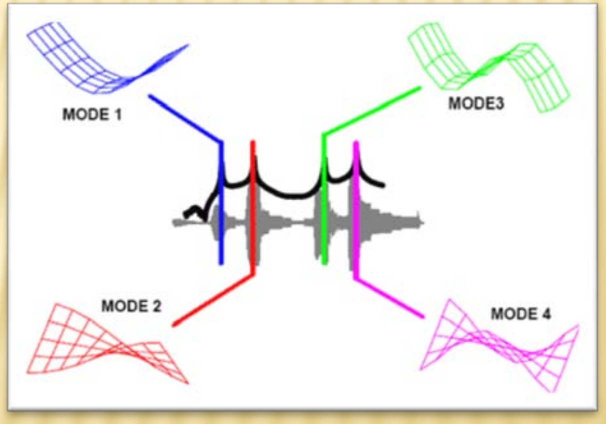
Acoustic Resonant Inspection (ARI)

SonicDiagnostic Co.

Theory

- ARI is based on the analysis of the natural frequencies of a part. An impact causes the part to vibrate in certain characteristic frequencies.

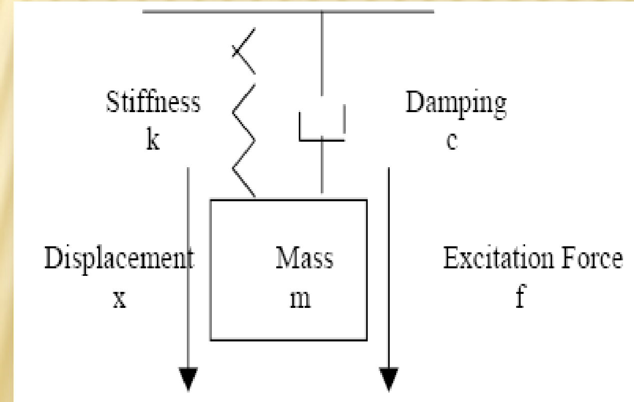
- These frequencies (f_r) are whole-body properties of a given structure, which are determined by dimensions and material properties of the part.



Theory

- A simplified physical model of the resonance can be expressed with a mass and string as $f_r = \sqrt{k/m}$, where k is stiffness (material properties) and m is mass (dimensions, density).

- Any structure has an infinite number of resonances, each determined by a combination of material properties and dimensions.



Theory

- The presence of structural defects results in out-of-specification condition for material properties or dimensions, which causes:
  - shifts in these frequencies,
  - Changes in damping factors,
  - Nonlinear effects such as generation of new frequencies
- By monitoring the above changes and analyzing the multi-variable relations between the natural frequencies, various structural defects can be detected.

Description

- To Excite the structure and cause it to vibrate an impact hammer is used.
- The part vibrations can be measured by two microphones or two accelerometers.
  - Every part has a unique resonant signature and any deviation from the expected signature indicates the presence of a flaw.
  - A single measurement can detect defects at any location throughout the part.

Excitation Hammer & Part Microphone Acoustic Analyzer Decision Making

Typical Applications

- ARI offers rapid and inexpensive method of 100% inspection of parts.
- ARI is designed to detect defects such as:
  - Cracks
  - Cavity
  - Cold shuts
  - Low nodularity
  - Residual stress
  - Hardness deviations
  - Out-of-tolerance dimensions

