GARRETT ADVANCING MOTION - Thaon les Vosges

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GEARS AND BEARINGS FAULTS DETECTION: FROM INSTRUMENTATION TO CLASSIFICATION

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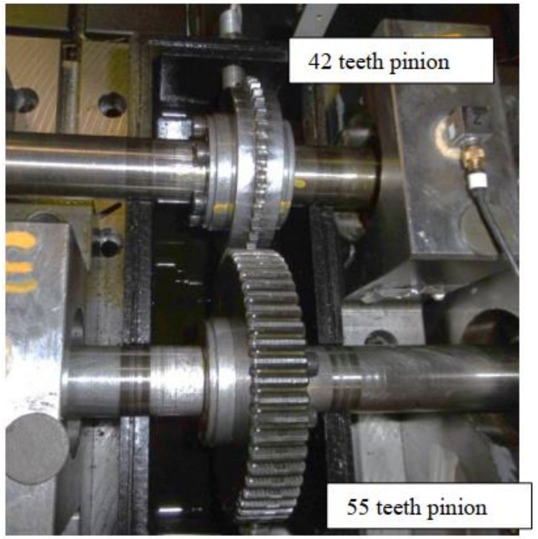
- Current trend :
    - **detect failures** (cracks, spall, pitting …) as soon as possible;
    - **identify** them and **control their evolution**.
    - → Monitoring and processing of a huge amount of data.

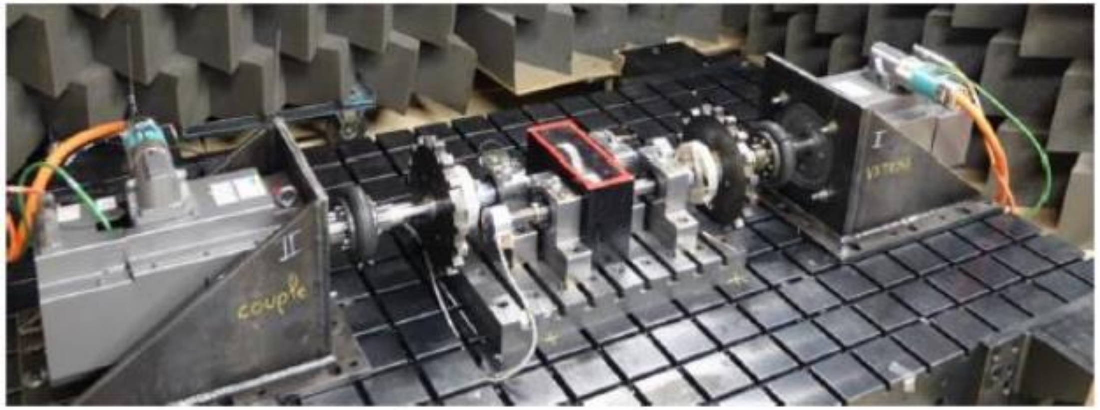
- Vibratec proposes an approach based on its double competence in **instrumentation** and **simulation**: the **IAS measurement** coupled with **numeric simulation** and **machine learning**.

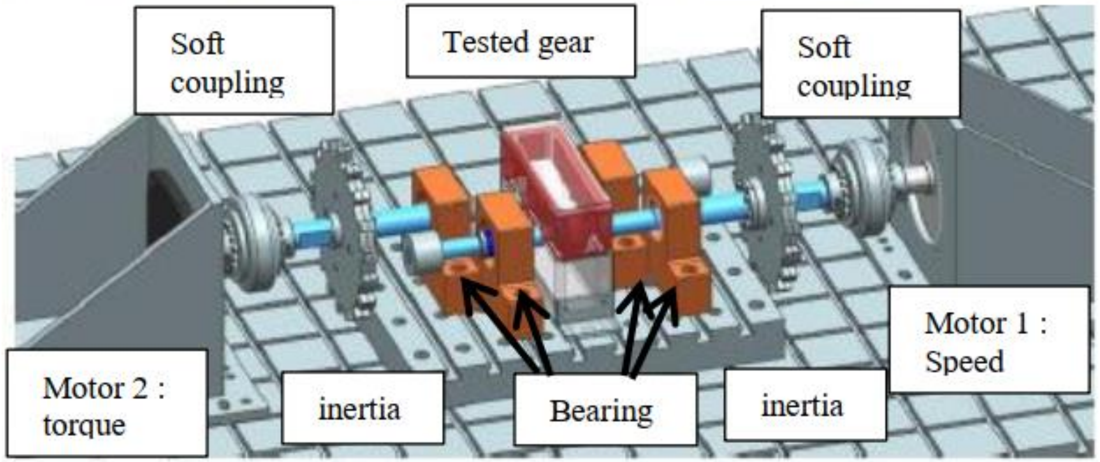
- In this presentation:
    - global approach applied on a **specific HMS test bench**;
    - **preliminary work** on a database before the application of the process **to an industrial case**.
    - The aim: **detect and classify the failure of a gear or a bearing**.

