RUS Methods (Resonant Ultrasound Spectroscopy)

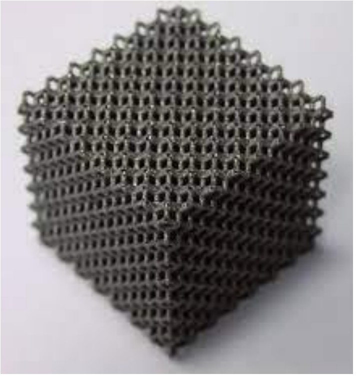
Applied to quality control of heat treatments on additive manufactured parts

Florian RAZAFINTSALAMA - CETIM

Context – RUS interest for AM

Parts with complex geometry, guarantee the integrity of parts is problematic

Use of volumetric NDTs : **X-ray computed tomography (XCT)**



Advantages

- The most efficient technic today : material health check, dimensional

Drawbacks

- But limited:
  - High cost, long measurements, not adapted to routine check
  - Not suitable to parts with large size and high density

Context – RUS interest for AM

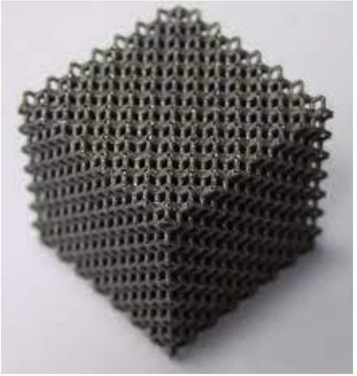
Promising volumetric NDT alternative : **RUS methods**

Advantages

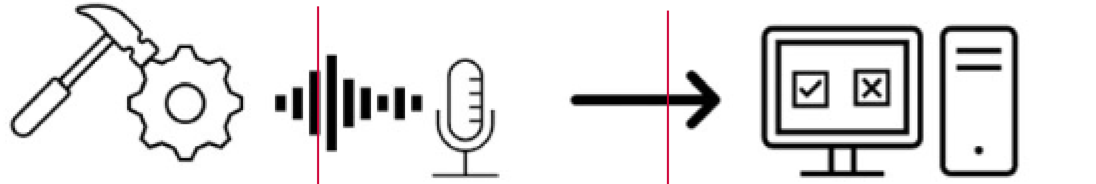
- Low cost, fast measurements, adapted to routine check
- Applicable to any geometry, surface roughness, size or density

Drawbacks

- Not explanatory (blind method), does not give any direct information on nature / position of the defect



