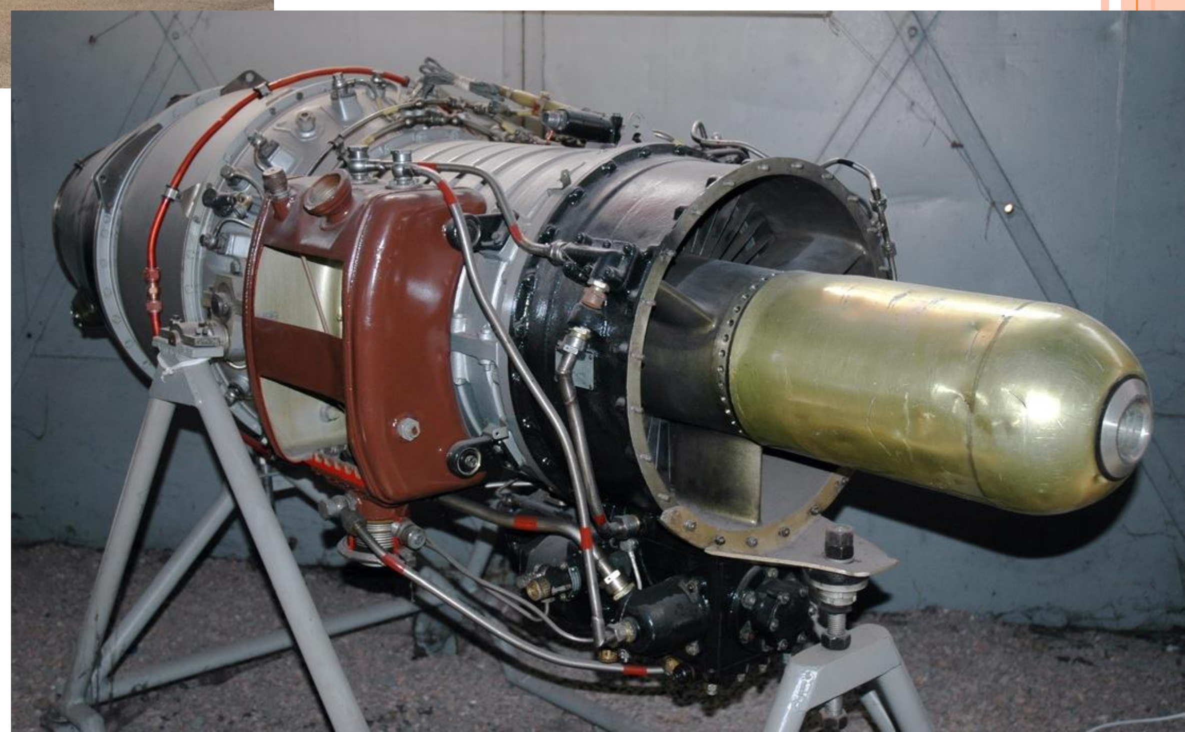


The **measured frequency** is the same of the imposed one.
The **measured amplitude** is 0,25mm, the **imposed** is 0,3mm

Test at ITWL on a real engine

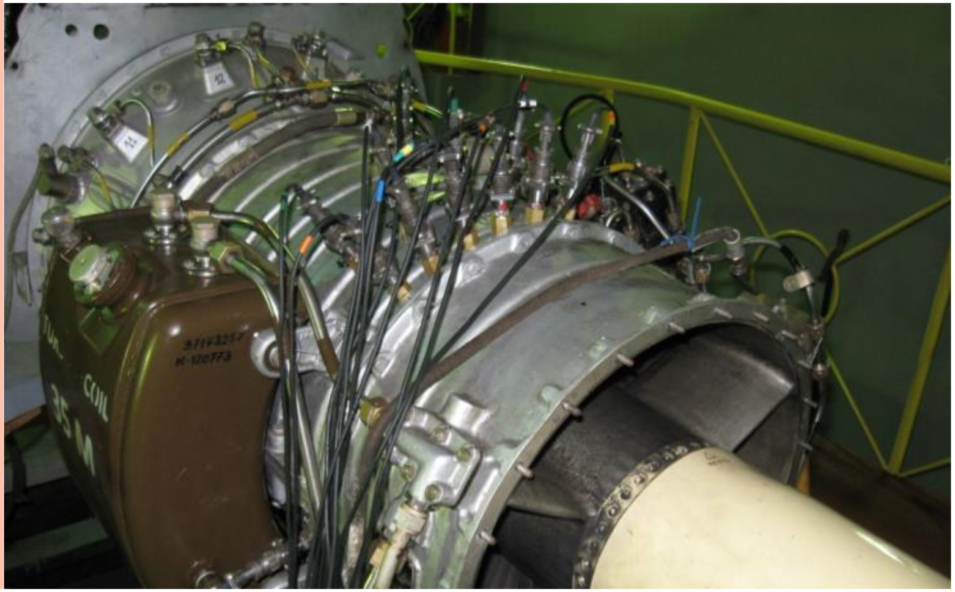
PZL_TS-11_Iskra
Polish_Air_Force

The SO-3
Jet Engine



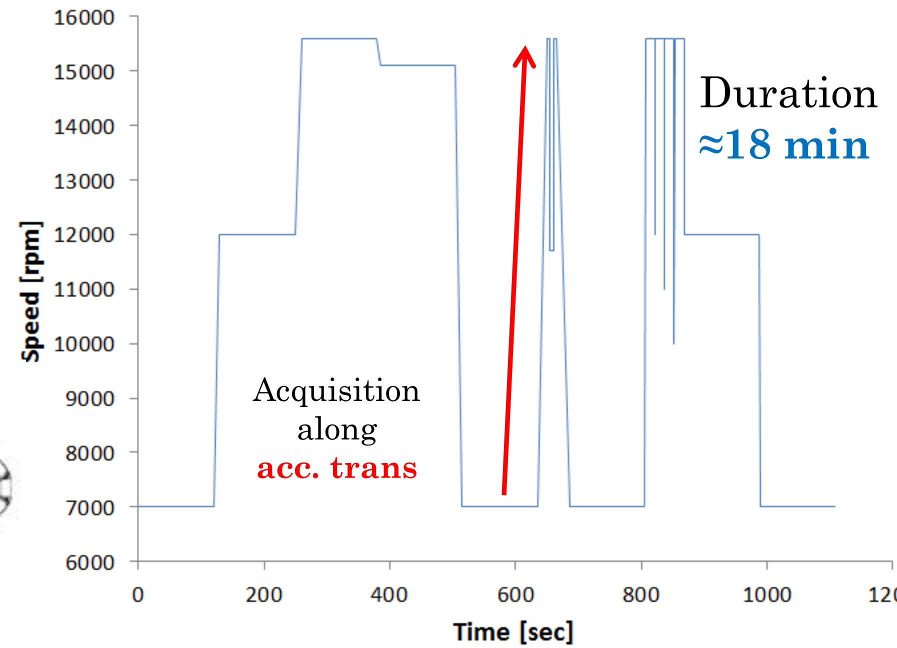
Dr. Radoslaw Przysowa
Air Force Institute
of Technology - ITWL - Warsaw

Test at ITWL on a real engine

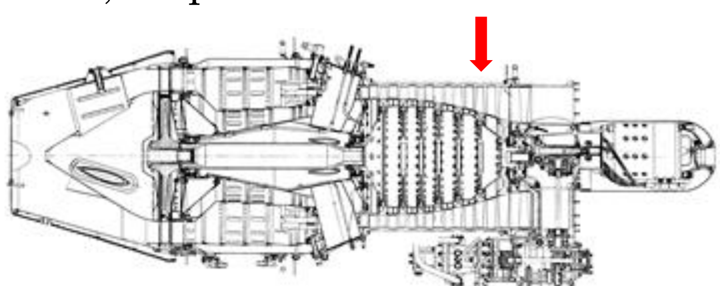


4 sensors in the **second compressor**

Typical engine test up to **15600rpm**



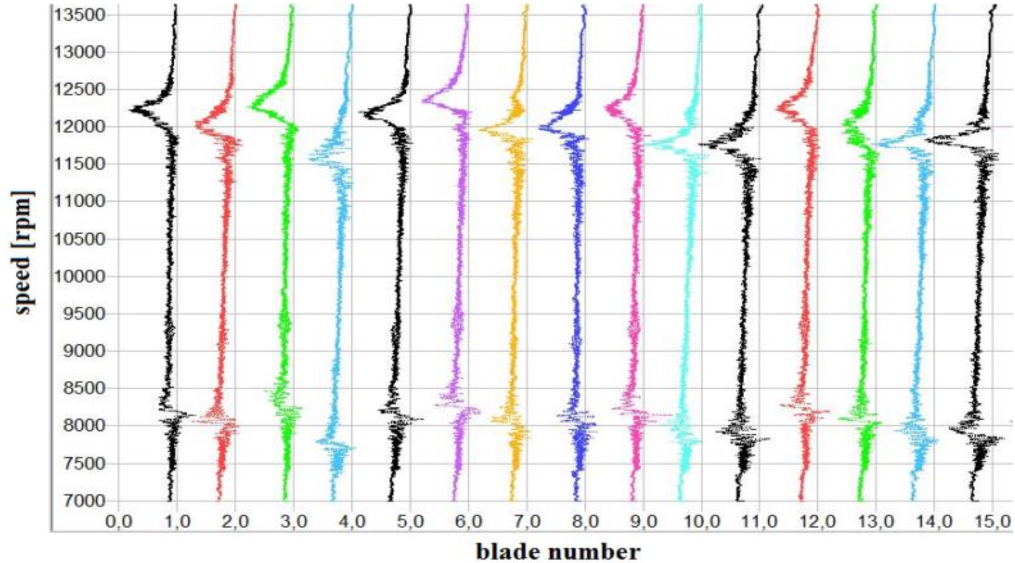
The SO-3 turbojet engine:
Thrust 10 kN, 7 comp stages,
$\pi = 4{,}69$, $m = 17{,}8$ Kg/s
2° stage: 41 blades, Rtip = 207mm