- The test bench:
  - one motor driven in speed (input shaft),
  - the other motor driven in torque (output shaft).
  - → The **load applied on the gear is controlled**.

  - soft couplings used to uncouple the motors
  - inertia added to be **representative of an industrial case** (e.g. wheel, sprocket, shaft line...)

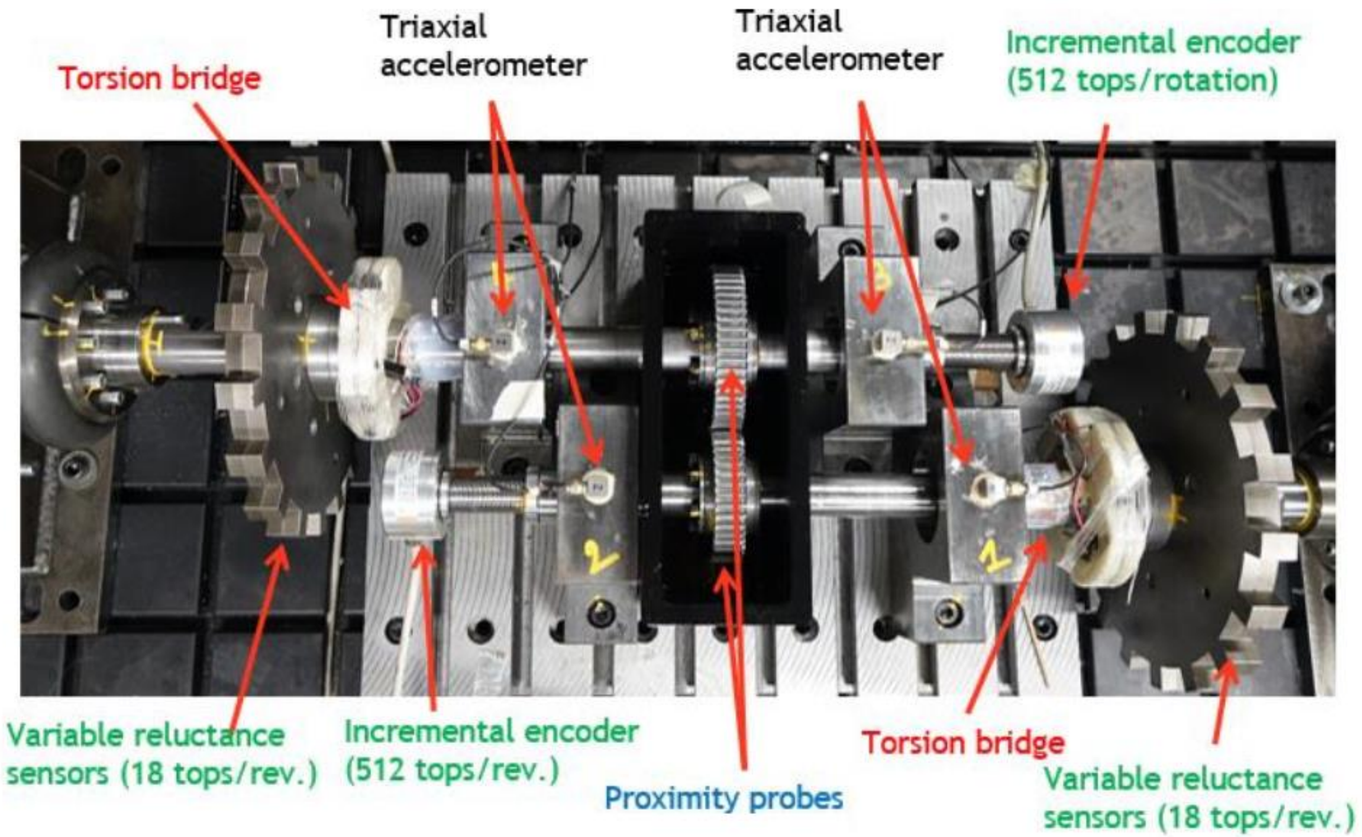




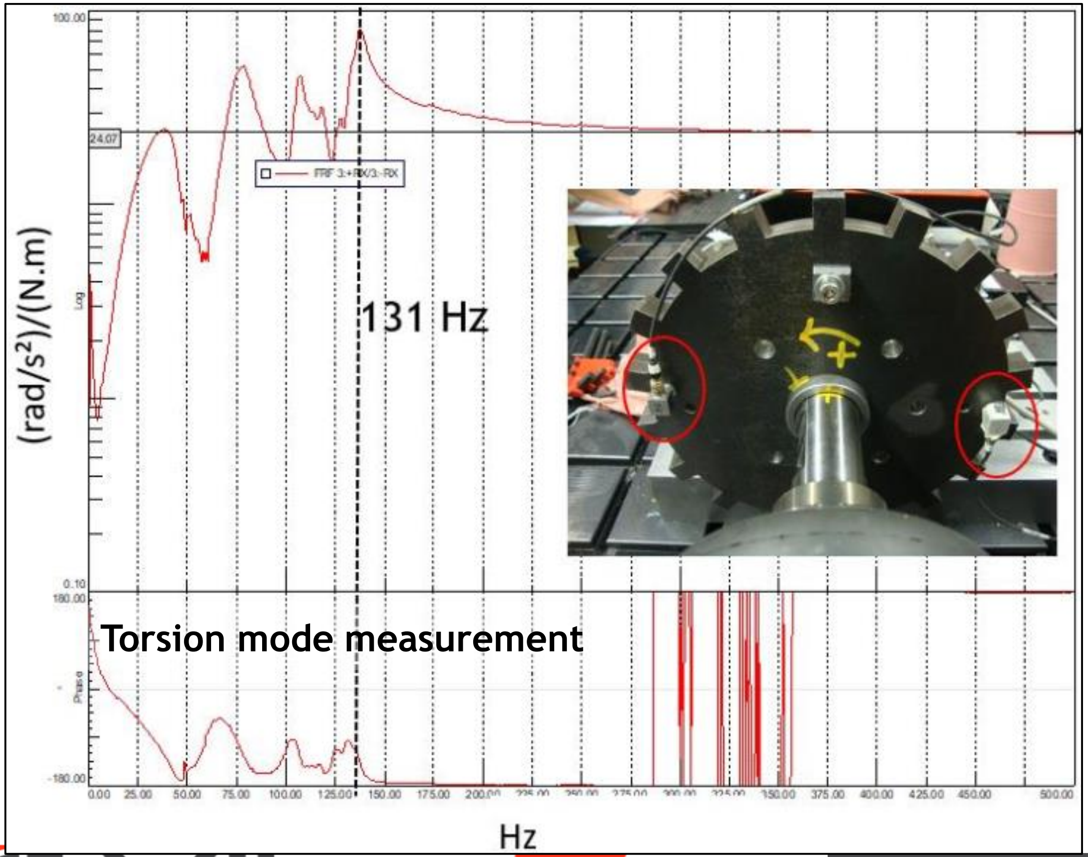


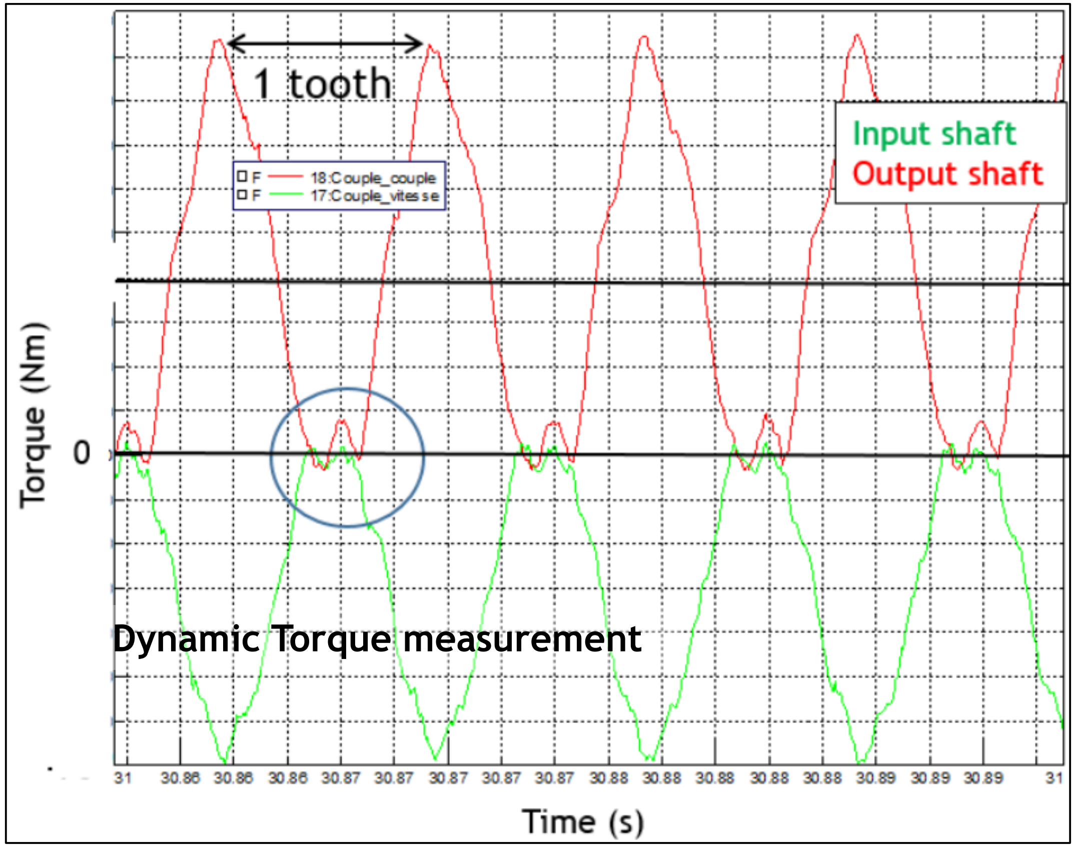
- Incremental encoders
- Variable reluctance sensors
- Proximity probes
- Tri axial accelerometers
- Torsion bridges + telemetry

- Aim :
  - Monitor the torque
  - Resample signals in angular domain
  - Detect the failure with different sensors (intrusive or not)

