

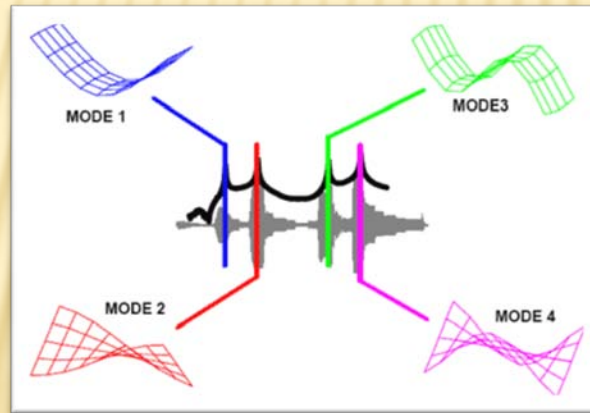
# Acoustic Resonant Inspection (ARI)



SonicDiagnostic Co.

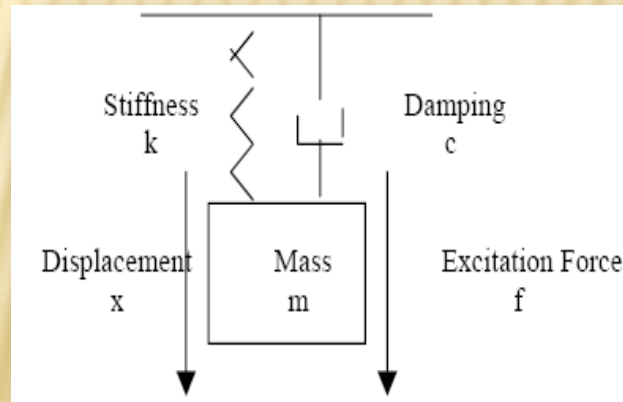
# Theory

- ❑ 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 spring 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

The screenshot displays the 'Classify\_Groups' software window, which is used for configuring analysis and classification parameters. The interface is divided into several sections:

- Analysis Steps:** A list of seven steps with checkboxes. Step 7, 'Show Statistical Results', is checked and has an 'Edit' button next to it.
- Clustering (Good-Good):** Includes a 'Method' dropdown set to 'K-Means', an 'Edit Clusters' button, and input fields for 'Number of Clusters (L)' (1), 'Number of Clusters (R)' (empty), and 'PCA Threshold (%)' (99.5).
- Classification (Good-Bad):** Includes a 'Method' dropdown set to 'Logistic Regression', 'PCA Threshold (%)' (99), 'Network Size' (L2=10, L3=5), and buttons for 'Save & Classify', 'Save & Exit', and 'Cancel'.
- Check Statistical Criteria:** A section with a list of frequency modes (F1-F20) on the left and various checkboxes and input fields on the right. The 'Enable Decision Making' checkbox is checked. Other options include 'Include F3 in Clustering', 'Check F3 Range', 'Check F3 Range with respect to F' (with a range of 6-20), 'Check Subtraction (Fx-Fy)', 'Include F3 in Classification', 'Include F3 in Frequency Prediction', 'PCA Cumulative Variance Threshold (%)' (99.8), 'Predict Frequency F' (18), 'Acceptance Window (Hz)' (70), 'Check D3 Range (1/s)' (0-0), 'Check F3 for Frequency Split', 'F3 Search Range (Hz) ±', 'Split Peak Ratio (%)', 'Outlier Percentile (%)' (0), 'Dilate Percentile (%)' (50), and 'Dilate Min-Max Range (%)' (10).



