# ACOUSTIC RESONANT INSPECTION (ARI)

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# Introduction

Acoustic Resonant Inspection (ARI) offers a rapid and inexpensive method of 100% inspection of parts. This can contribute to improving quality of products, adding to the safety of products and at the same time provide substantial cost savings.

We offer a **complete solution** including feasibility study, parts analysis, design and installation of automated equipment, calibration and training.

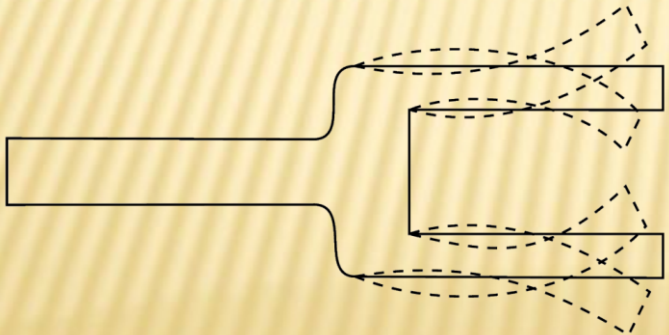
# Introduction

ARI is based on the analysis of the natural frequencies of a part. The presence of structural defects causes measurable changes from which various defects can be detected, including cracks, residual stress, dimensional and hardness variations.

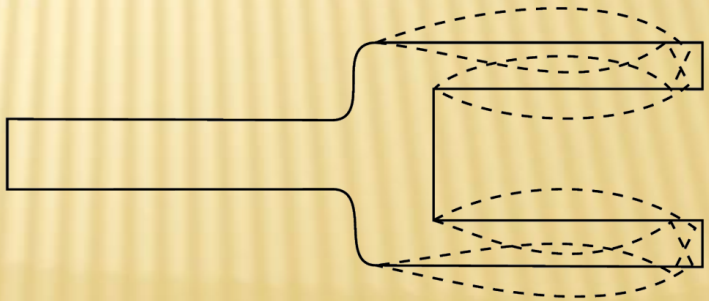
# Theory

Most structures vibrate. When a part is struck, it produces an acoustical response containing a limited number of tones. The part stores the energy from the impact and dissipates it by vibrating at particular frequencies.

We can express the vibration of any structure as a sum of its vibration modes. Each mode is a **Degree-of-Freedom** of vibration.



1st mode



2nd mode

# Theory of Resonant Testing

We perform the following steps using Signal Processing techniques:

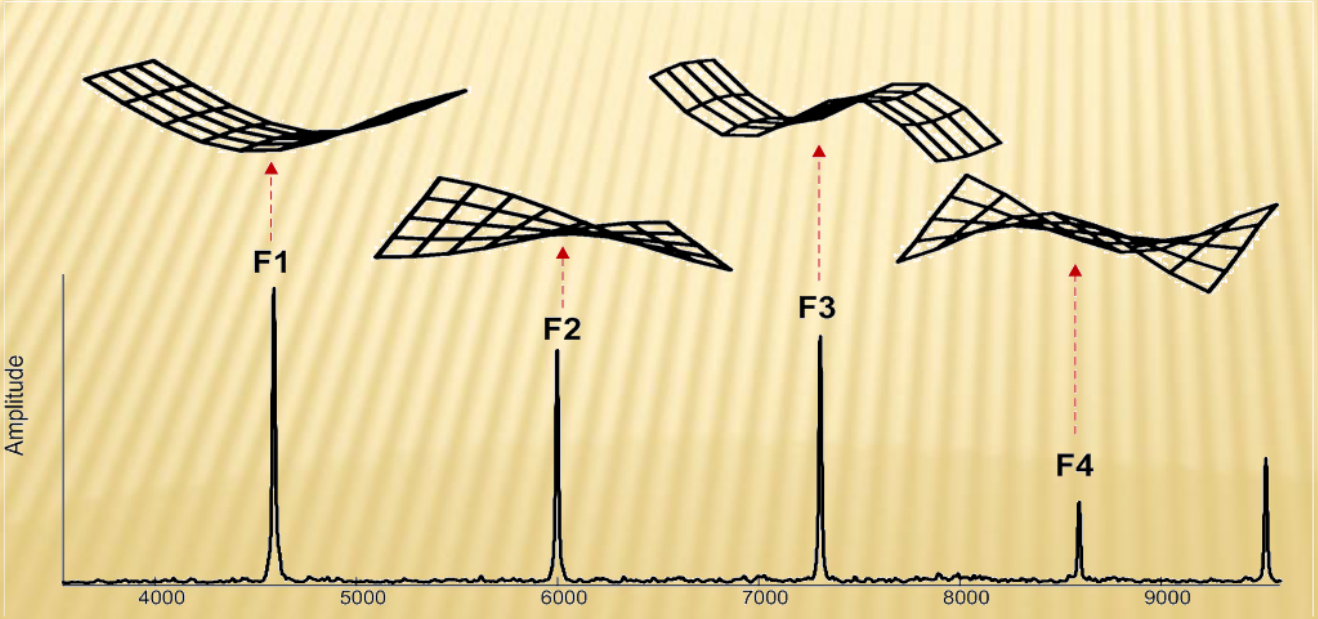
1. Measure vibration of a part
2. Calculate frequency response
3. Find natural frequencies
4. Compare the pattern of natural frequencies with known reference parts
5. Make decision: Pass or Fail