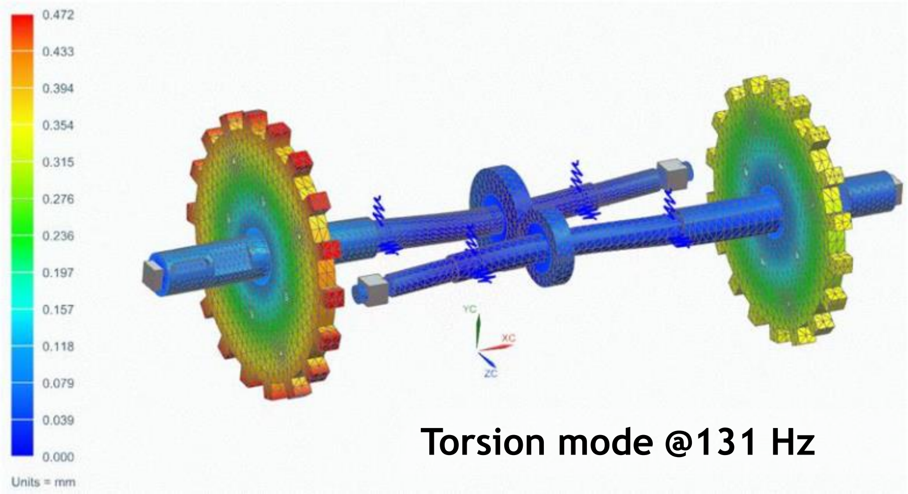


- Accelerated test process: the **gear mesh frequency** is **coincident with the torsional mode of the shaft line**
- The **dynamic torque is twice the value of the static one**, leading to torque inversion and **rattle**. Some **backlash** is expected on the gear.