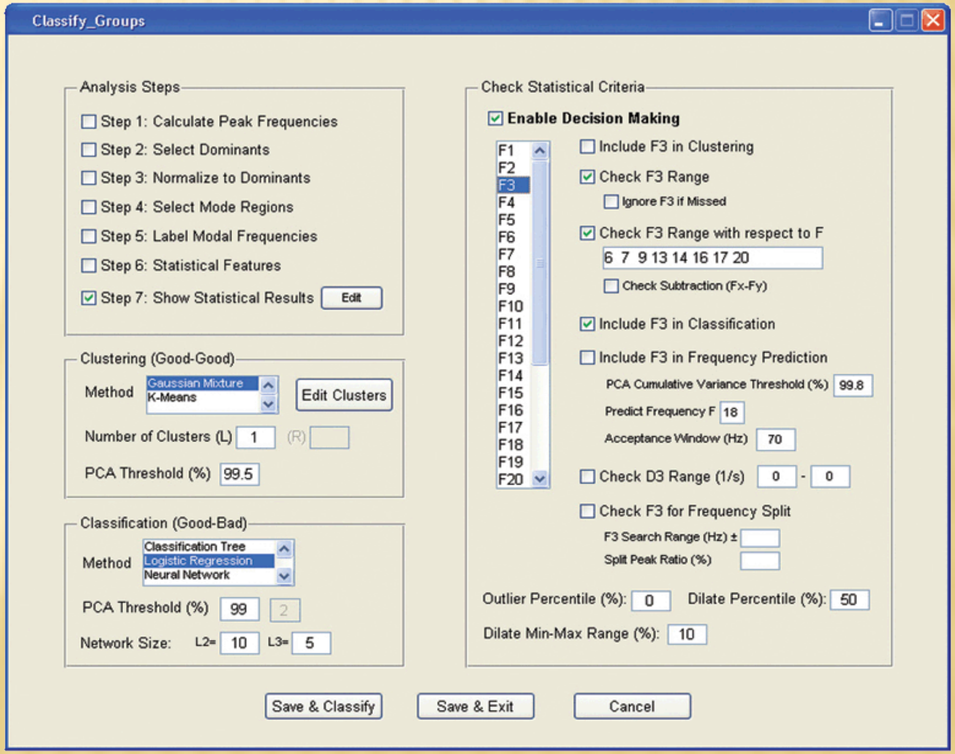
Training the System – Reference parts

- ARI is a relative test method, which requires a database of known parts.
  - Typically 100 to 500 good parts from different production batches
  - 10 to 30 defective parts from each type of flaw (optional)

Training the System – Decision Module

- ARI generates a Decision Module based on advanced statistical methods and classification algorithms to sort the parts.

  - Acceptance range of resonant frequencies
  - Mutual relation between two frequencies
  - Relationship between multiple frequencies
  - Classification of Pass – Fail groups
  - Clustering of Good parts for process compensation
  - Frequency split check for crack detection
  - Damping factors of modes