Impact Hammer | Part Vibration | Recording | Analysis | Decision Making

# Theory of Resonant Testing

If we strike a part and compute the frequency spectrum of its vibration, we see some peaks that occur at the resonance frequencies of the part.

The frequency of the peaks are independent of the impact position, impact force, and microphone position.

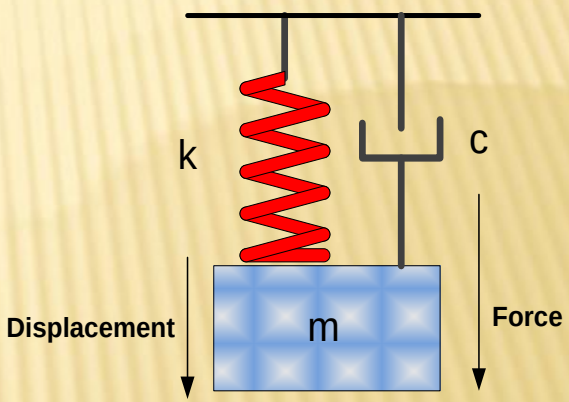



Vibration modes of a rectangular plate

Frequency Response

# Theory of Resonant Testing

Resonance frequency can be modeled with vibration of a mass and spring as $f = \sqrt{k/m}$ , where *k* is stiffness of spring and *m* is mass.




*k* reflects **mechanical properties** of the part (such as Young's Modulus, Break Strength), *m* reflects the **geometrical properties** (such as volume, density, shape).

Therefore, by measuring resonance frequencies we can directly assess mechanical and geometrical properties of a part.

# Theory of Resonant Testing

Structural defects reduces the stiffness (k), and hence the resonant frequency is reduced.

The **frequency shift** has a high correlation with **fatigue or break strength**. This dependency is the basis of Acoustic Resonant Inspection (ARI).

# Acoustic Resonant Inspection - ARI

ARI can be used to detect defects in:

- Hardness uniformity, heat treatment
- Fatigue, residual stress
- Nodularity, nodule count
- Detached layers, cold lap
- Crack

# Data Mining

There are many **physical and metallurgical factors** that influence the variations in the resonant frequencies. For example, in ductile cast iron the following factors can shift the resonant frequencies:

- Nodularity and nodule count
- Hardness
- Residual stress
- Crack
- Temperature
- Mass and dimensions (e.g.: major casting flash)
- Etc.

Some of the factors are not defects, but can hide the effect of other defective factors. **Data mining** techniques should be used to **compensate for unwanted factors**.

# Data Mining

Data mining is the process of extracting **statistical information or patterns** from the data and searching for **relationships** between variables.