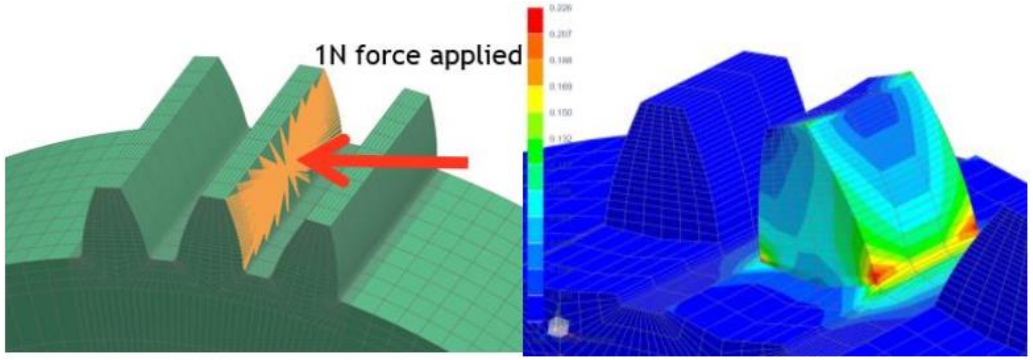




- **FEM analysis:** The torsional mode is calculated and tuned, according to the measurement results;
- FEM results used as inputs to construct a **flexible multi-body model including the real pinions geometry and the contact stiffness**. Model tuned to be in accordance with the measured Transmission Static Error (TSE) and the teeth clearance;
- The pinions are clamped on their inner diameter, and a **unitary force is applied** on the contact point.
- The resulting stress is used as an input for the **fatigue analysis**. The peak torque value is converted into a force and applied on the contact point to obtain the corresponding stress.
- This stress occurs roughly 3 times/s (185 rpm), corresponding to an **estimated lifetime of 19 hours**, based on Wohler curve.