RUS Methods – General principle

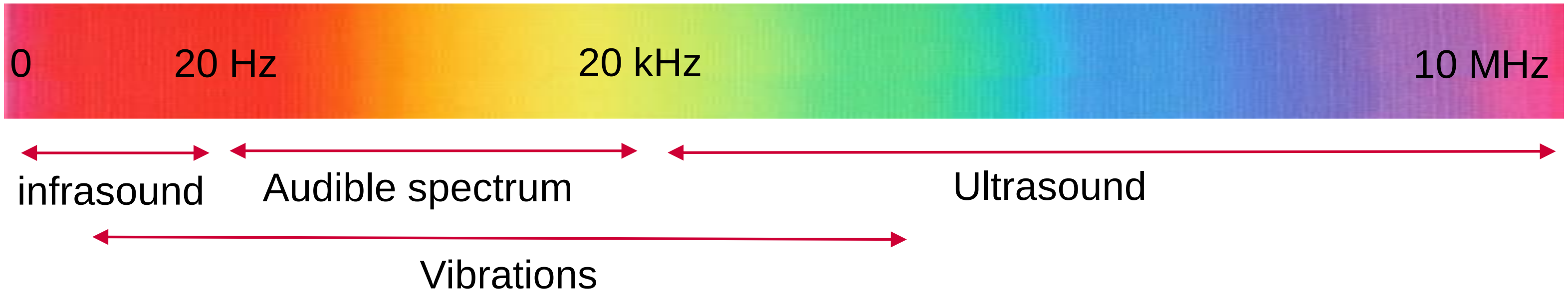


Source GMT+

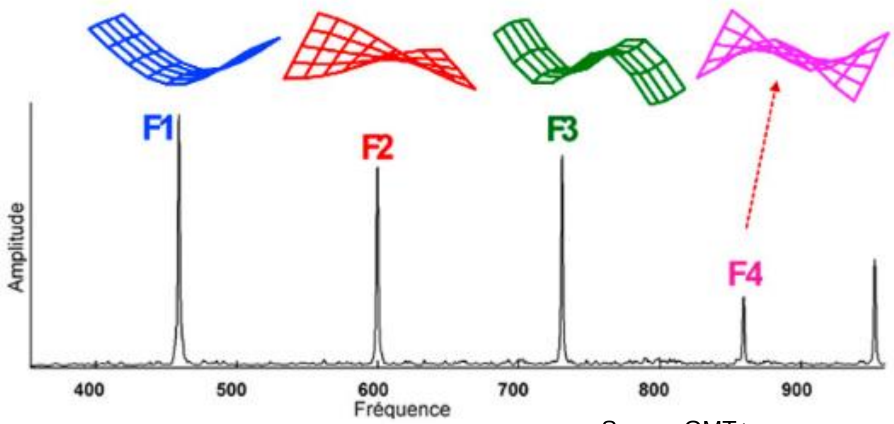
Stimulus :
Hammer, piezo, laser

Reception of the resonance :
Microphone, laser vibrometer, piezo, accelerometer

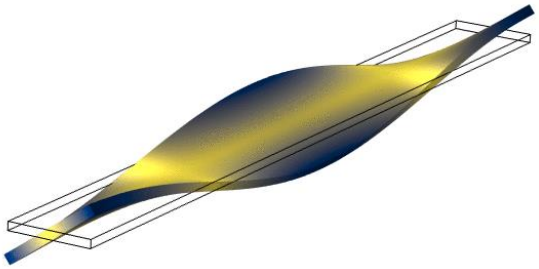
Signal processing : frequency spectrum
Oscilloscope, computer,...



RUS Methods – Resonance analysis



Source GMT+

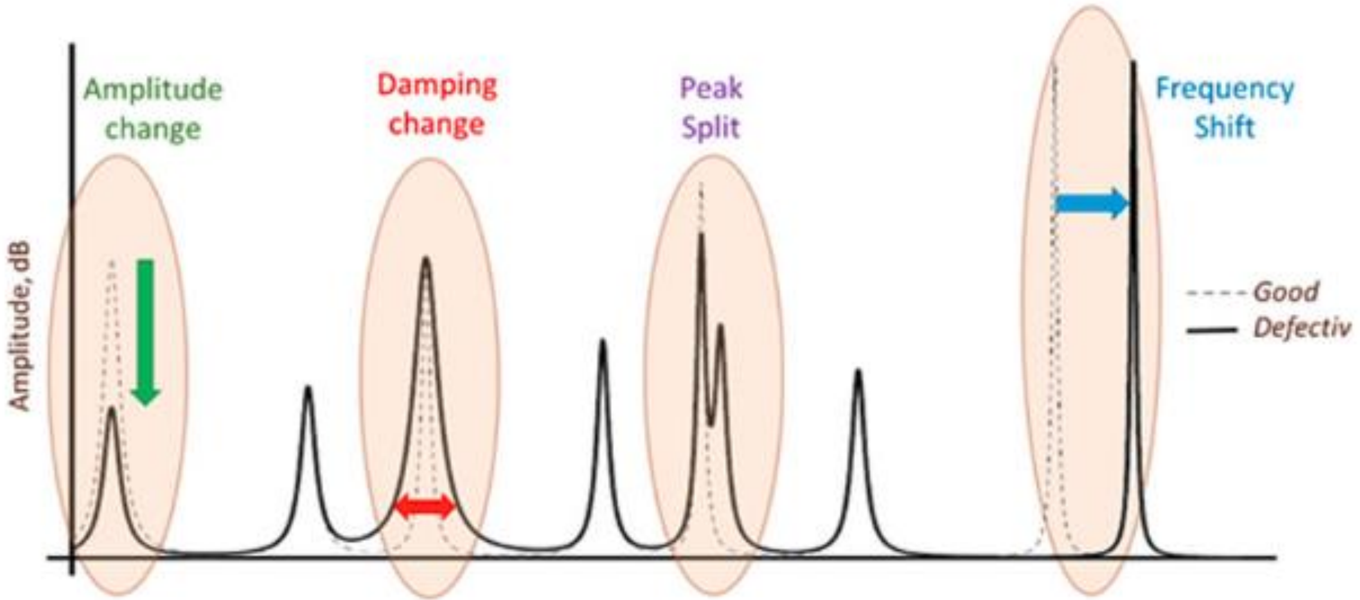


Torsion mode of a simple bar

Frequencies of modes of a part depends of :

- Its **geometry**
- Its material properties :
  - **Density**
  - Elastic mechanical properties : **Young modulus**, **Poisson coefficient**

RUS Methods – Resonance analysis



Source GMT+

Differences in the frequency spectrum → Sorting / classification of parts, correlations with other parameters