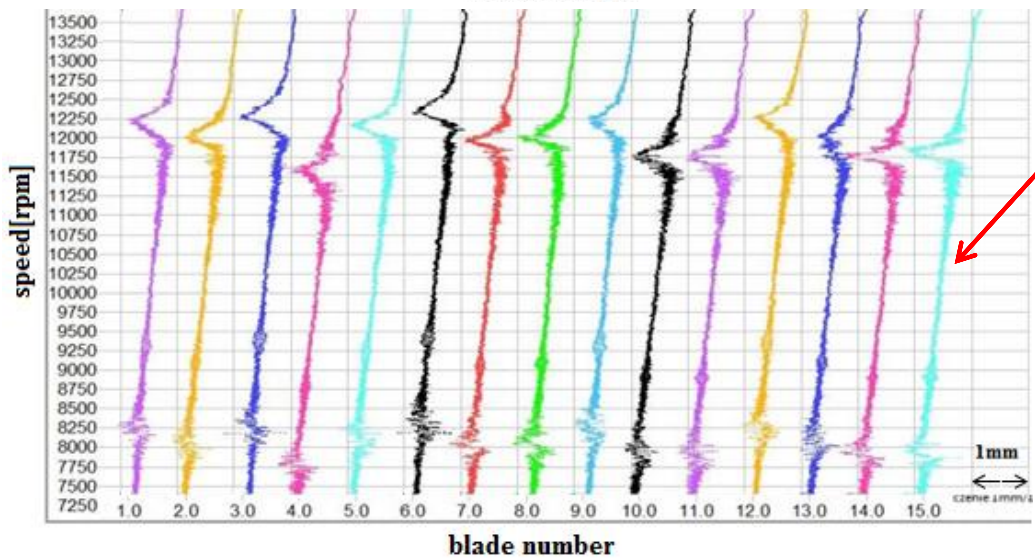
Dr. Radoslaw Przysowa
Air Force Institute of Technology - ITWL - Warsaw

The waterfalls of the measured displacements

Test1:
ITWL sensor

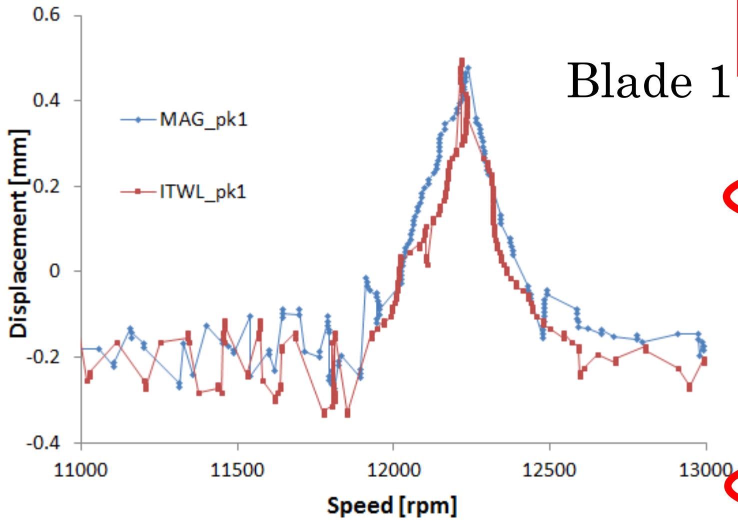


Test2:
Magnetoresistive sensor

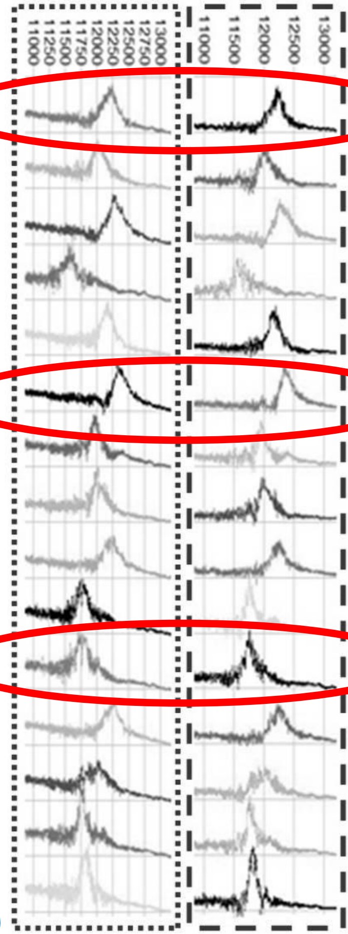


Drift !