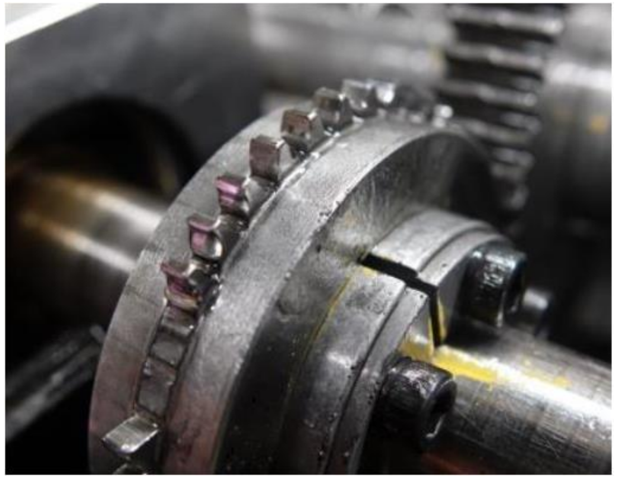


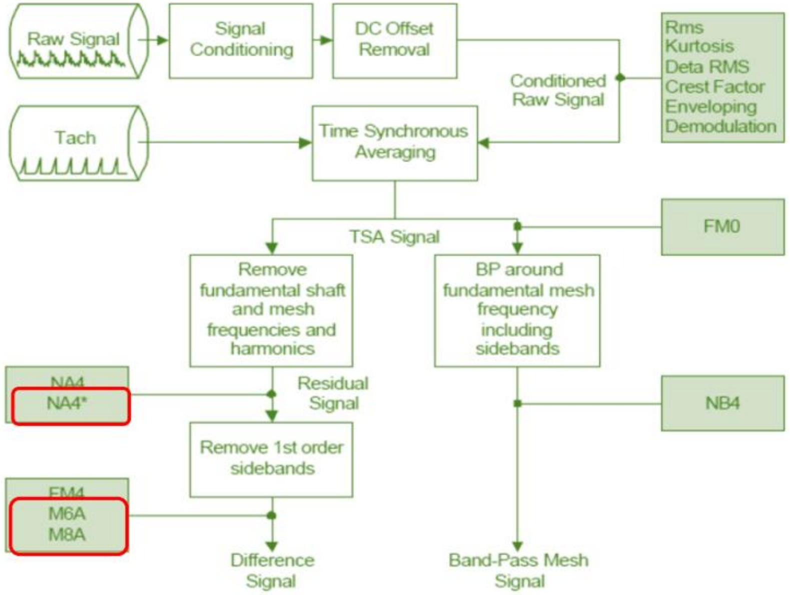
Torsion mode @131 Hz

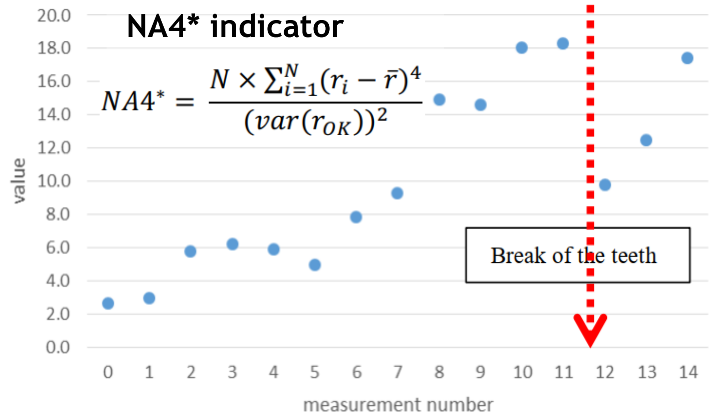


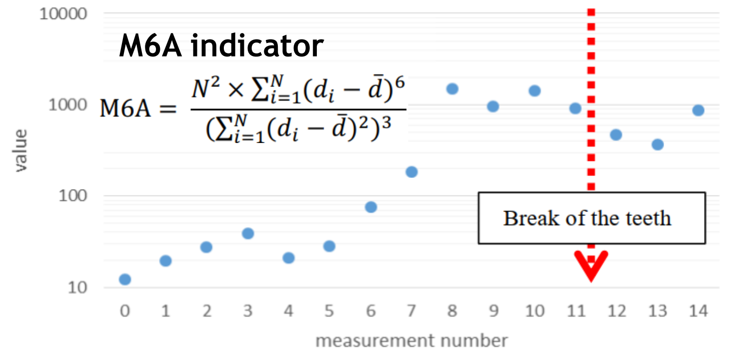
Stress analysis

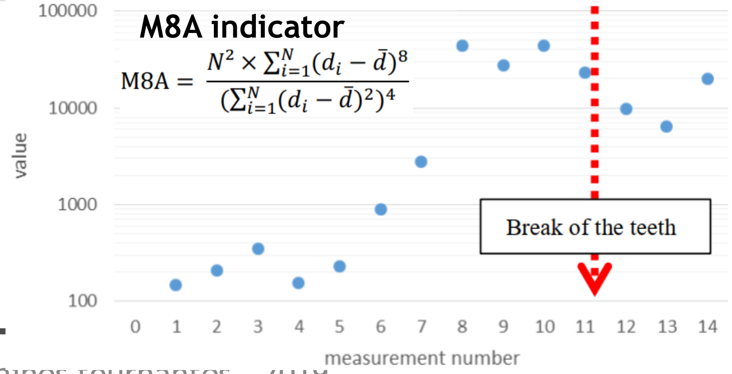
- After **20 hours of test**, two successive teeth of the 42 teeth pinion broke → **good correlation between the numerical model and the physical behavior**
- the **usual indicators** used in vibration analysis (RMS, Kurtosis, Crest factor) **do not provide evidence of gear wear**, as they are subject to a lot of shocks (backlash)
- other **indicators calculated on the TSA residual and differential signals:** clearly a change occurs in the gear dynamic response after a few hours of functioning