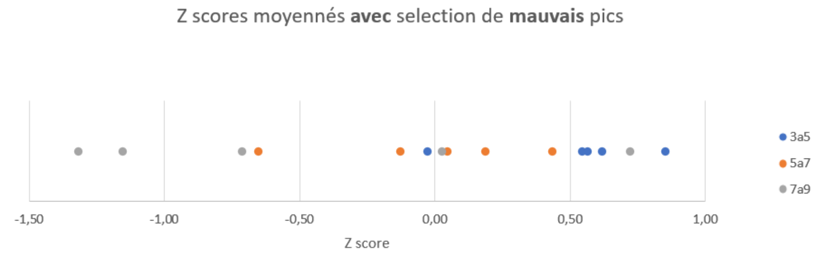
RUS Methods – Preliminary studies

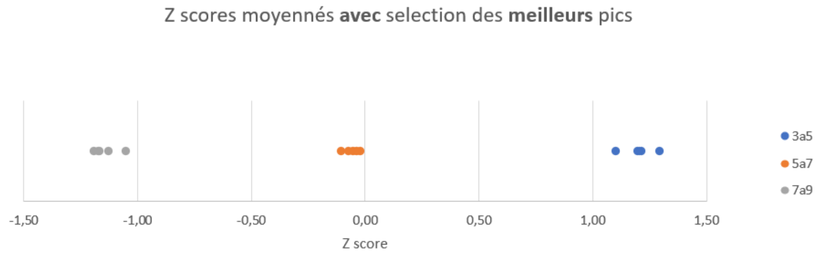
Blind method : preliminary studies for each case

- Are Sorting / Classification or a correlation possible?
- Creation of a reference

Need to **select relevant peaks** :

- Sorting / classification :
  - Maximize variations between classes
  - Minimize variations inside classe
- Correlation : maximize correlation coefficient



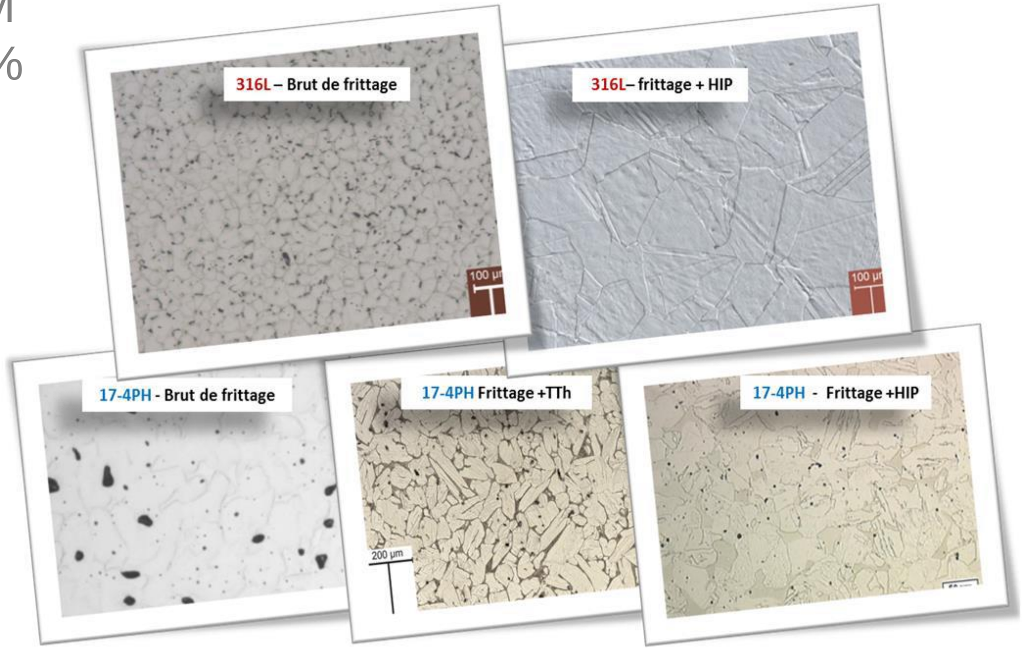


Case N°1 – Porosity control of MBJ parts after sintering

Porosity in sintered AM parts

After sintering, porosity rate in AM parts oscillates between 1 and 5%

- High impact on mechanical properties
  - Elongation
  - Shock resistance
  - Fatigue resistance



Need to easily control this rate :

RUS Methods

Link between frequency and Young’s modulus

- Estimated porosity based on : mass, geometry, theorical density
- Young’s modulus calculated with RUS measurements
  - Simple geometry parts (bar, cylinder) : **ASTM E 1876**