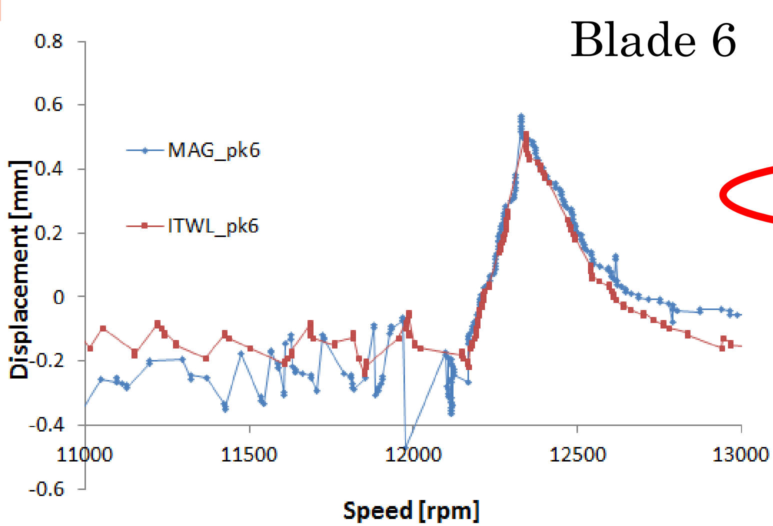
Get data plot digitizer

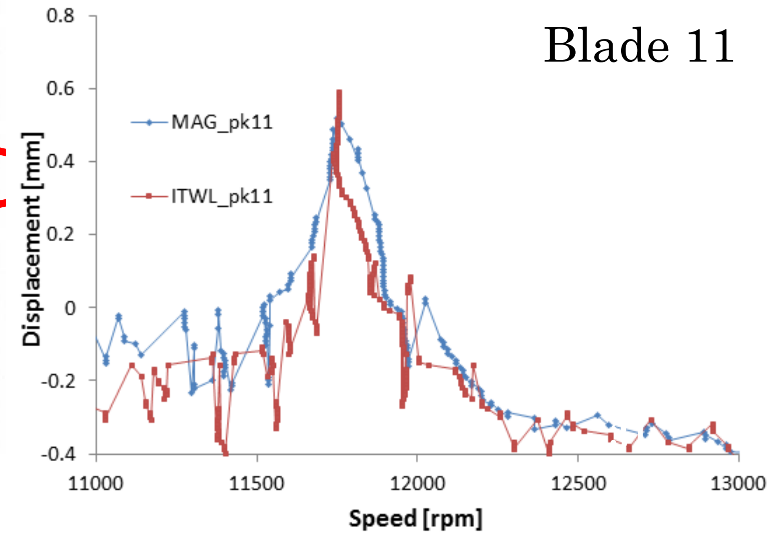


MAG ITWL

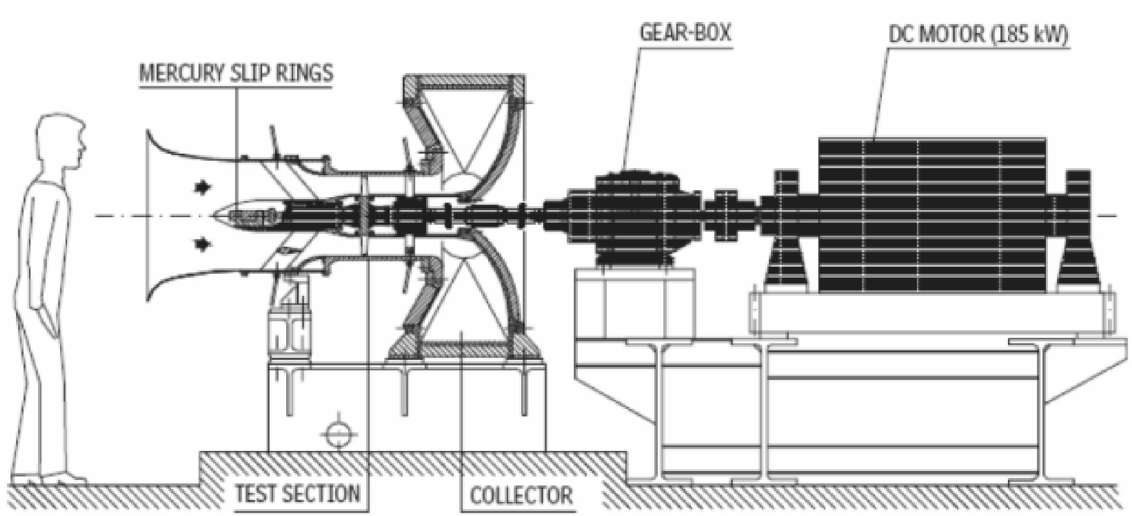


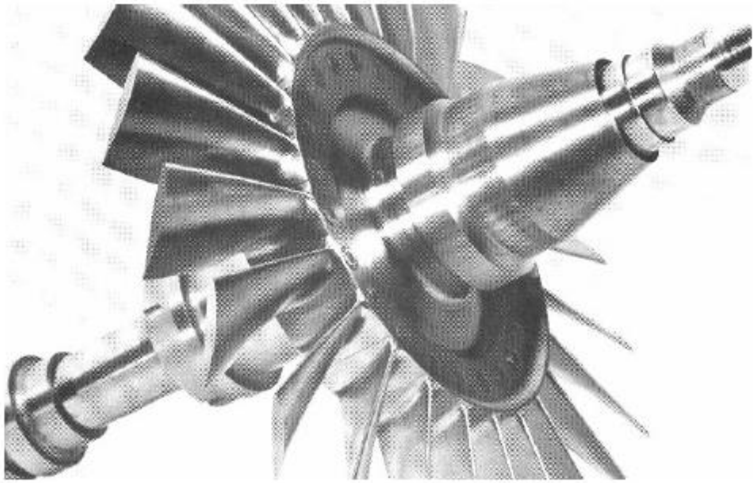
Strong agreement, both in amplitude and respect to the speed.
The expected resonances were measured correctly.





Test in the R2 compressor rig

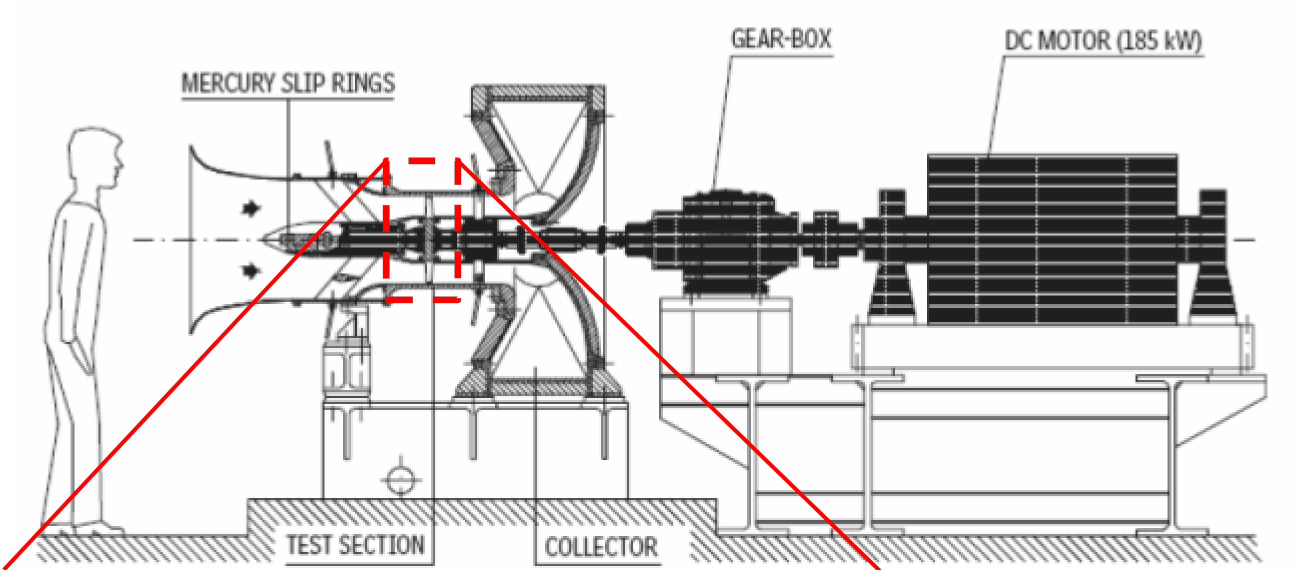


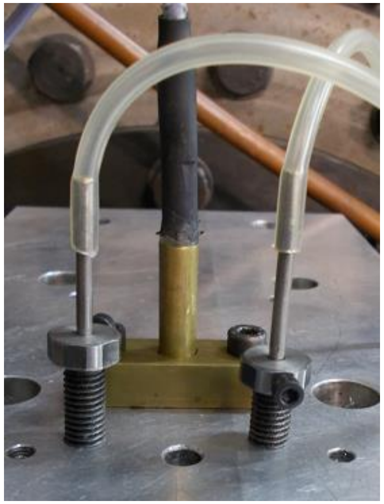


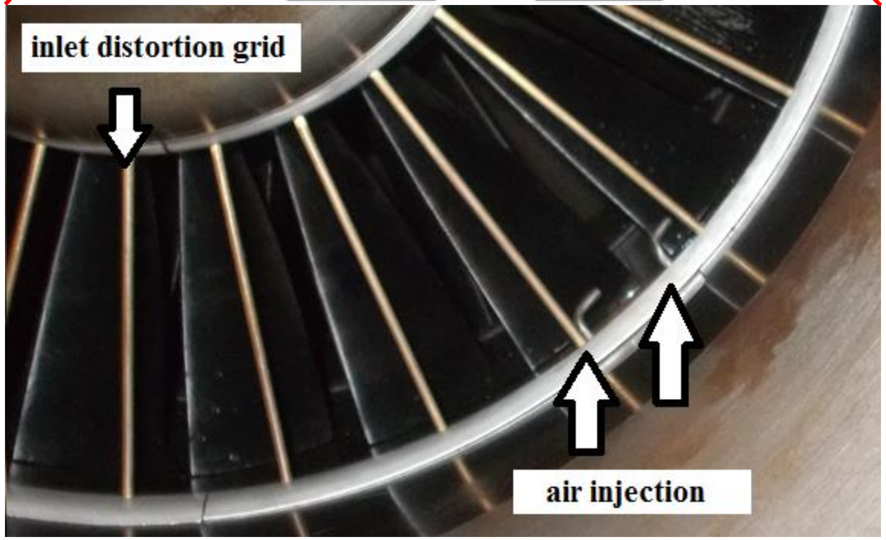