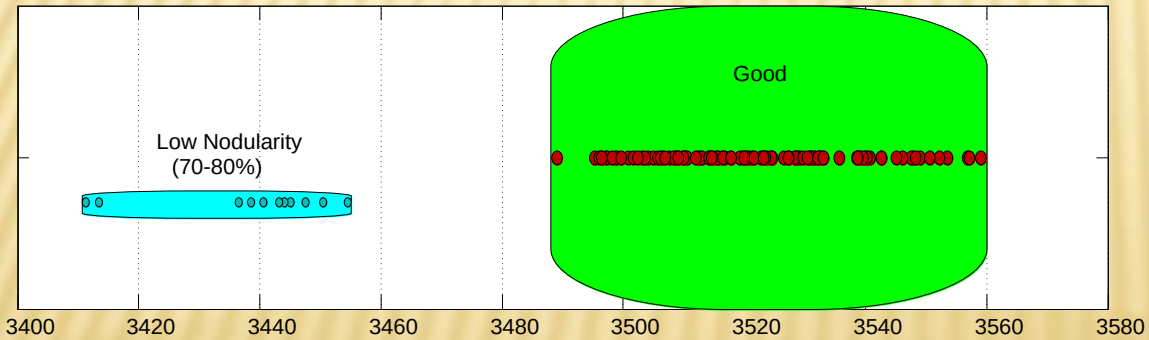
Data mining is a **multivariate analysis**, which analyzes more than one statistical variable (resonant frequency) at a time. The following techniques are used in ARI system:

- **Clustering** – is used to discover groups in the data that are in some way similar. It is used to cluster variations of Good parts.
- **Classification** – is used to extract patterns to separate Good from Defective parts. It is a supervised learning procedure based on known reference parts.
- **Regression** – Attempts to find a function which models the data.

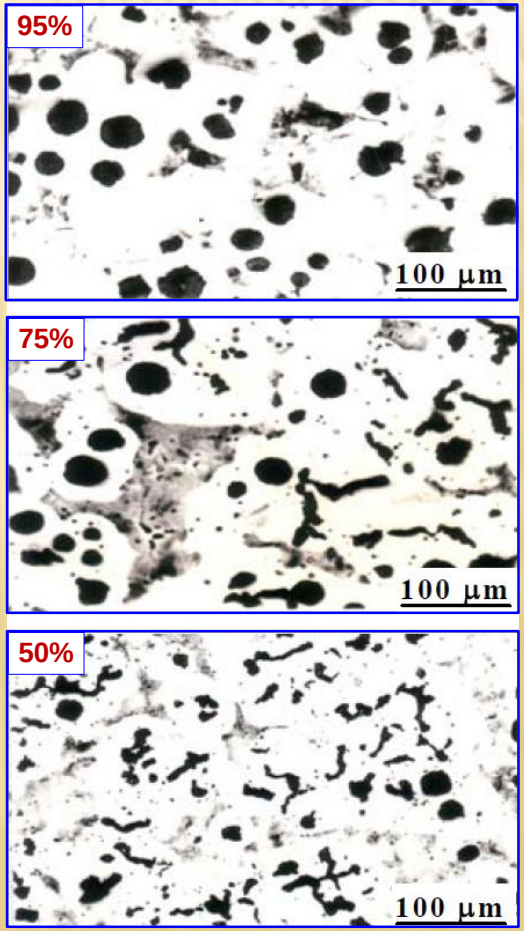
# Application 1: Nodularity Test

Resonant frequency has a high correlation with nodularity. So defective parts with low nodularity (<85%) can be detected.

Traditional nodularity testing method is ultrasonic testing. But it scans a small volume, needs preparation of the part, and needs coupling liquid.