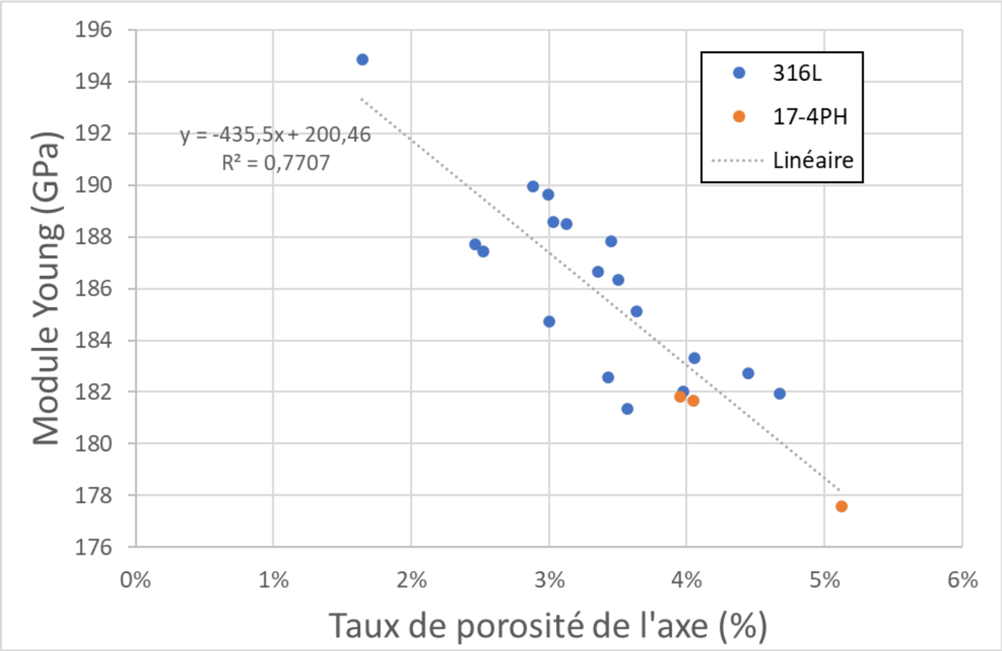
$$E = \frac{0,94642 \rho L^4 f^2 \mathrm{T}}{t^2}$$

E = Young modulus
ρ = theorical density (kg/m3)
L = length (m)
f = frequency (Hz)
T = shape factor (linked to Poisson’s coefficient)
t = thickness (m).

Results

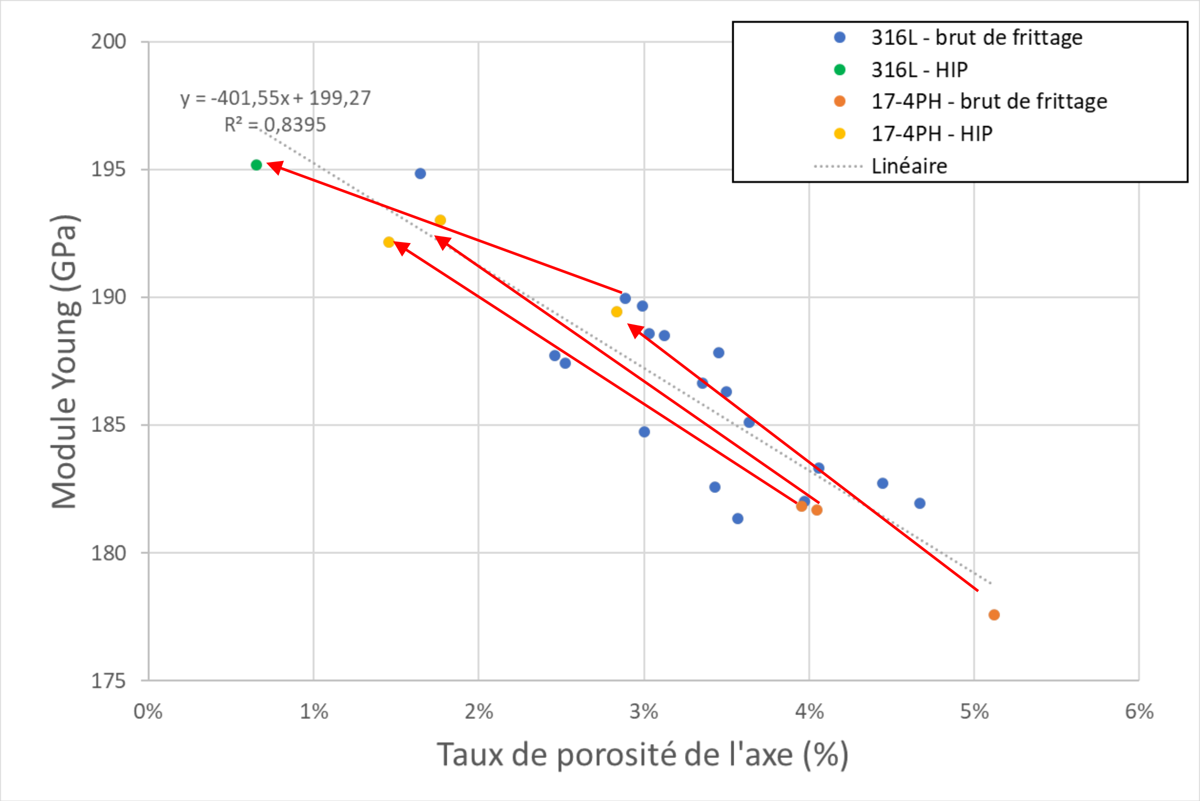
- 0% porosity rate is equivalent to E=200 GPa, which is consistent with the value given by the **norm 10088**