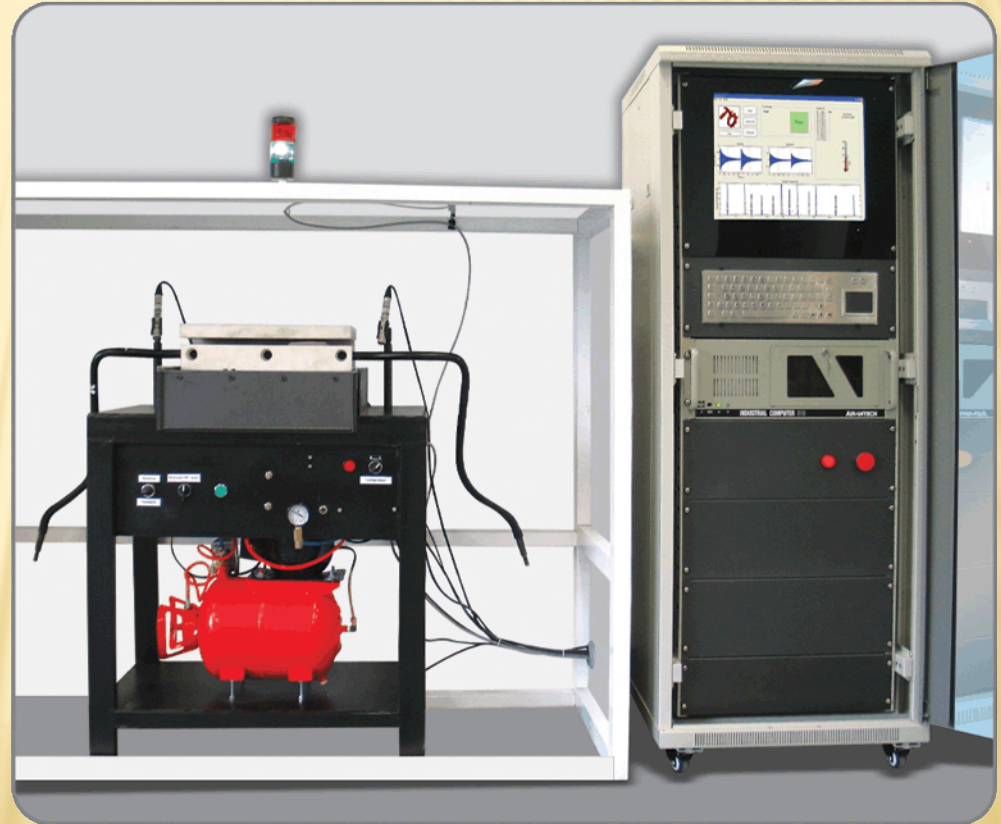
# Training the System – Decision Module

---

- ❑ “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.

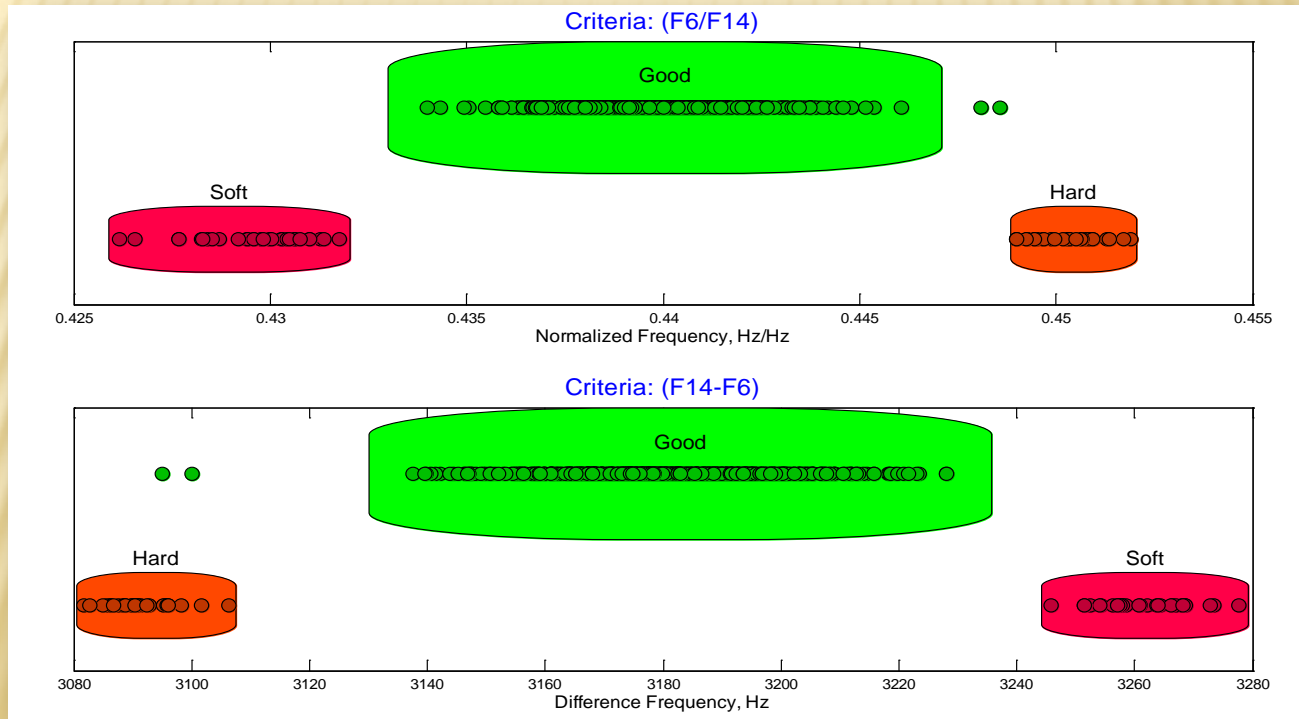
# Industrial Applications (No.1)