High speed compressor driven by a 185kW DC motor. The rotational speed can vary up to 6000 rpm. It is a single
stage axial compressor with a 400 mm tip diameter test section. The rotor is composed of 24 subsonic blades of the NACA 65 family.

3 BTT sensors
at [0 90 180]°
Speed transient:
2000 to 5500 rpm
Fs: 1 MHz

Test in the R2 compressor rig



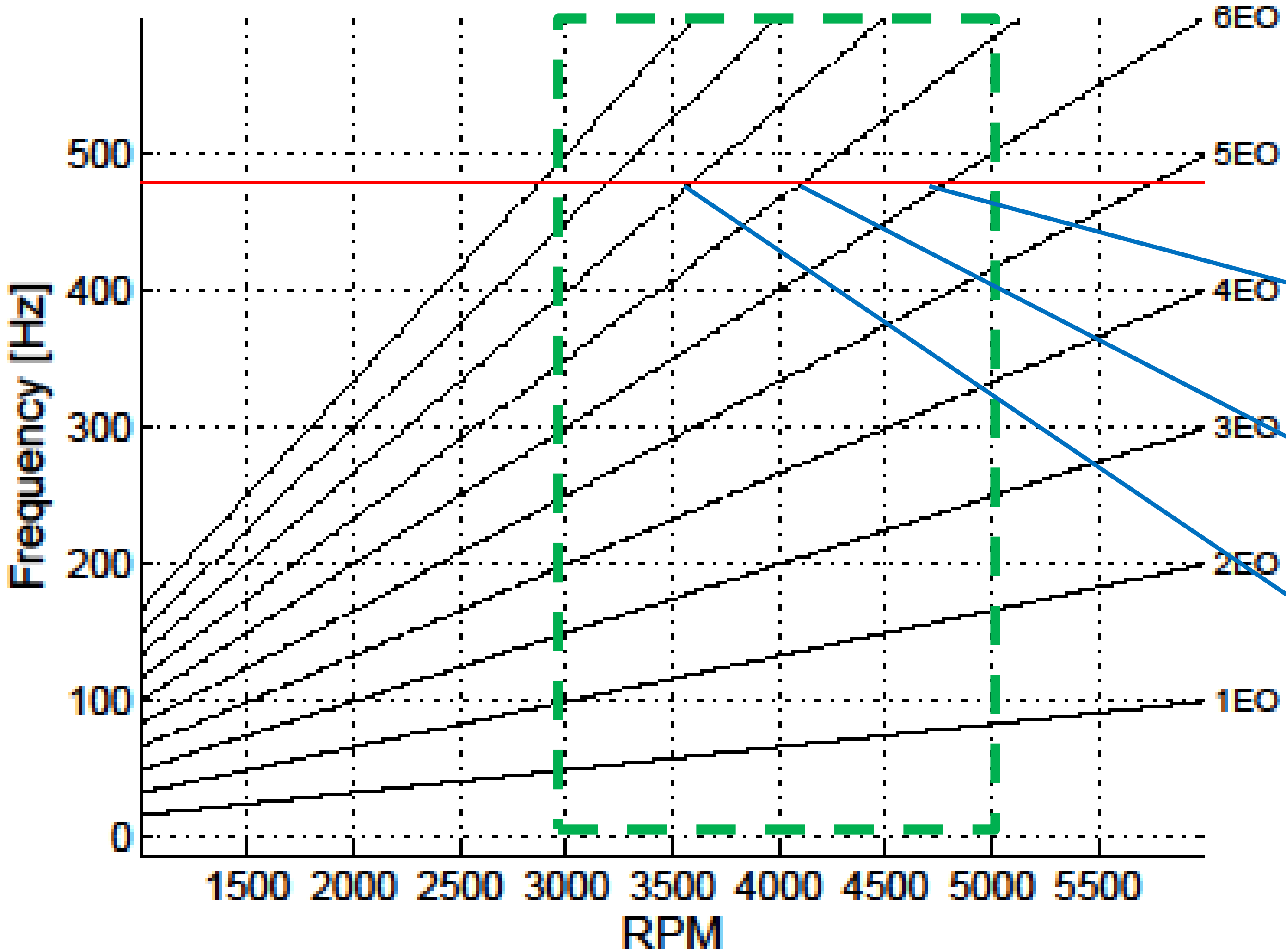




- <u>Inlet distortion grid</u> → excite synchronous blade resonances
- <u>Air injection</u> → excite asynchronous blade resonances

What do we expect ?