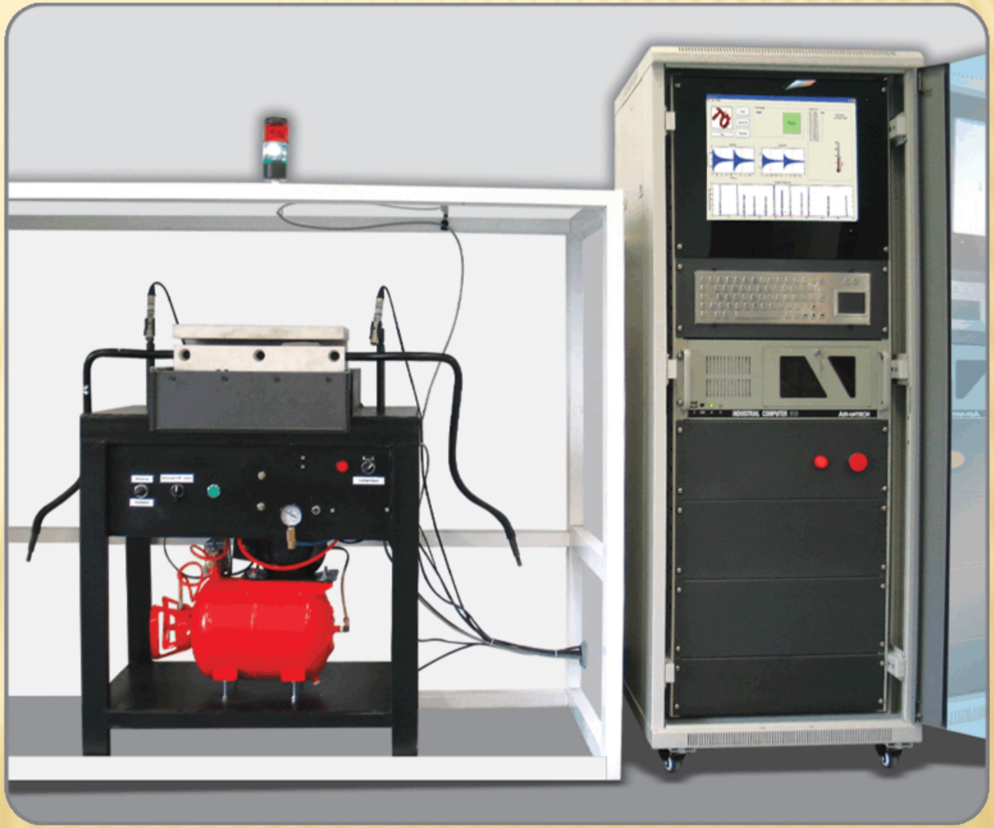


Training the System – Decision Module

- "Good" parts have consistent spectral signatures, meaning that their resonant frequencies are the same among the reference parts; while the resonances of "Fail" parts are different.
  - A crack in a part causes certain resonances displaced to low frequencies or split up into two frequencies; whilst others remain the same.
  - With hardness testing, "all" resonances are changed due to hardness deviation in a part.

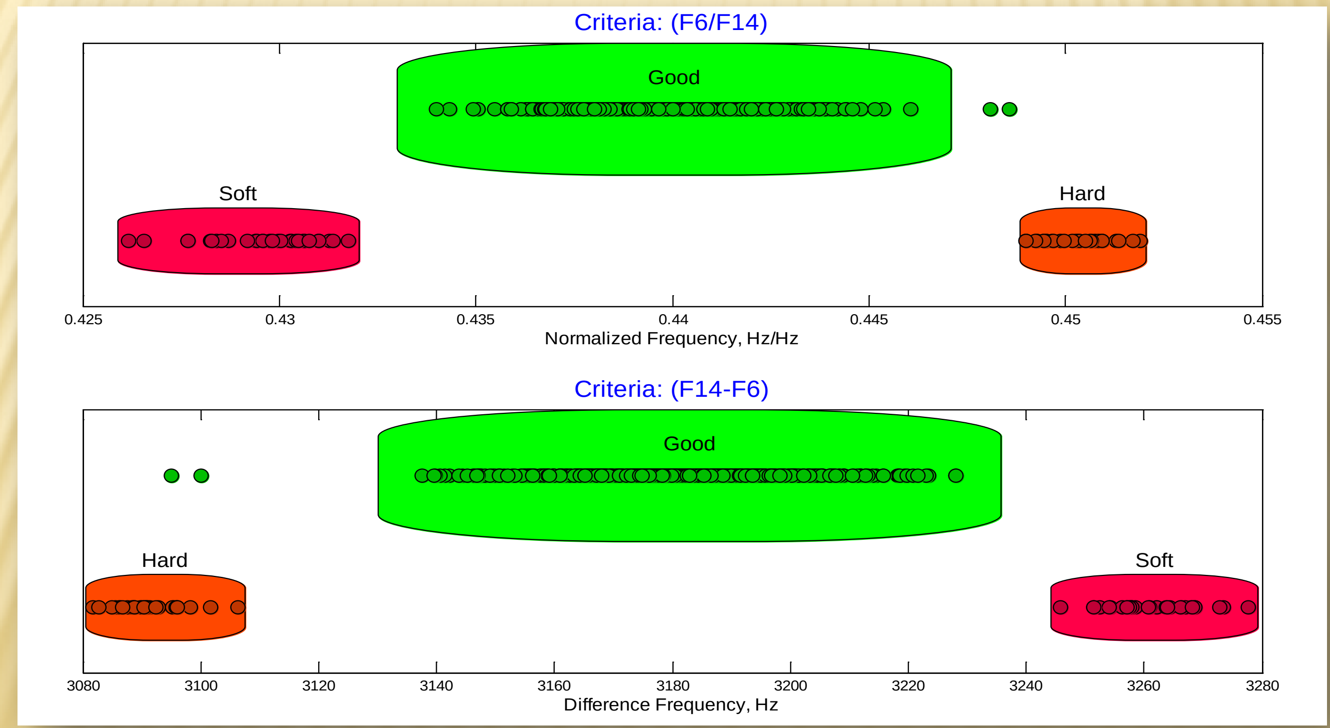
Industrial Applications (No.1)