- **It is possible to estimate porosity rate of a part from RUS measurements**



Complement after HIP

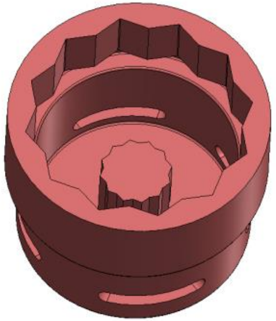
- Les 4 éprouvettes mesurées avant et après HIP ont un module plus élevé



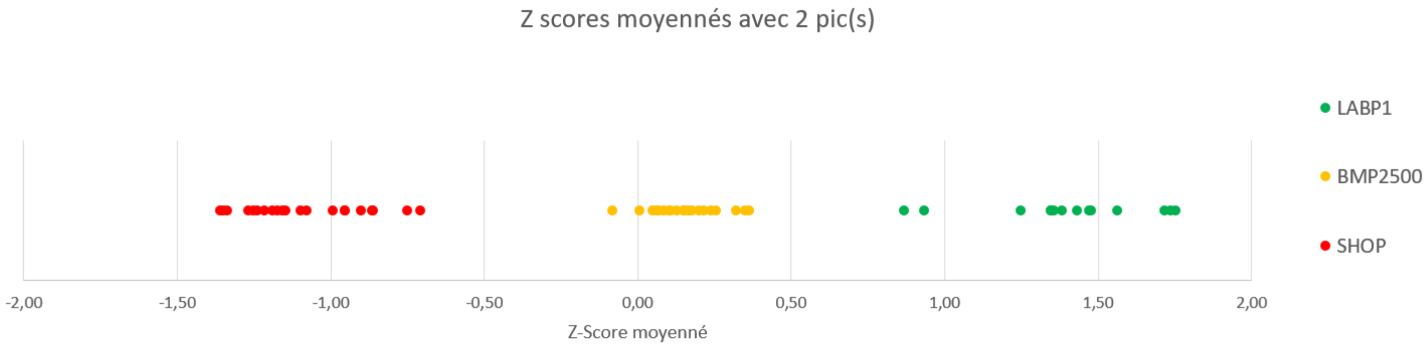
Case N°2 – Classification of caps (MBJ)

Case N°2 - Classification of caps

- 63 caps : MBJ + sintered
- From 3 different AM machines (21 caps each)



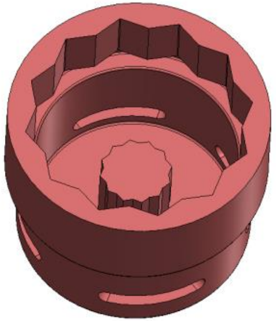
Classification of each cap by machine :



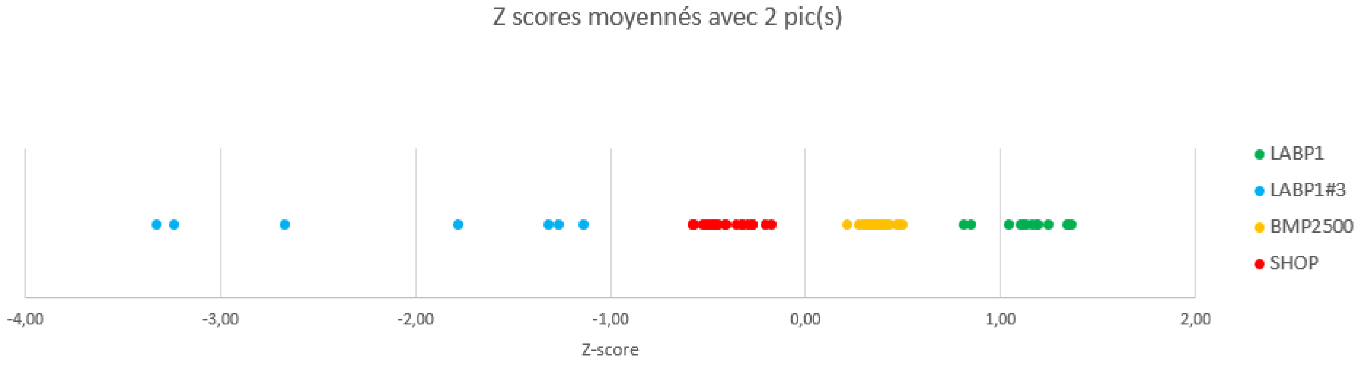
- **Identification of a lack of reproductibility between different machines**
- **Highlighting of reproductibility for each machine**