SPEED TRANSIENT: 3000 – 5000 RPM



Synchronous Resonances:

4800 rpm

4200 rpm

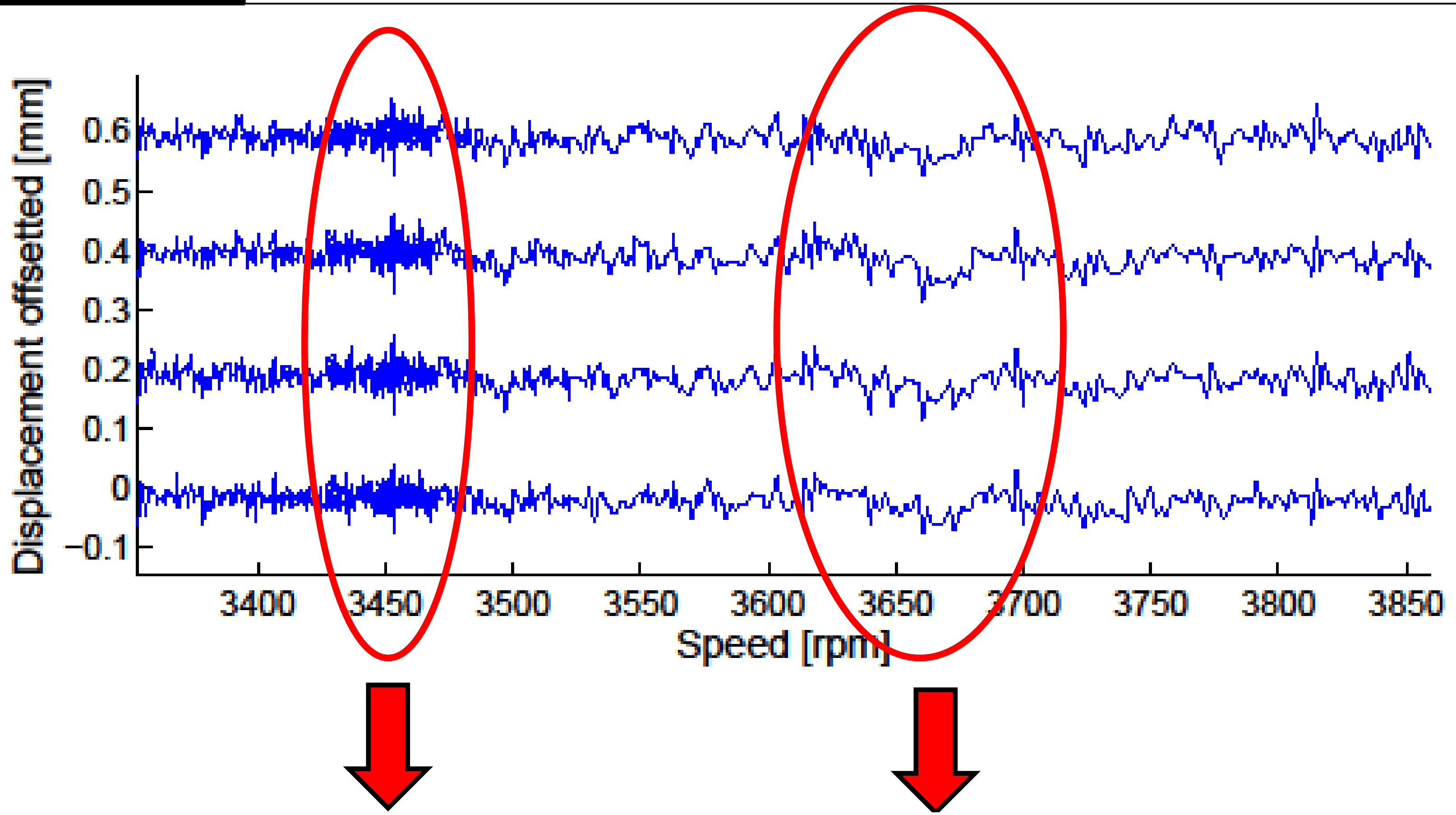
3600 rpm

+

Asynchronous Resonance

3500 rpm

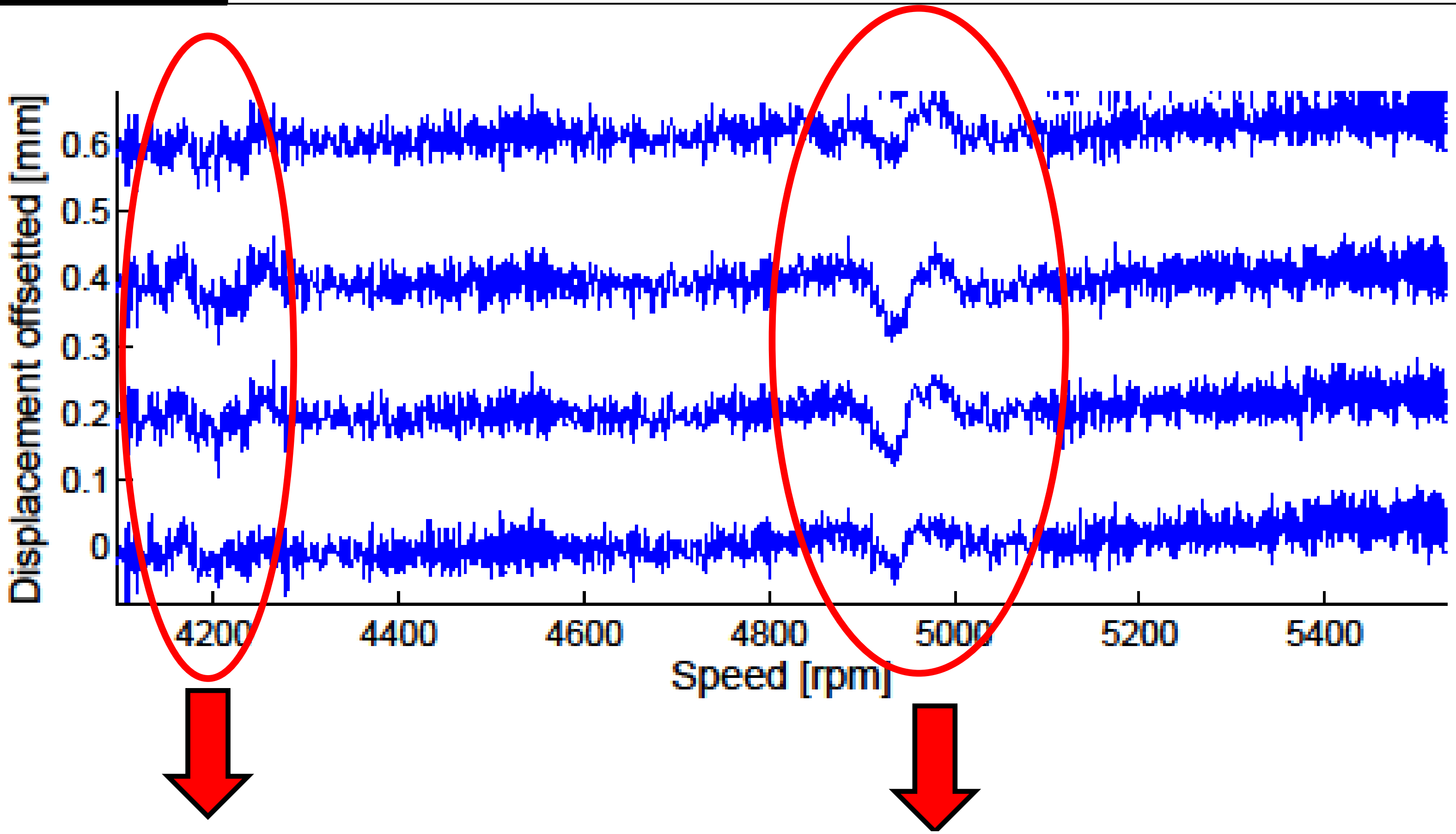
Test in the R2 compressor rig



Asynchronous Resonance 3500 rpm

Synchronous Resonance 3650 rpm

Test in the R2 compressor rig

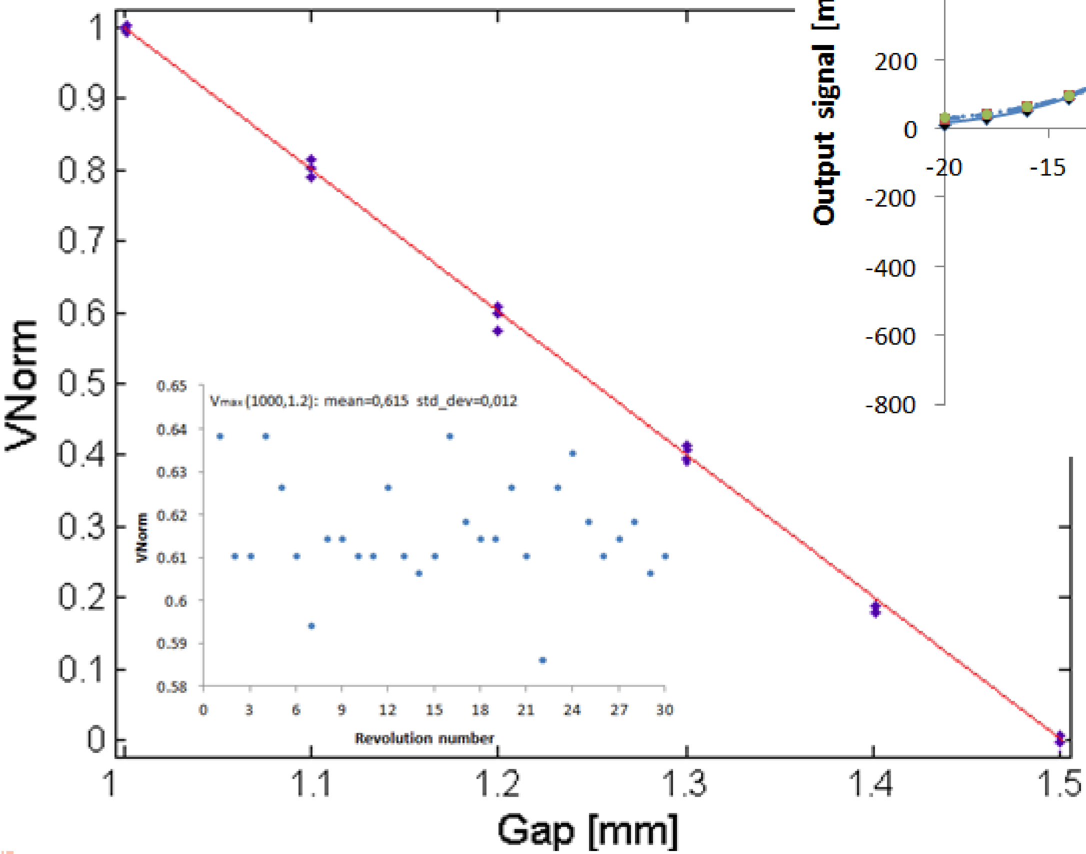


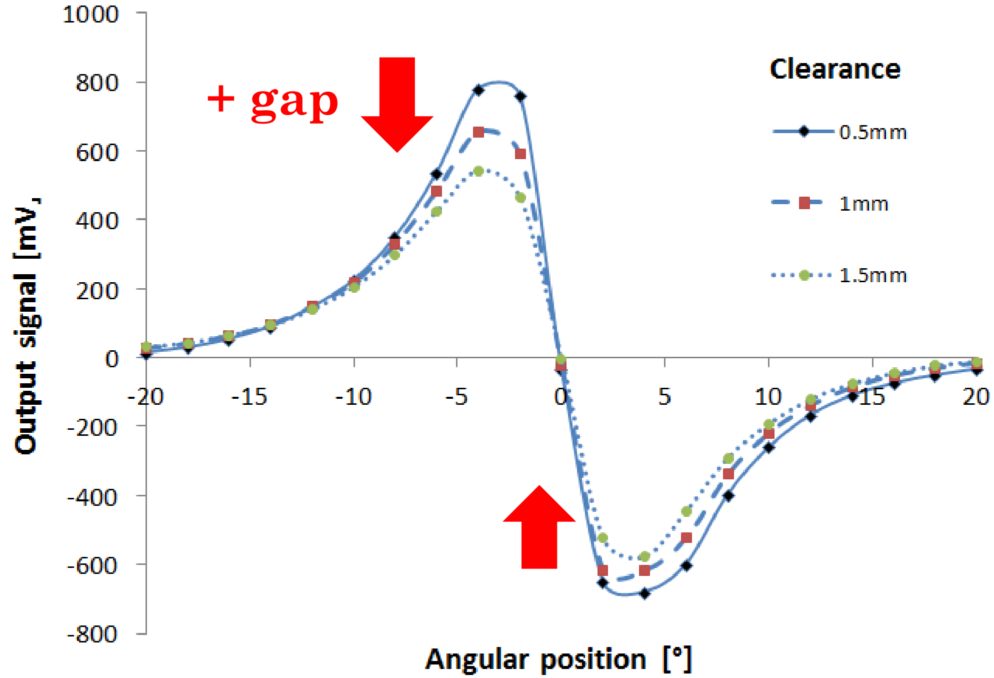
Synchronous Resonance 4200 rpm

Synchronous Resonance 4900 rpm