- Hardness evaluation in Pride (Kia Motors) Stabilizer bar
  - 40 natural frequencies are tested
  - A multi-variate statistical classifier is used to separate Good parts from Soft (<37HRC) and Hard (>41.5 HRC) parts



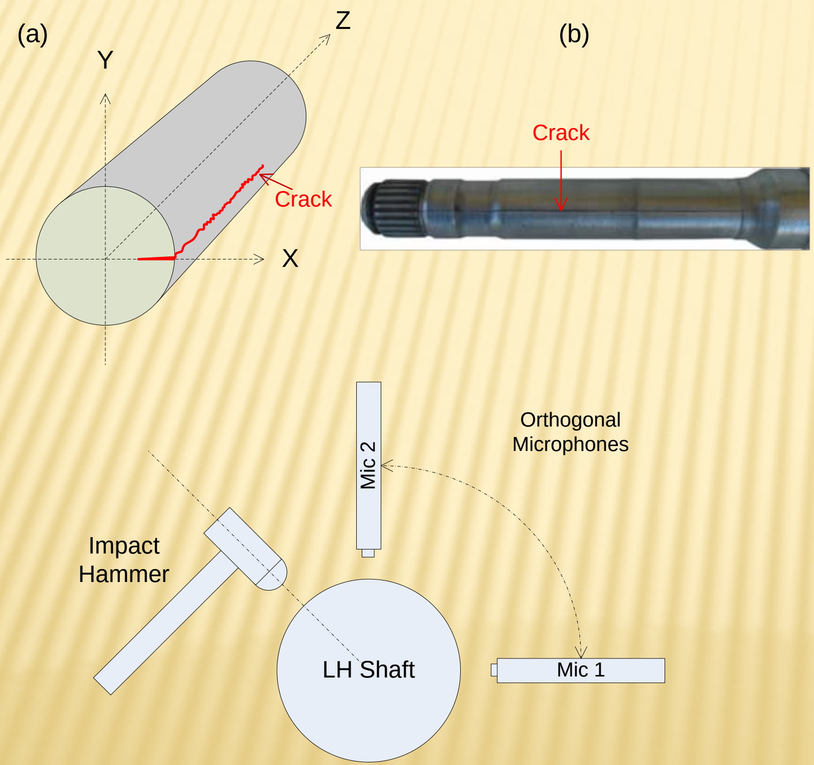
Industrial Applications (No.1)

- Distribution of a relative feature (F_x / F_y) or ($F_x - F_y$) is one of the criteria to separate defective parts.