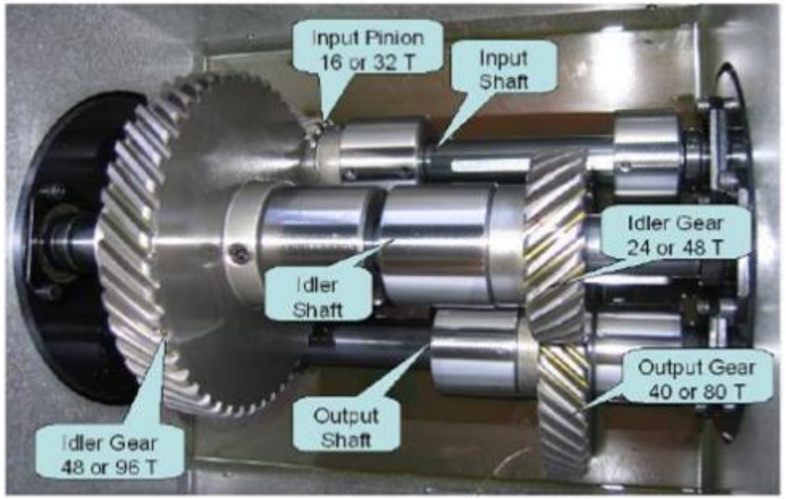






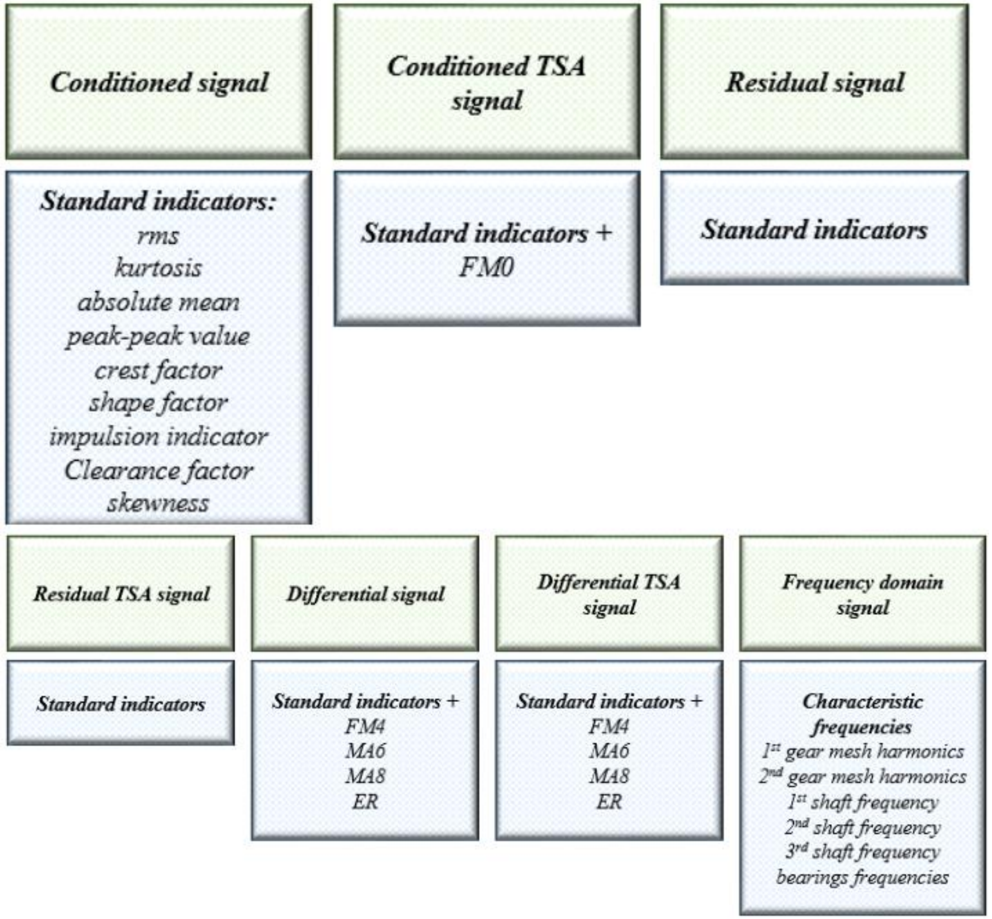


- Applied on PHM society database:
  - **Two gear stages** mounted on **three** shafts, with **six bearings**;
  - **Spur gears** and **helical gears.**
  - 140 configurations (faulty and healthy gears, 5 rotation speeds, 2 load cases) repeated 4 times.
  - → **560 measurement inputs**