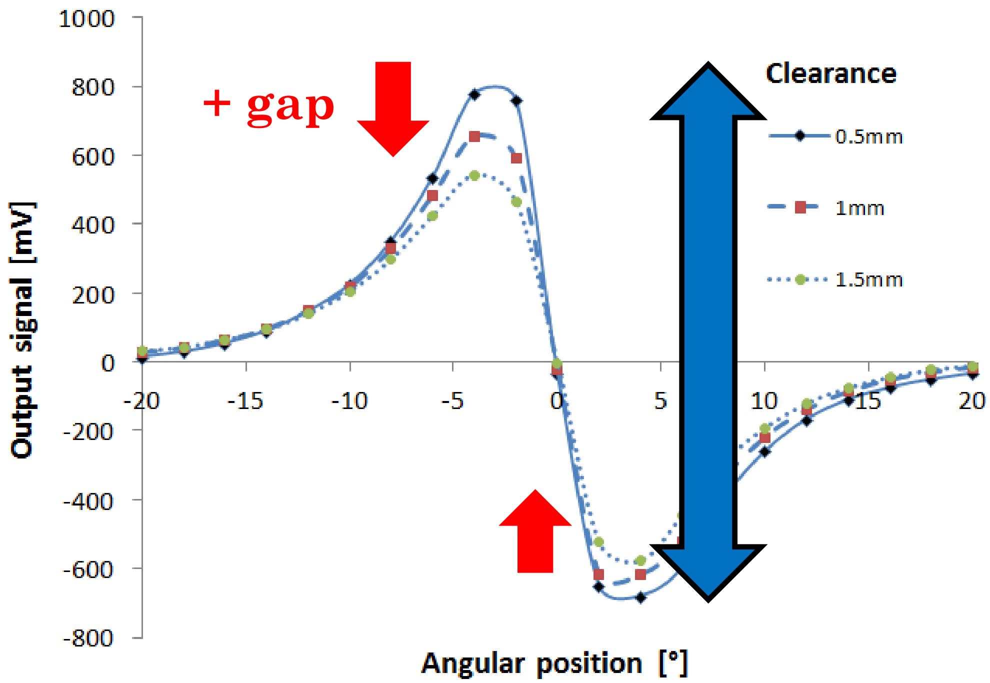
Effect of the gap variation

CALIBRATION CURVE FOR GAP MEASUREMENTS



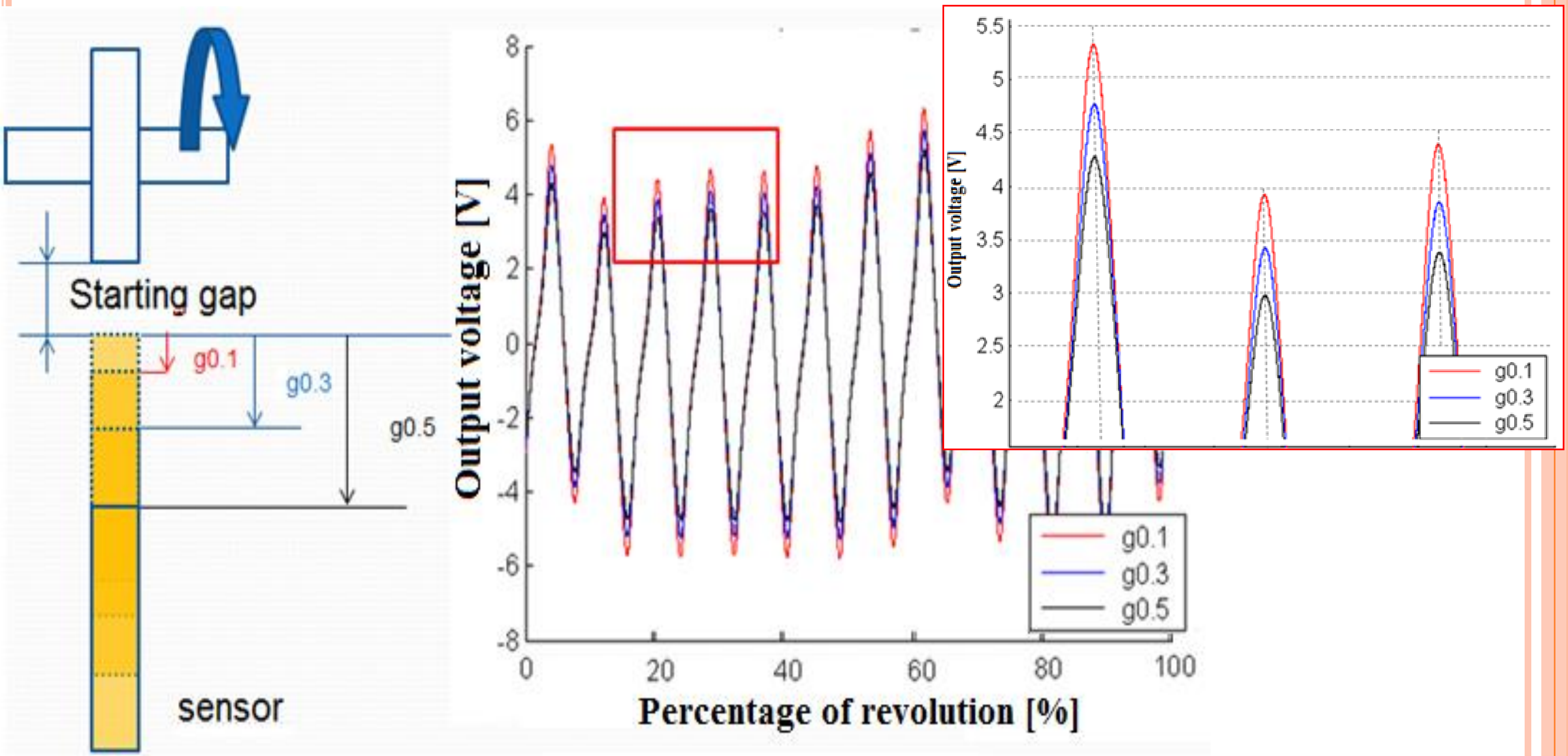


Effect of different blades



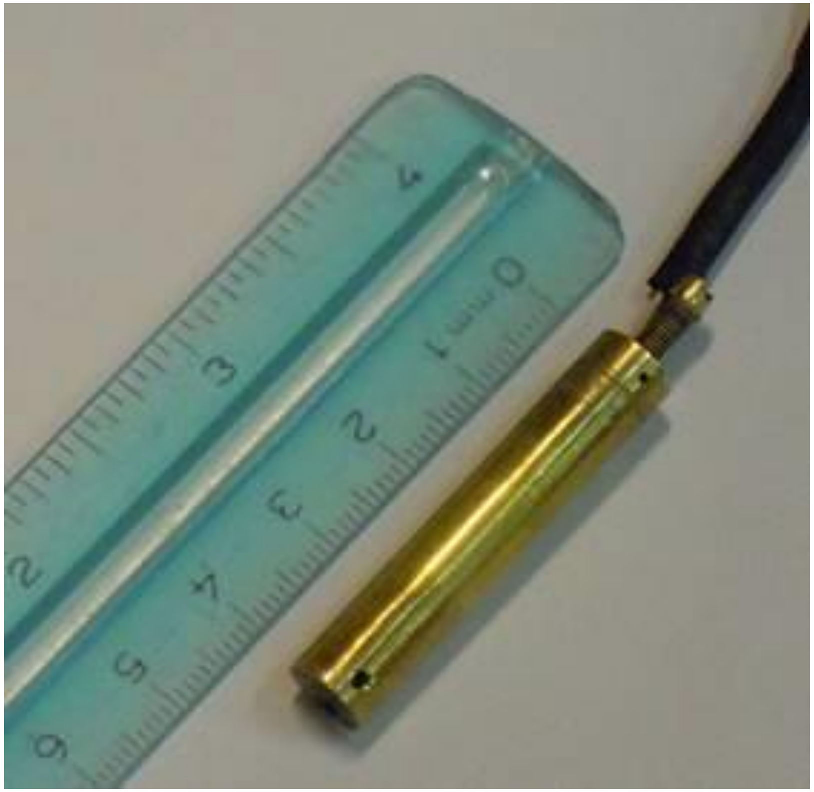
Different Blades

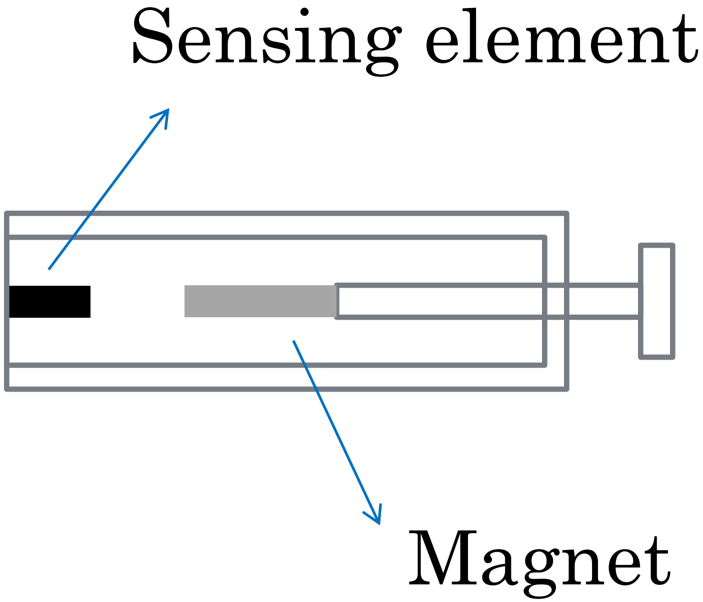
Effect of different blades and gap variation



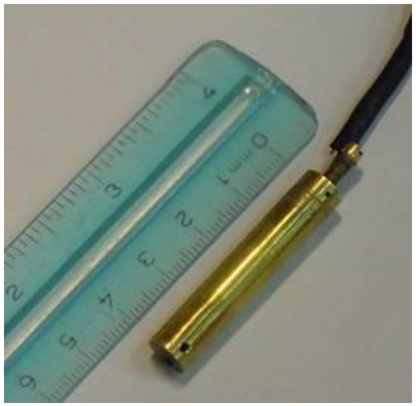
<u>Different peak to peak values:</u>
<u>It is possible to measure clearance but it requires a normalization</u>