Case N°2 - Classification of caps

- 63 caps : MBJ + sintered
- From 3 different AM machines (21 caps each)

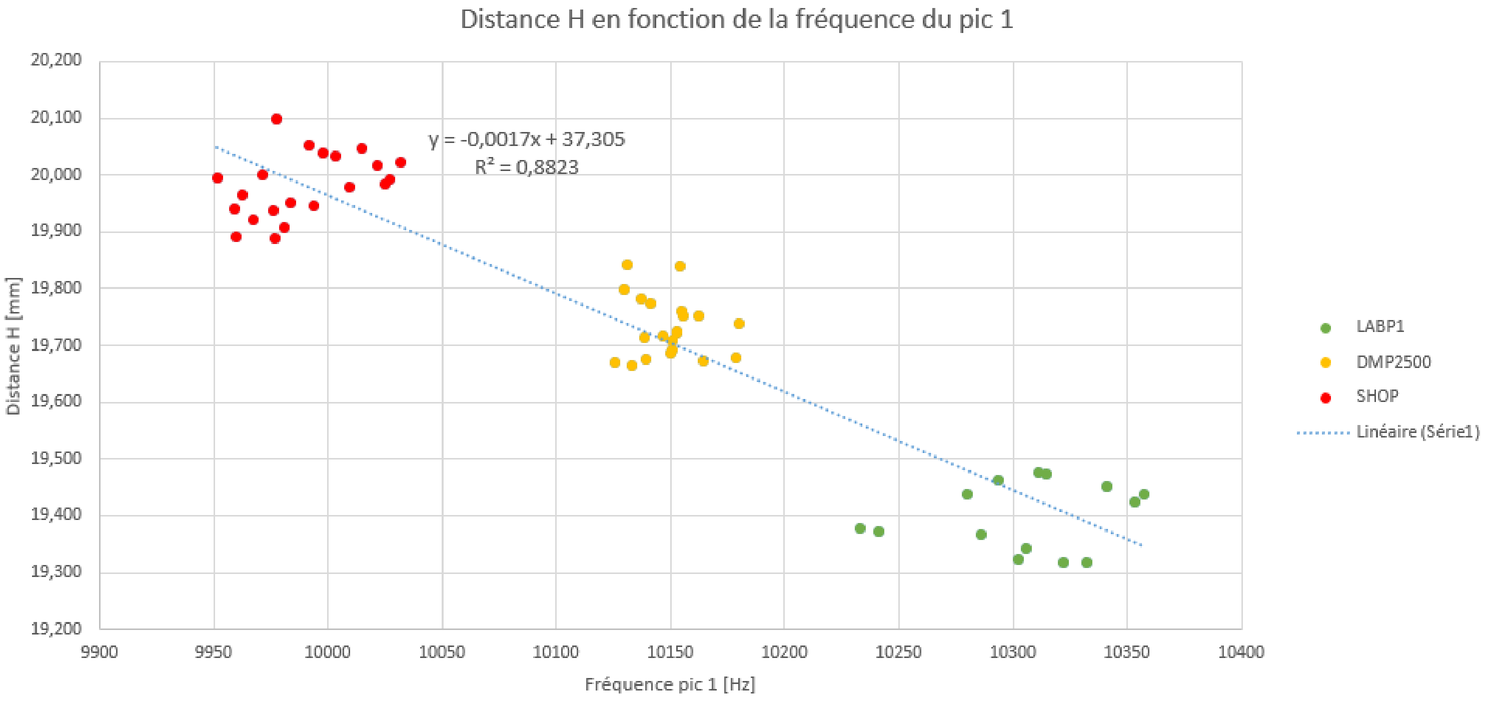


Classification of each cap by machine :