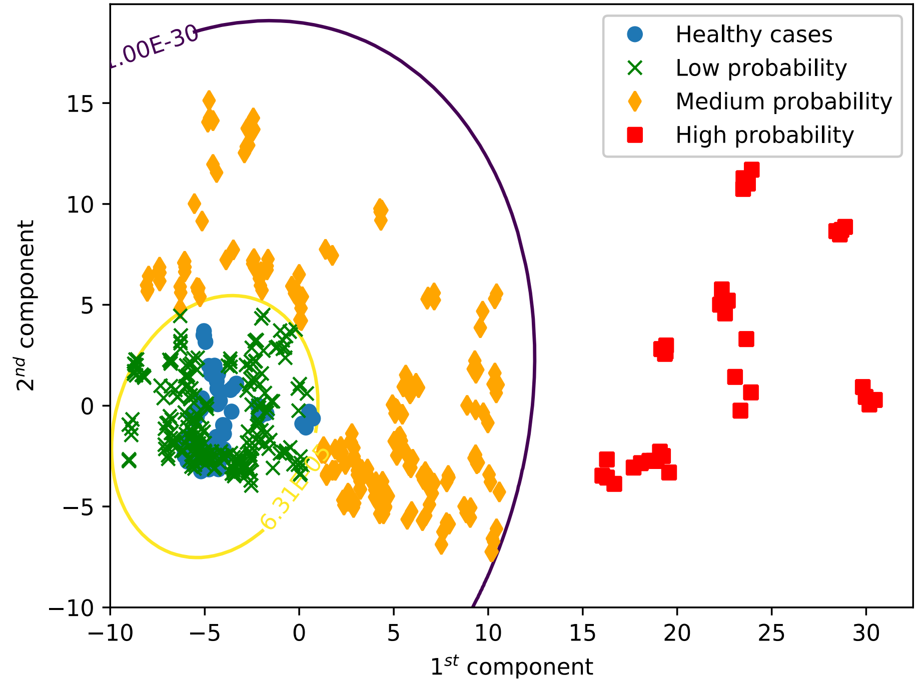


PHM Society test bench

- Three steps:
  - ***Condition indicators (CI) computation***: two accelerometers → **298 indicators** extracted
  - ***Classification using machine learning (ML):*** supervised algorithms (Support Vector classifier (SVC), Nearest Neighbours classifier (KNN), random forest) → **ensemble learning**
  - ***Qualitative analysis using new global indicators***: The indicators not equally sensitive to the different type of faults. A **selection based on the physics described by each indicator** is operated to predict the type of fault detected.→ Aim: divide the faults into 3 classes: bearings fault (BFI), gear generalized fault (GFI) and gear localized fault (LFI)



- **PCA Analysis**: to find, on a scatter plot, the direction in which the data projection has a **maximum variance**. This direction is called the first principal component. The orthogonal directions to this first PCA also display the maximum variance
- **Good feature extraction for the bearing faults**, allowing a qualitative analysis of the data
- Difficulties encountered to predict localized or generalized gears faults. The selected features are not enough relevant. → **Work in progress to find better sets of features.**



PCA result with the bearings fault feature selection. Yellow and purple lines represent respectively the $10^{-4.2}$ and 10^{-30} isolines of the probability density function derived from the healthy data. Healthy cases are given by blue dots, cases with a low / medium / high probability to have a bearings fault are given by green crosses / orange diamonds / red squares.

- **Complete (numeric + experimental) approach** set up to detect and to classify gears and bearings faults.
- Numerous sensors have been implemented on the test bench:
  - processing of the accelerometers signals have provided promising results;
  - Further processing ongoing on the speed sensors.

- Endurance test at a frequency close to the torsional mode → strongly decreases the lifetime of the gear, and reduces the test duration. **The achieved lifetime is correctly predicted**, opening the use of **digital twin** as a way to build data base for machine learning.

- Work on a database → **good ML indicators to predict the bearings faults**. Improvements needed for gears indicators.

- **Ongoing application** on an industrial aircraft engine gearbox (same test bench): will consolidate the approach, and enable to apply the fault classification method

Thank you for your attention!

Any question?