- ❑ 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 ( $<37\text{HRC}$ ) and Hard ( $>41.5\text{HRC}$ ) parts



# Industrial Applications (No.1)

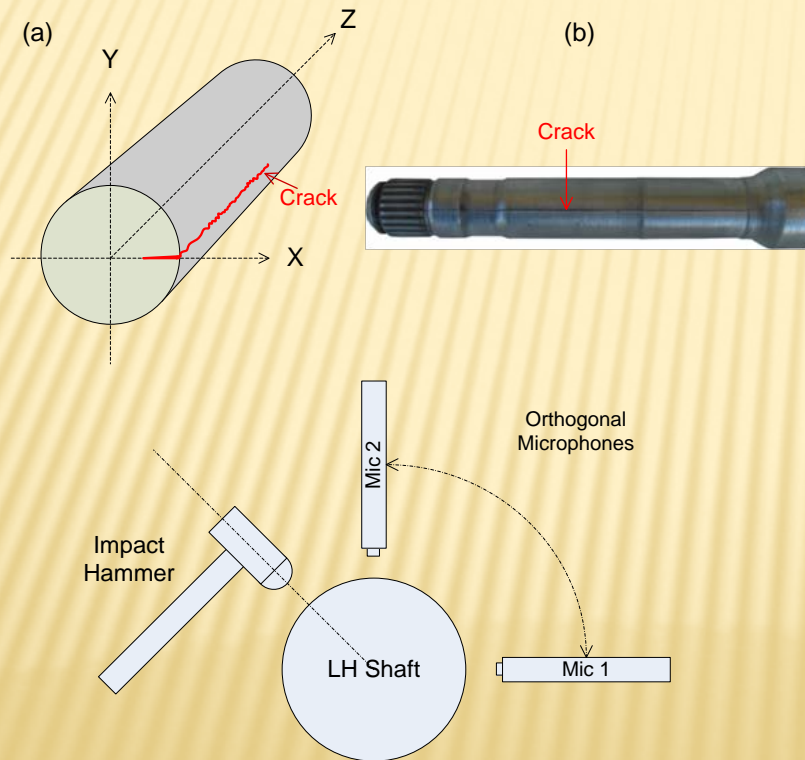
- Distribution of a relative feature ( $F_x/F_y$ ) or ( $F_x - F_y$ ) is one of the criteria to separate defective parts.