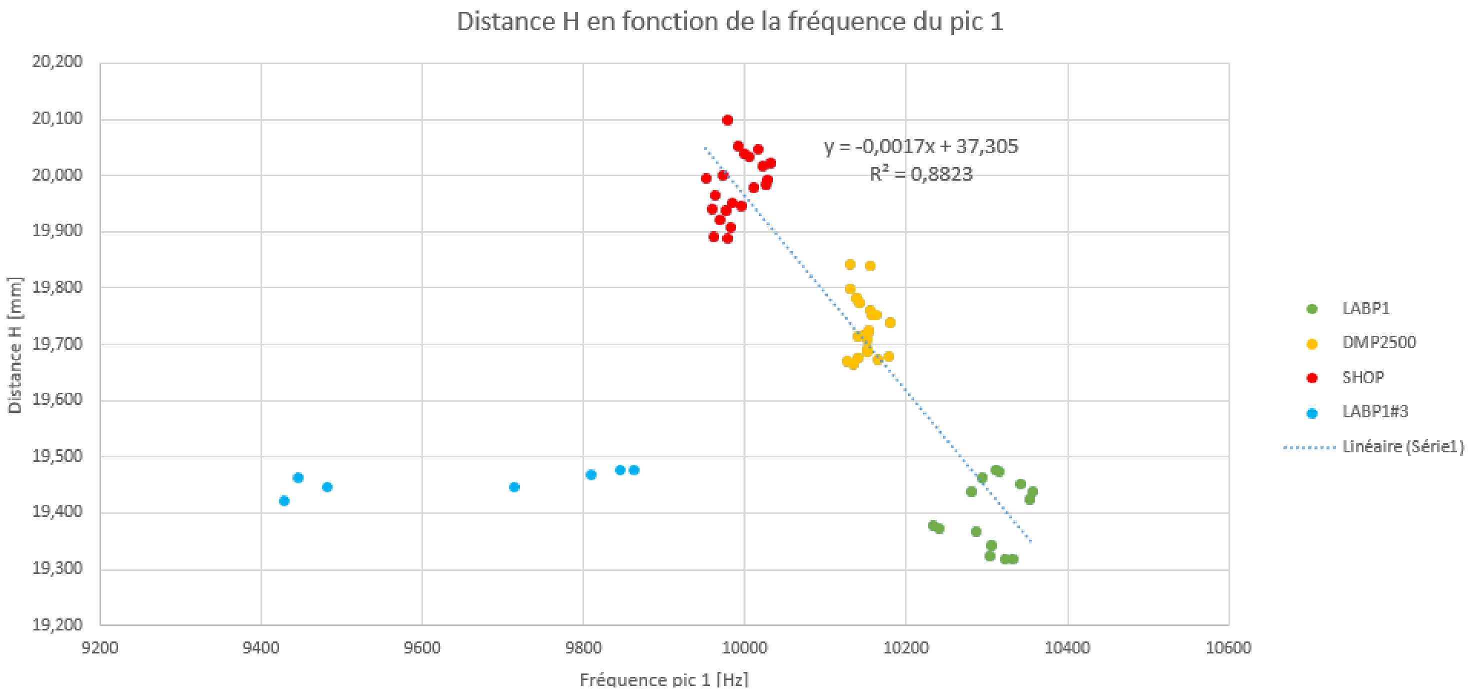
- **Identification of a lack of reproductibility between different machines**
- **Highlighting of reproductibility for each machine**

Correlation with metrologic data & limits



- **Good correlation between geometry and RUS data**

Correlation with metrologic data & limits

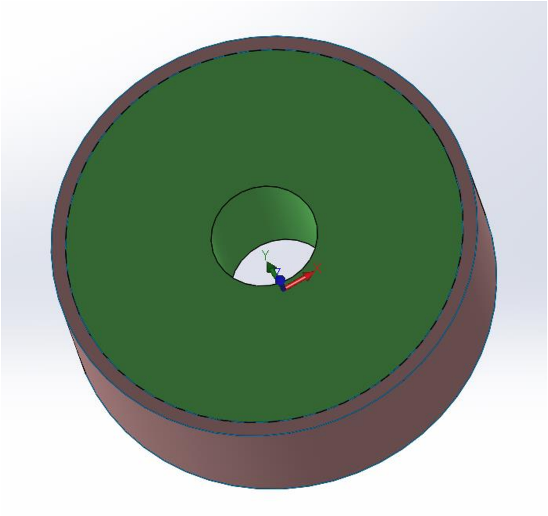


- RUS variations of last batch (blue) are not explained by geometry : **Can only come from variations of mechanical properties or density of the material.** Further studies will be carried out.