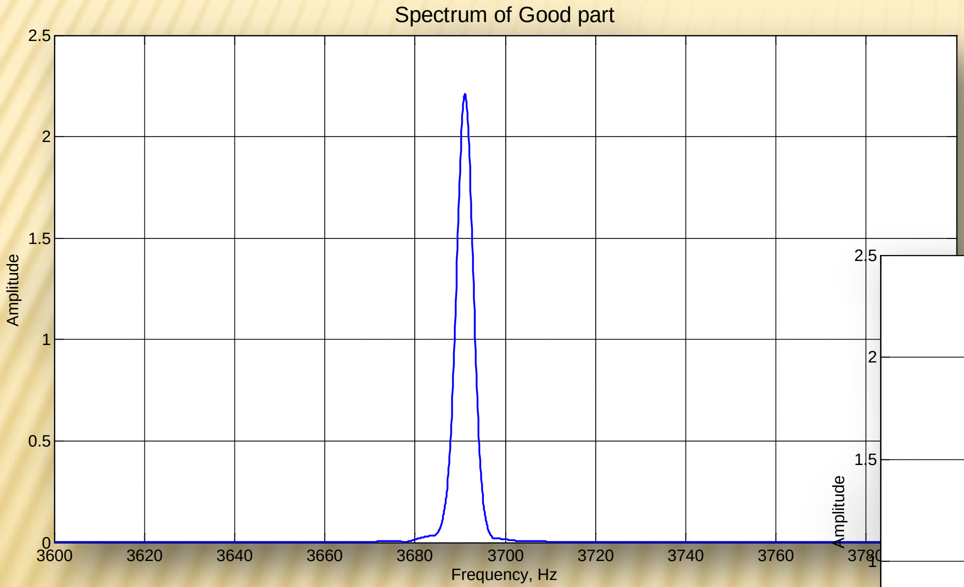
Industrial Applications (No.2)

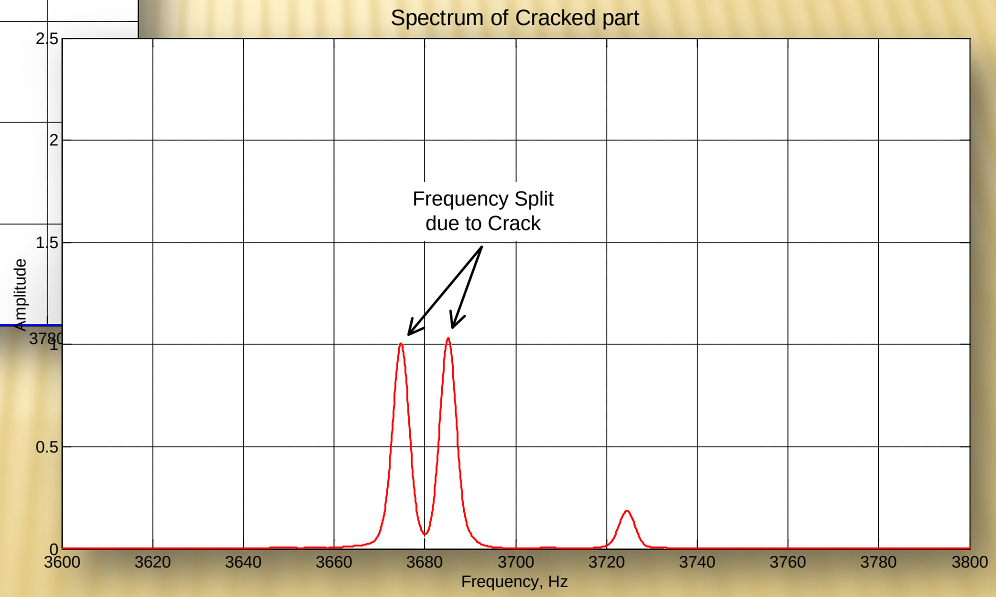
- Longitudinal crack detection in Renault L90 driveshaft



Industrial Applications (No.2)