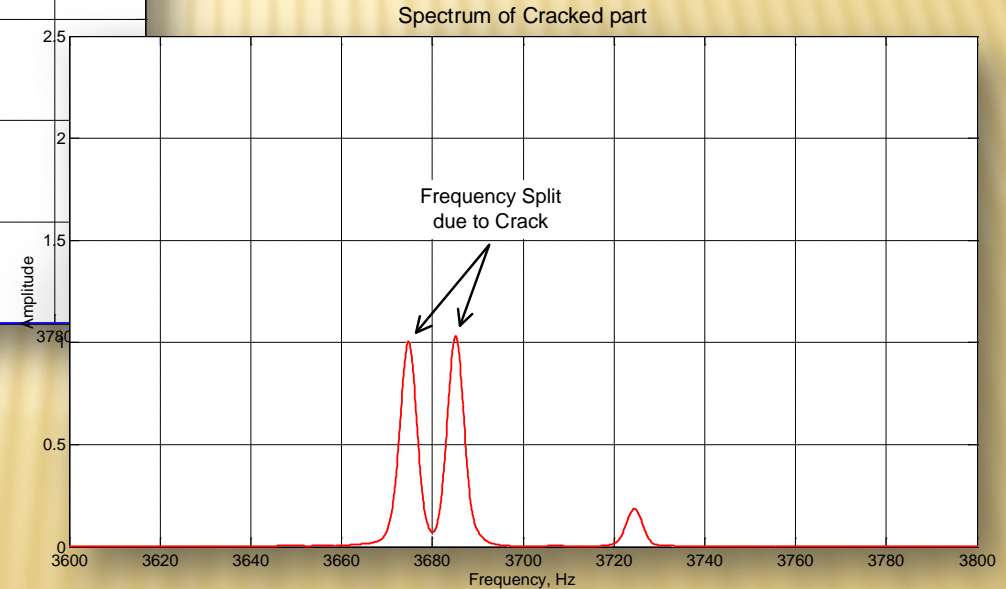
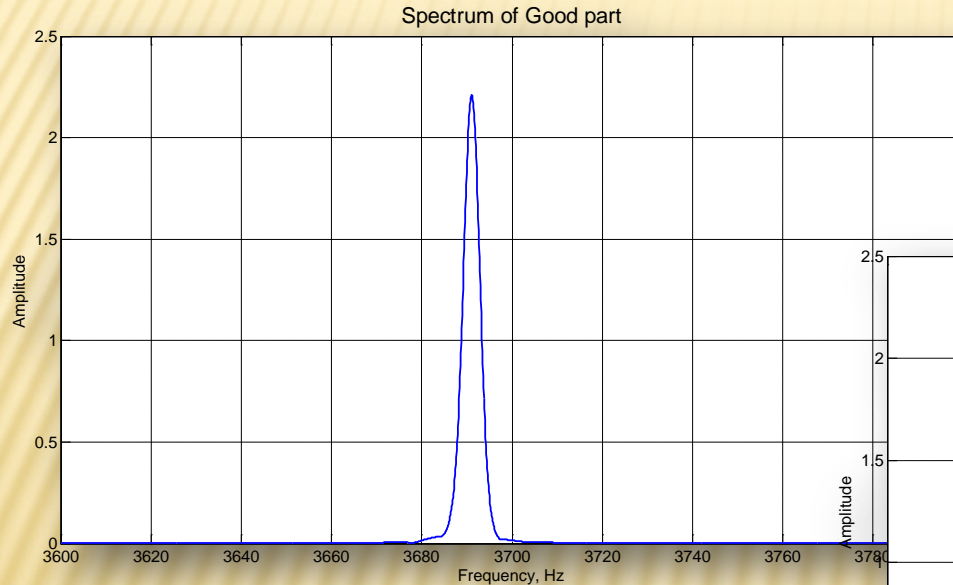
# Industrial Applications (No.2)

- Longitudinal crack detection in Renault L90 driveshaft



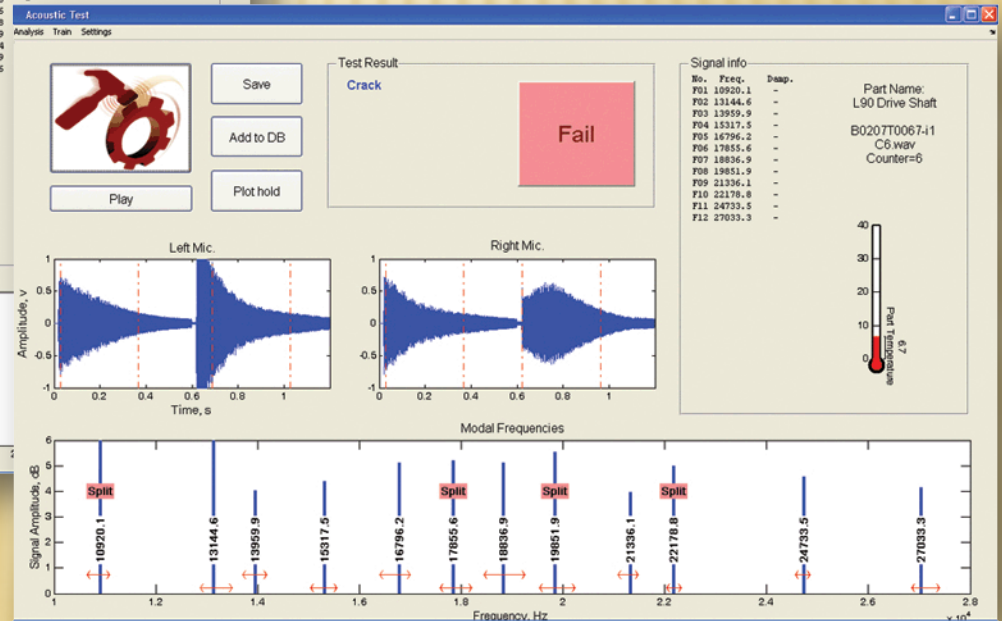
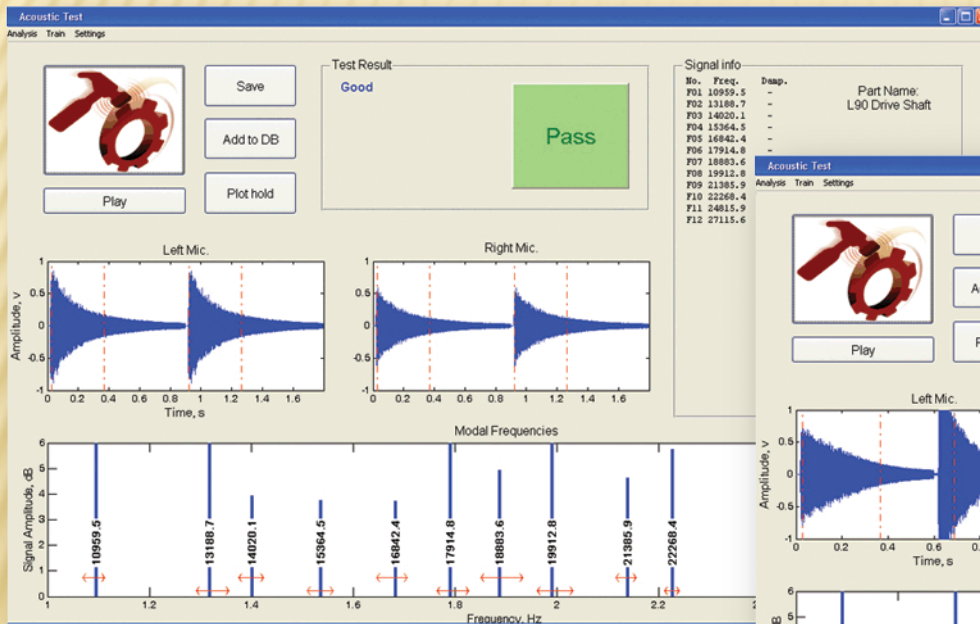
# Industrial Applications (No.2)