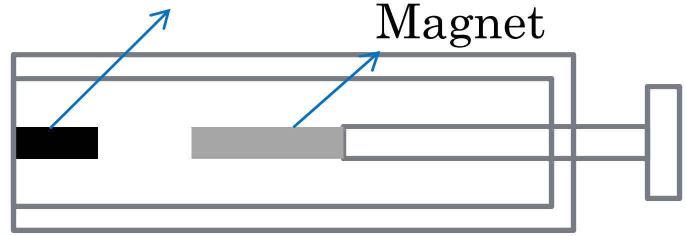
First sensor prototype



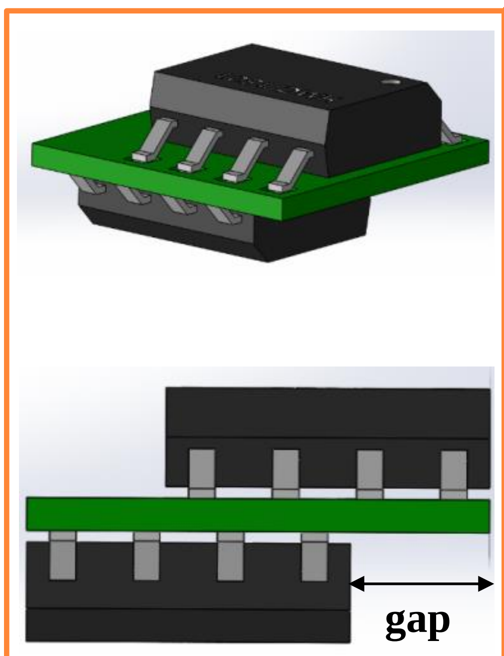


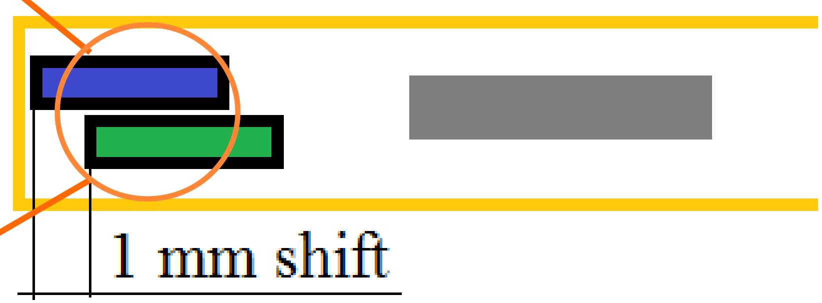
Differential sensor



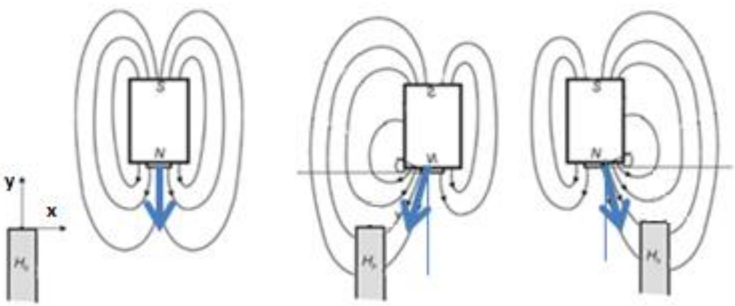


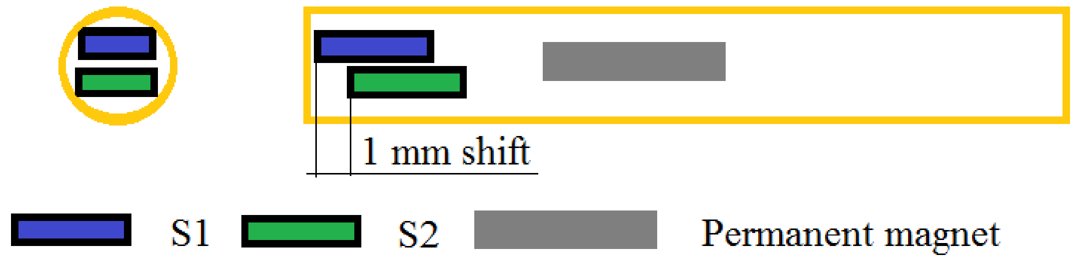
The differential sensor



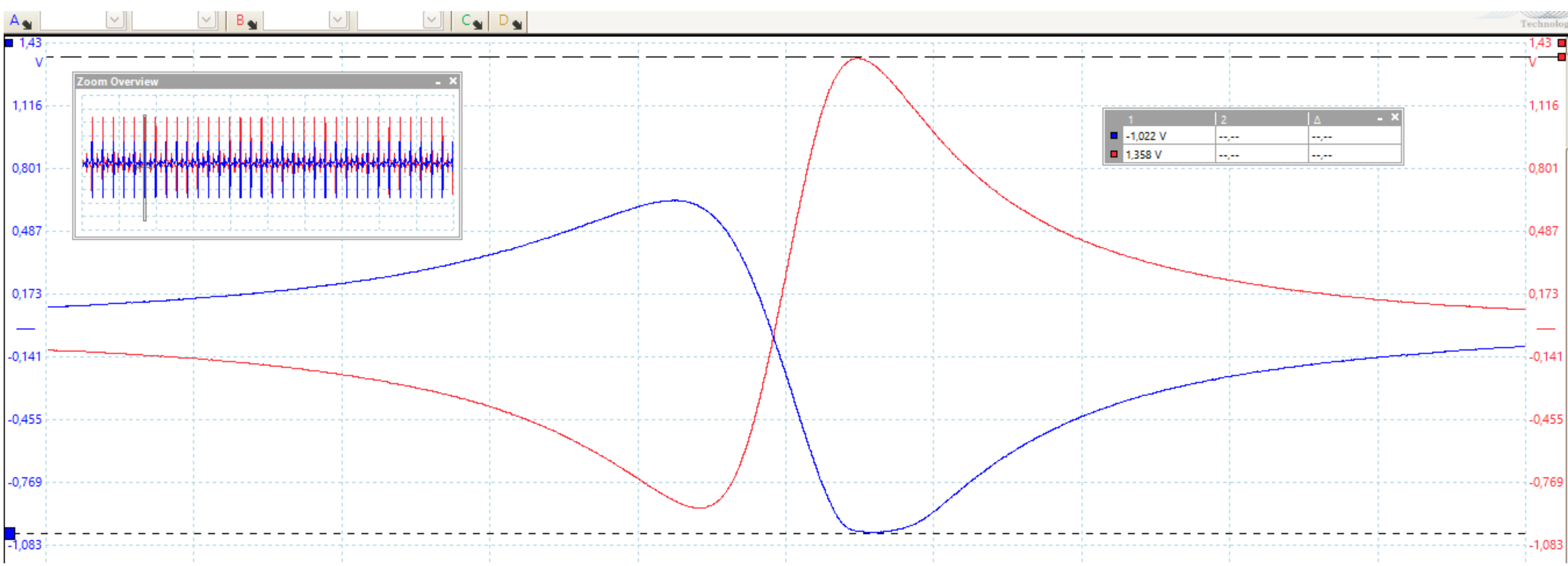


Differential sensor

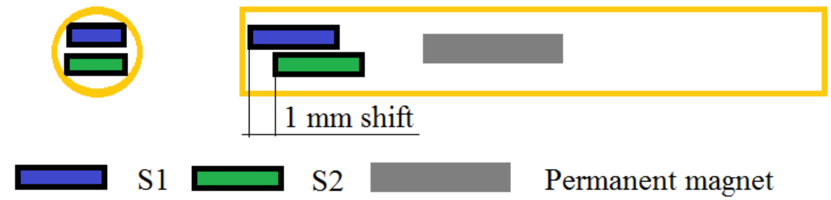


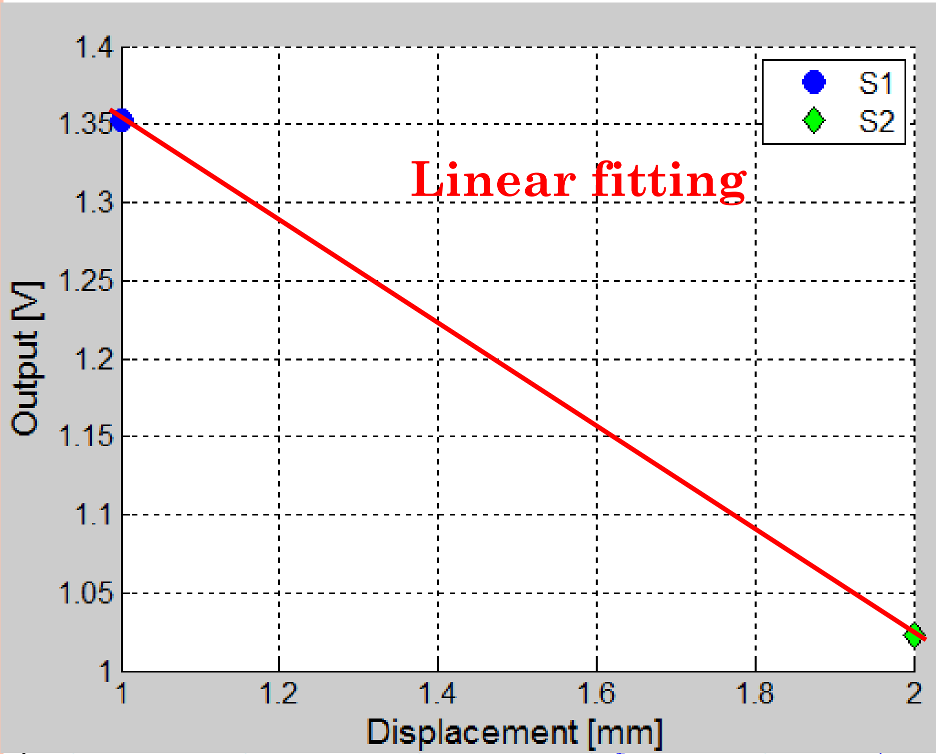


Blade passage → two pulses:

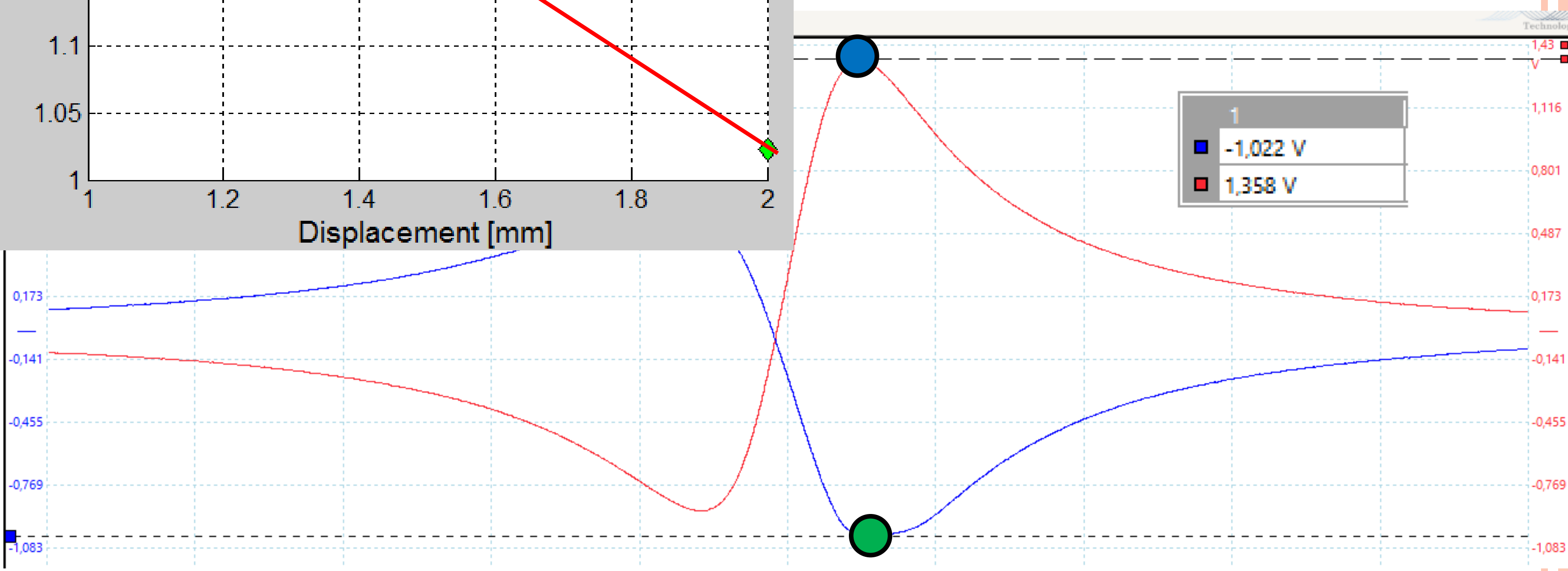


Differential sensor

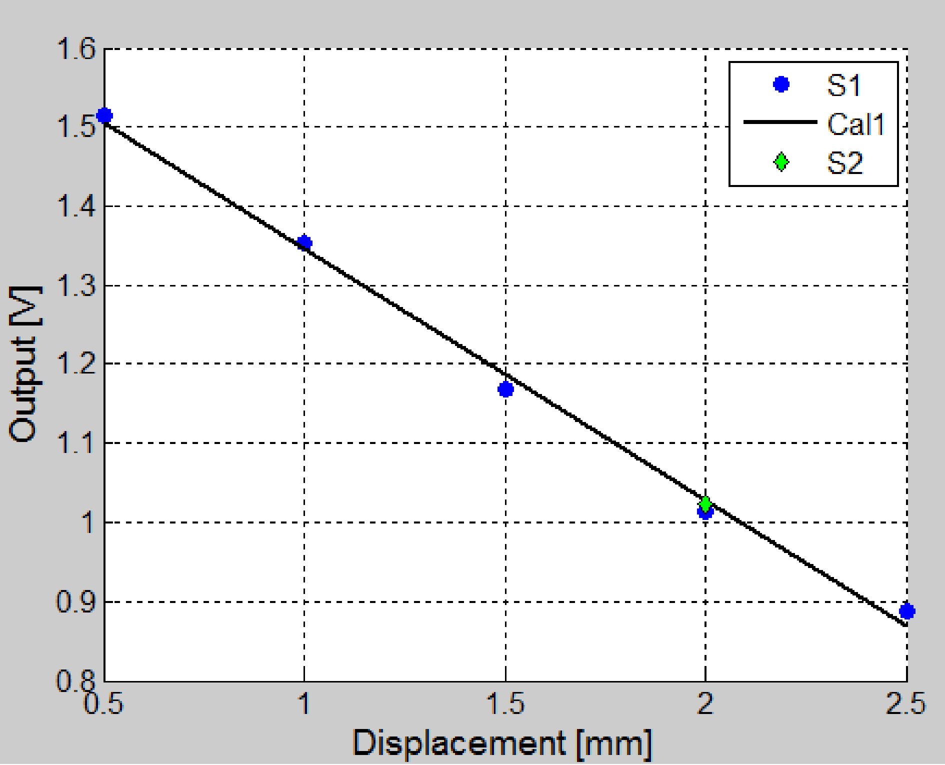


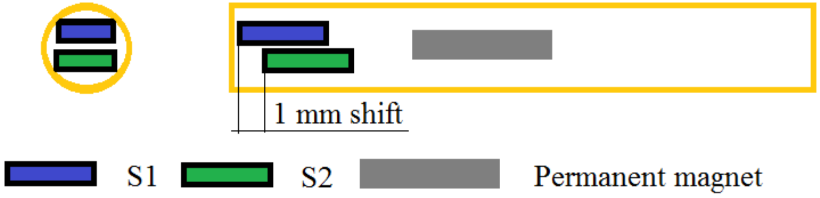


Blade tip – S1: 1mm – 1,358V
Blade tip – S2: 2mm – 1,022V



Differential sensor



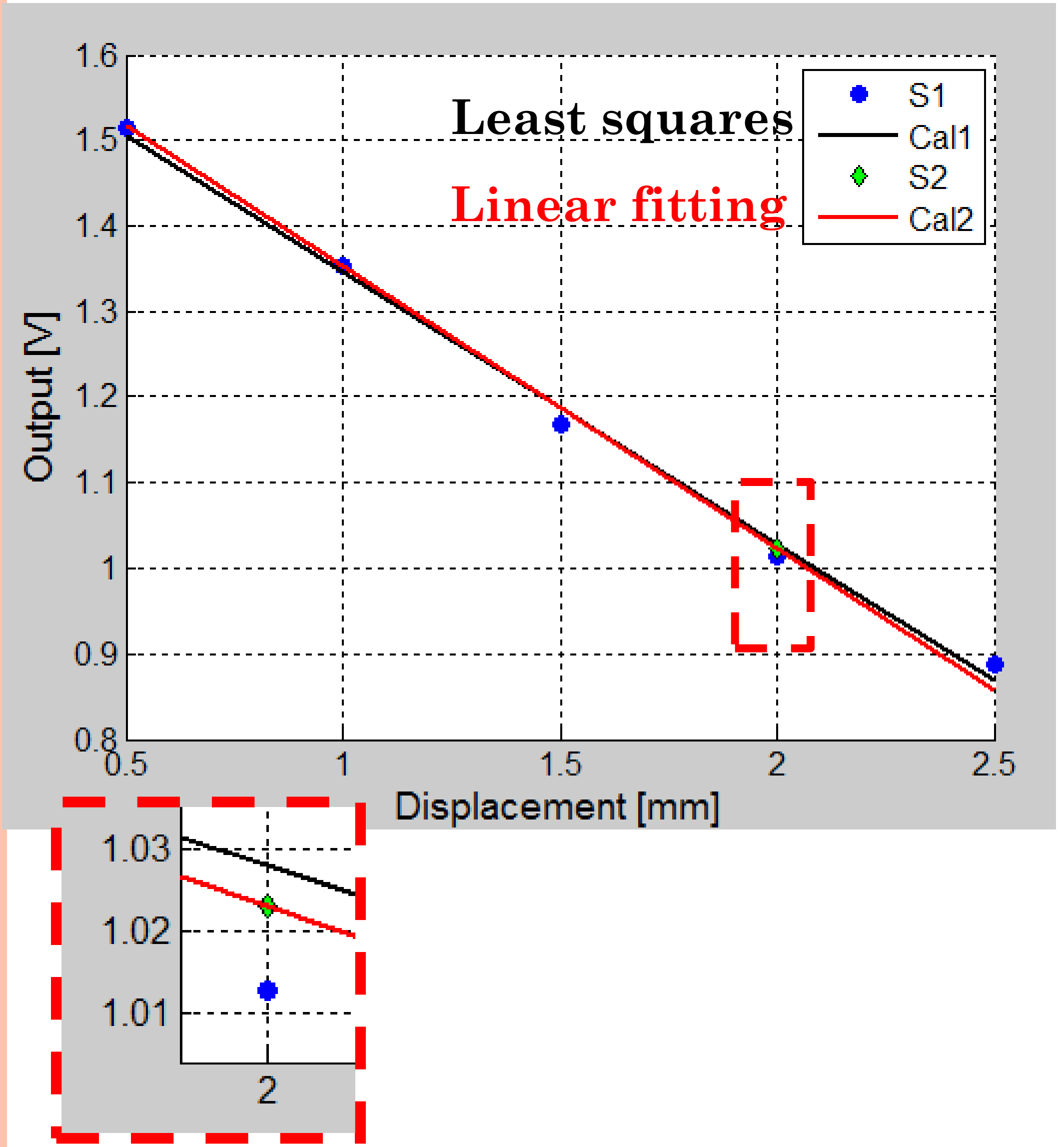


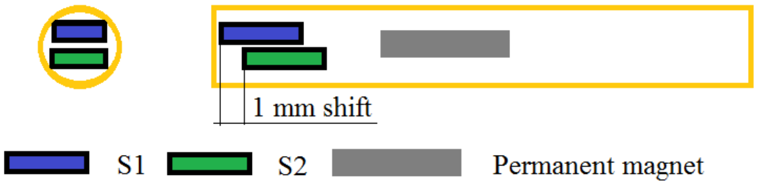
Typical calibration (sensor S1):

Range: 0,5mm – 2,5mm

Step: 0,5mm

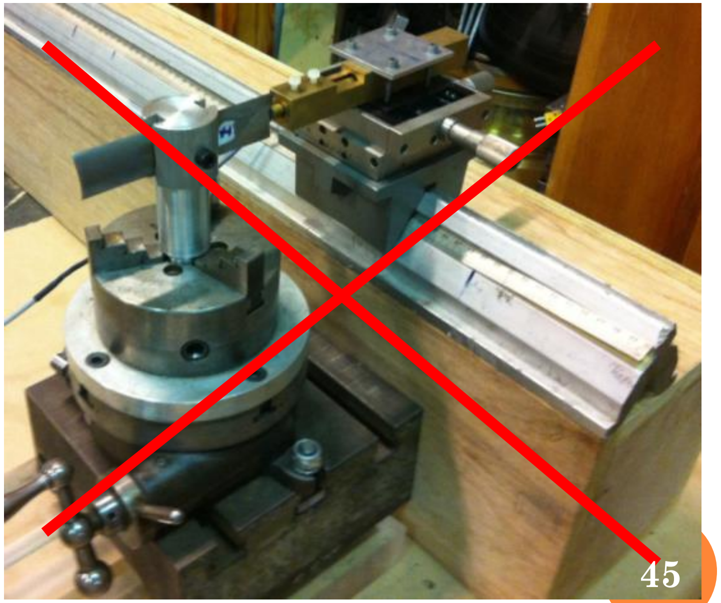
No calibration !





Two points → linear fitting

S1 S2 → Calibration 2



Conclusions and future developments

Magnetoresistive sensors can be used for simultaneous BTT and BTC measurements

Features:
small size, fast rise time, cheap technology, high S/N, possibility to measure withouth making holes

Limitations:
need of ferromagnetic materials (or special expedients)

Developments:
Rotary dies monitoring ?
Anti – Aliasing algorithm ?
Applications at higher temperature ?

Thank you!