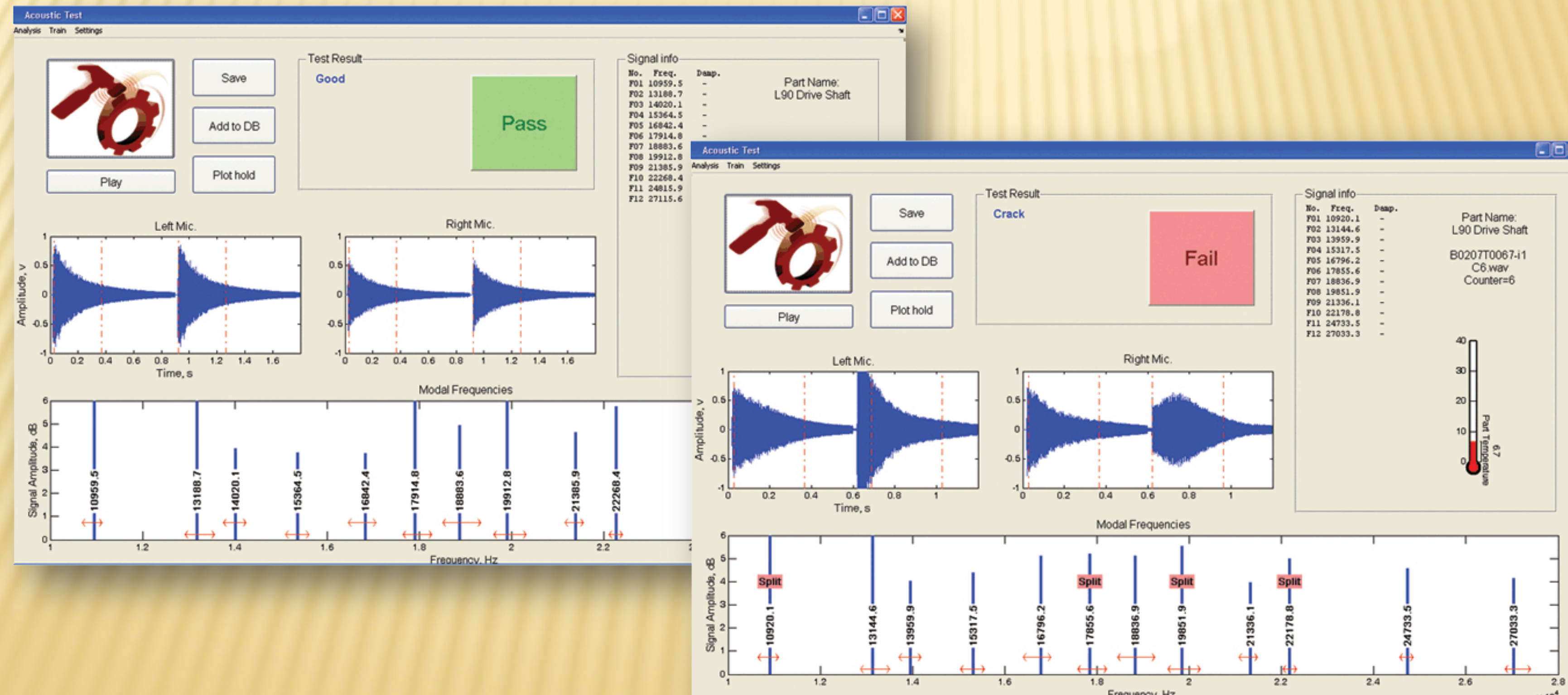
- A longitudinal crack causes non-linear effects such as frequency split