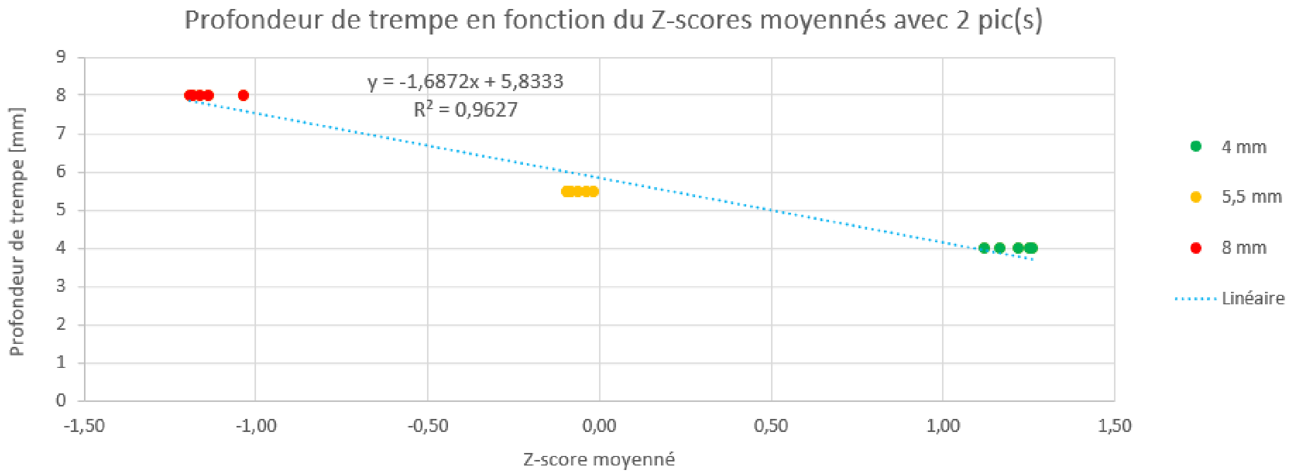
Other no AM cases – Quenching control

Simple case – hollow cylinder

- Hollow cylinder : Φ=120 mm ; t=40 mm
- Steel alloy : 42CrMo4
- 15 parts induction hardened at different depths (5 parts per depth)
  - 4 mm
  - 5,5 mm
  - 8 mm



Simple case – hollow cylinder : results



- Great correlation between quenching depth and RUS measurements :

  The more quenched, the lower the resonance

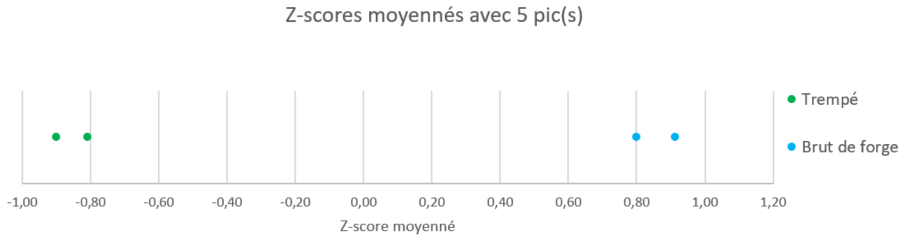
Industrial case - Ring

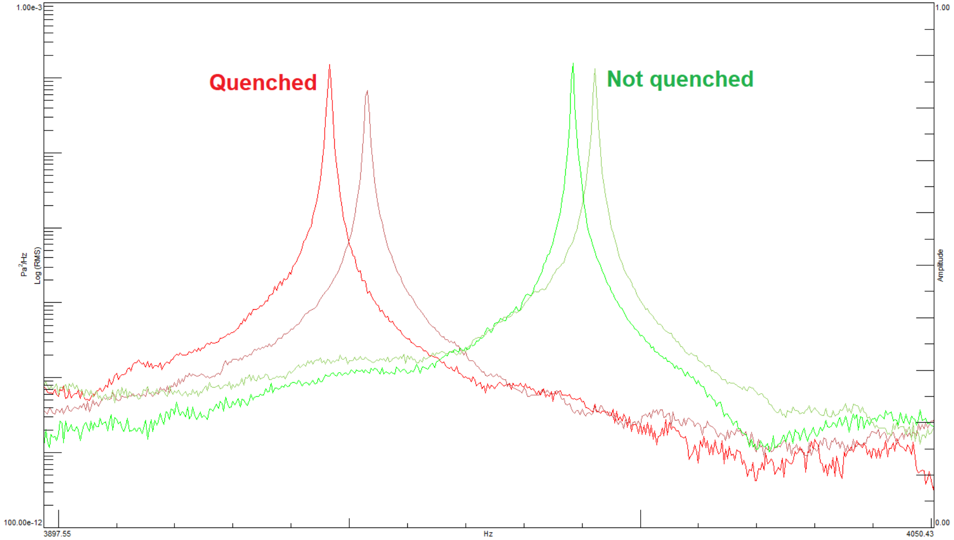
- Turbine disk, ring part of Φ=65 cm
- Nickel alloy : Inco718
- 4 parts : 2 quenched, 2 rough forged

cetim

Industrial case – Ring : results

- Same correlation : quenched part gives a lower resonance
- Validation of first observations : Highlighting the possibility of RUS methods to control the quenching process





Peak 11 – Example highlighting the separation of the two batches

Conclusion

- Here applied to sintered and quenched parts but it is a global method : can be applied to every case that has variability on :
  - Geometry,
  - Density,
  - Elastic mechanical properties

- Great alternative to XCT as a volumetric NDT

- Already proven technique with production installations for non AM parts : find application to more AM cases

CARNOT

cetim

Going for the future