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



# Industrial Applications (No.2)

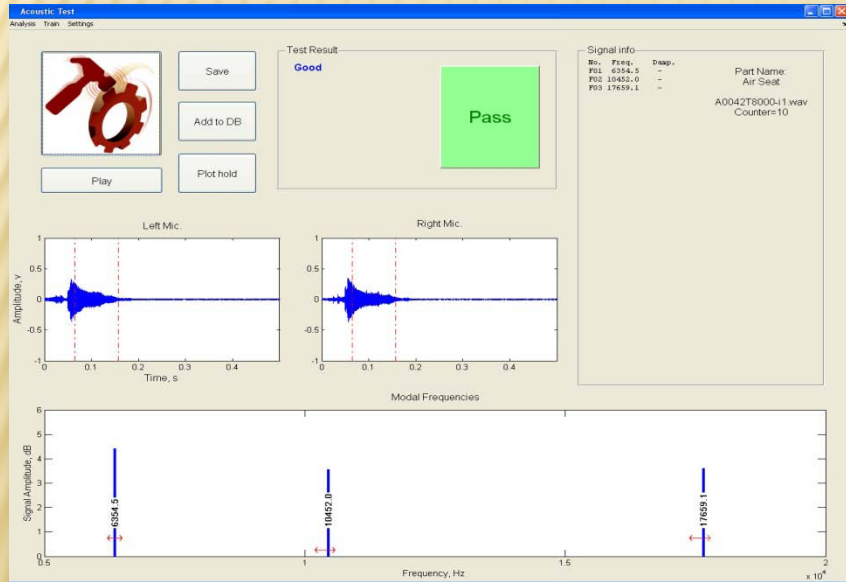
- For L90 shaft we check frequency splits of 12 modes between 11kHz – 28kHz