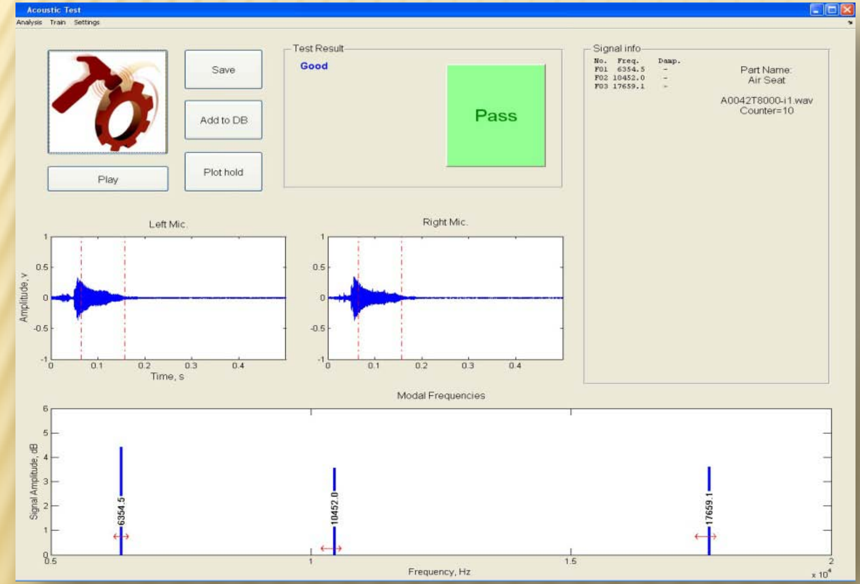
Industrial Applications (No.2)

- For L90 shaft we check frequency splits of 12 modes between 11kHz – 28kHz



Industrial Applications (No.3)

- Crack detection in Air Seat and Exhaust Seat used in EF7 cylinder head



Industrial Applications (No.4)

- Pride (Kia Motors) knuckle arm test for hardness uniformity after heat treatment
- Accepted hardness range: 150 – 210 HB, but hardness deviation between different points of a part <5HB

Industrial Applications (No.4)

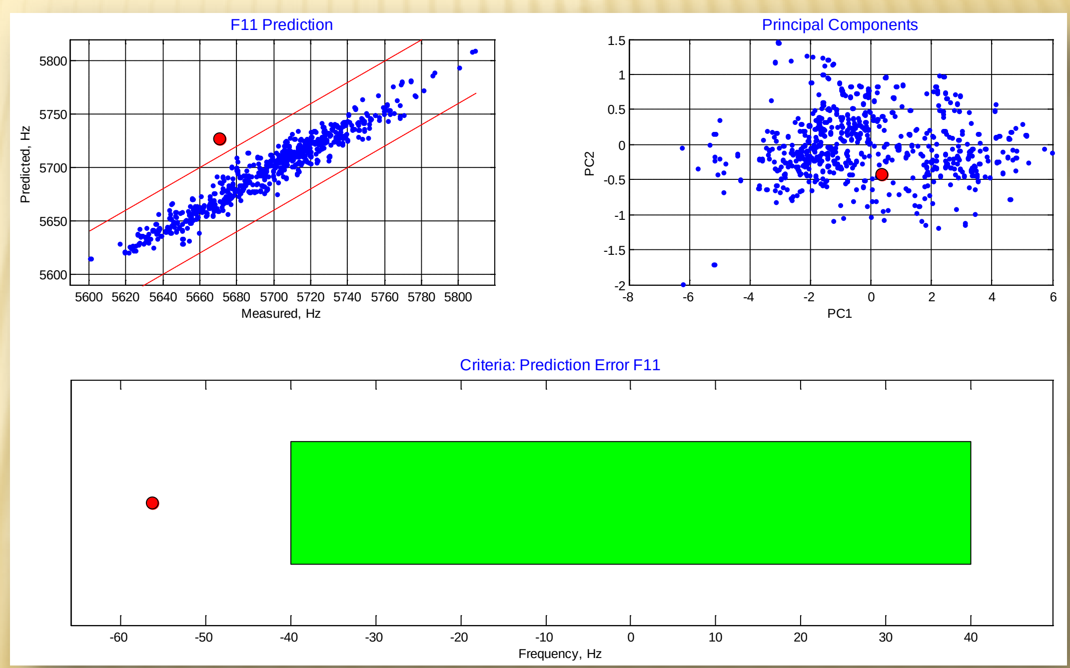
- The relationship between multiple frequencies using frequency prediction is a criterion to test hardness uniformity between different points of a part.

- If the part is homogenous in hardness, a frequency can be predicted by other natural frequencies:

$$\hat{F}_i = f(F_1, F_2, F_3, \ldots)$$

$$error = \hat{F}_i - F_i$$

If the prediction error is higher than a threshold, the part is rejected.



Industrial Applications (No.5)

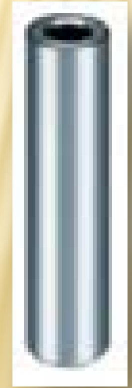
- Peugeot 206 knuckle arm test for hardness uniformity after heat treatment

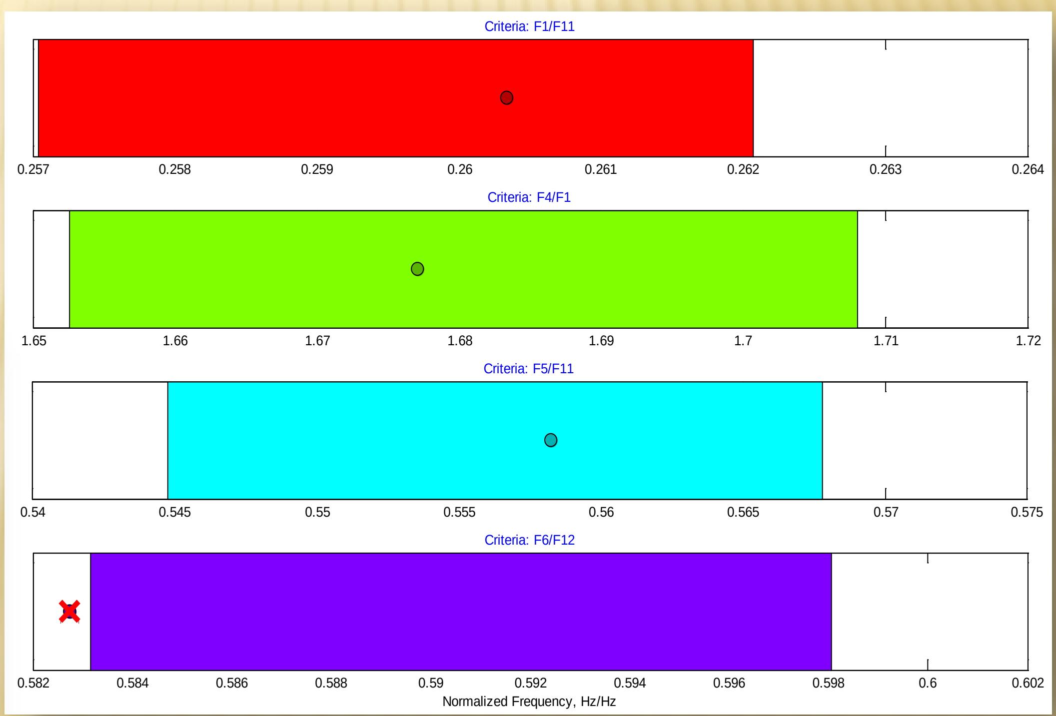
Industrial Applications (No.6)

- Peugeot axle shaft test for Hardness uniformity and Case depth after induction hardening

- The ratio of two natural frequencies is a criterion to separate defective parts

$$R_{Min} \leq \frac{F_i}{F_j} \leq R_{Max}$$





Features

- High speed, accurate and repeatable measurements
- Easy to use and user friendly interface
- Classification of parts based on advanced data modeling and multivariate statistics methods
- Temperature compensation of resonant frequencies using infrared thermometer
- Automatic impact using dual electromechanical or pneumatic hammers with adjustable strike force
- Dust-proof and weather resistant enclosure
- Customized fixture design with pneumatic control for part loading
- Report generation, including statistical analysis