# 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)

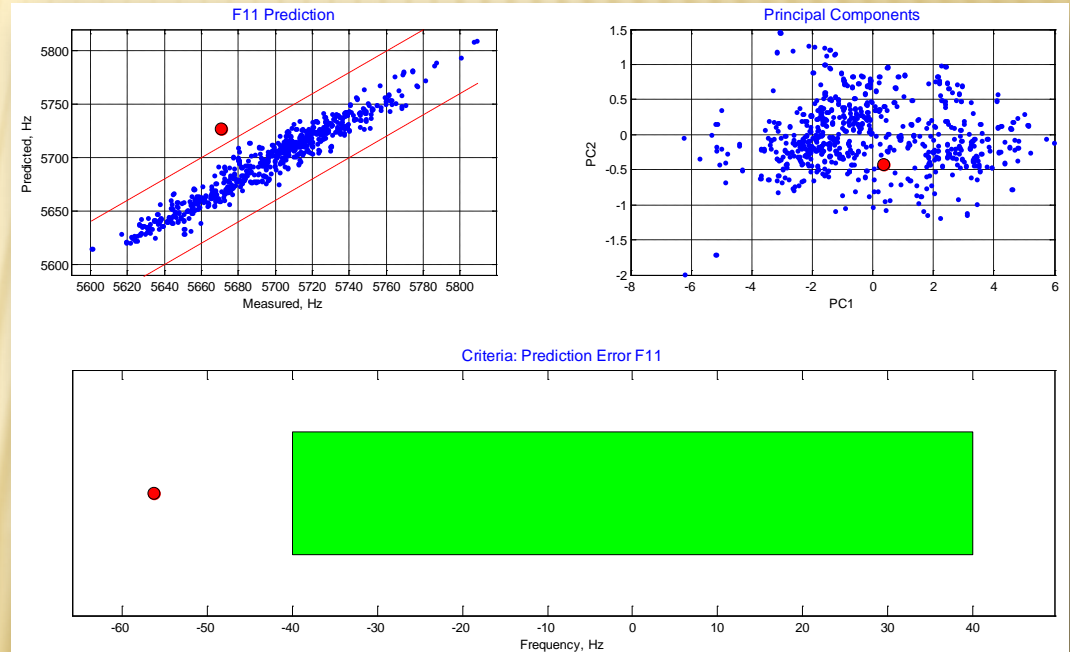
- The relationship between multiple frequencies using frequency prediction is a criterion to test hardness uniformity between different points of a part.

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

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

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

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





# Industrial Applications (No.5)

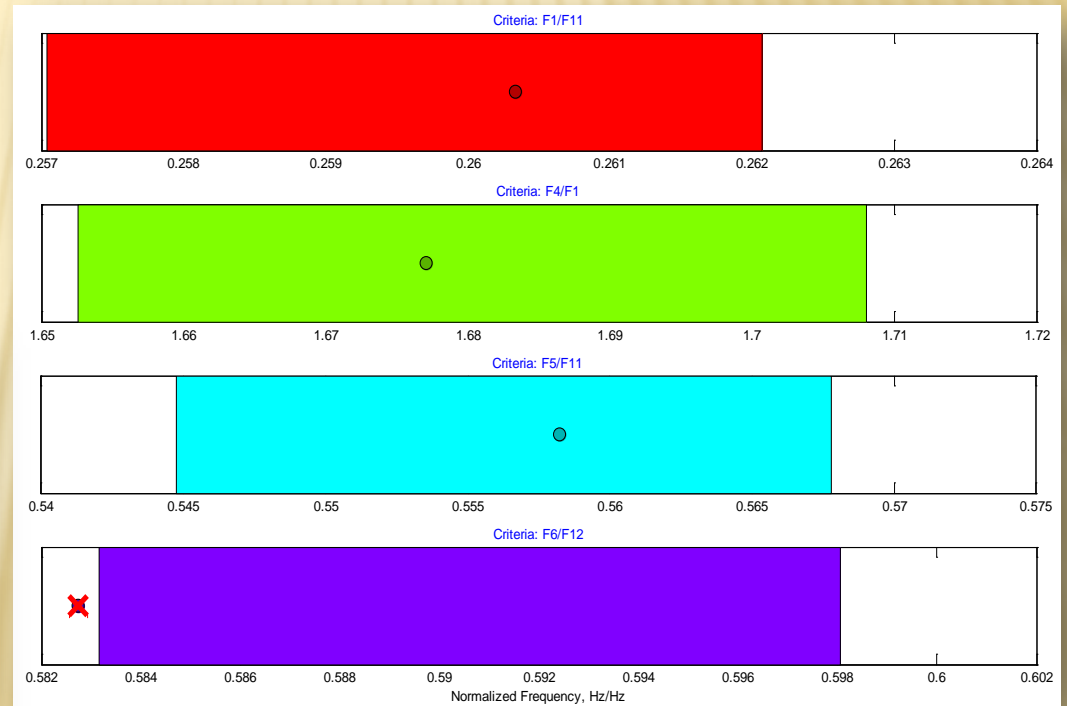
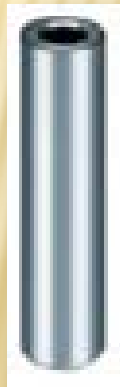
- ❑ Peugeot 206 knuckle arm test for hardness uniformity after heat treatment



# 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