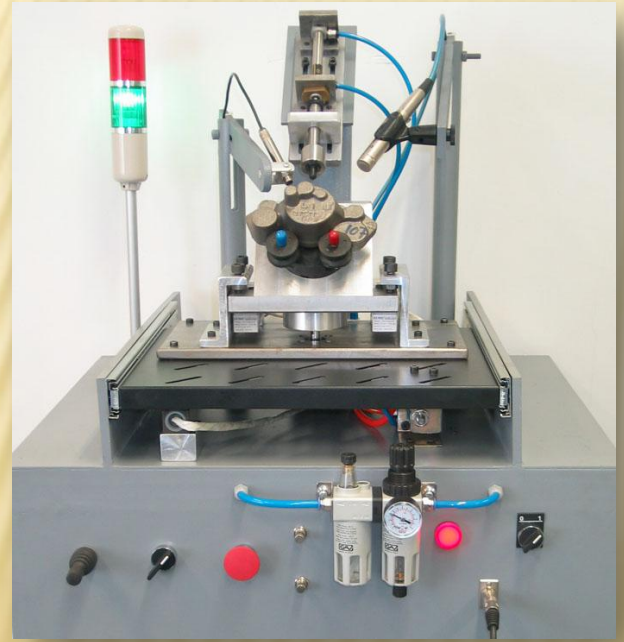



**Brake Caliper Nodularity Test:** Comparison of the natural frequencies (difference *F*4-*F*1) of 120 Good parts with 11 low nodularity parts.

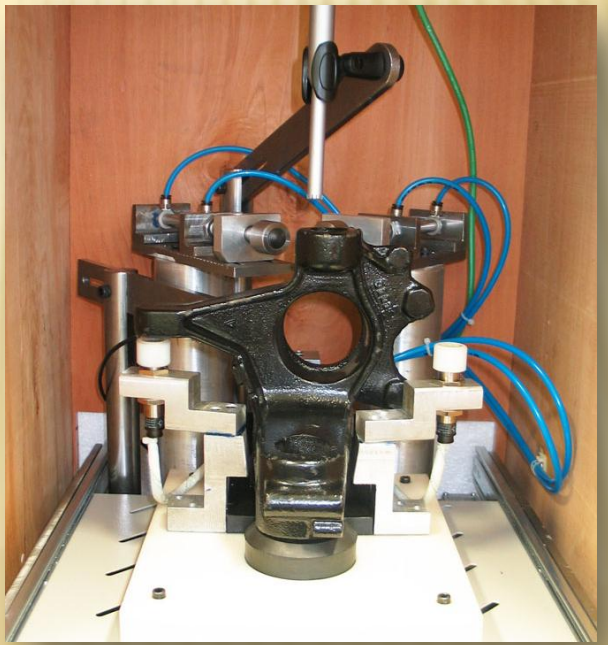


# Application 1: Nodularity Test

Examples of nodularity testing in ductile iron using ARI system:



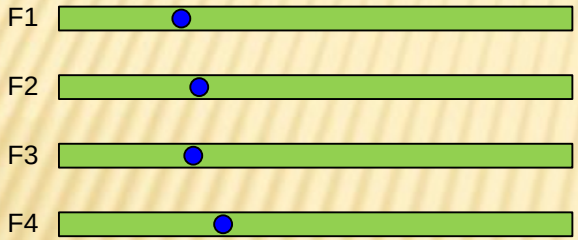
Brake Caliper Test



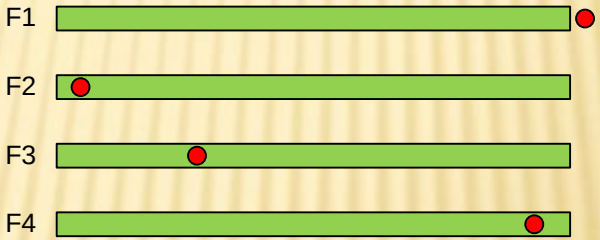
Knuckle Arm Test

# Application 2: Residual Stress Test

Some types of defects such as **residual stress** and **hardness non-uniformity** violates the **relationship and coordination** between resonant frequencies.




Resonant frequencies of a **good** part have a **consistent** pattern.




Resonant frequencies of a part with hardness **non-uniformity** have **no coordination**.


As-cast part with hardness non-uniformity

# Application 2: Residual Stress Test

Examples of hardness non-uniformity testing in ductile iron using ARI system:

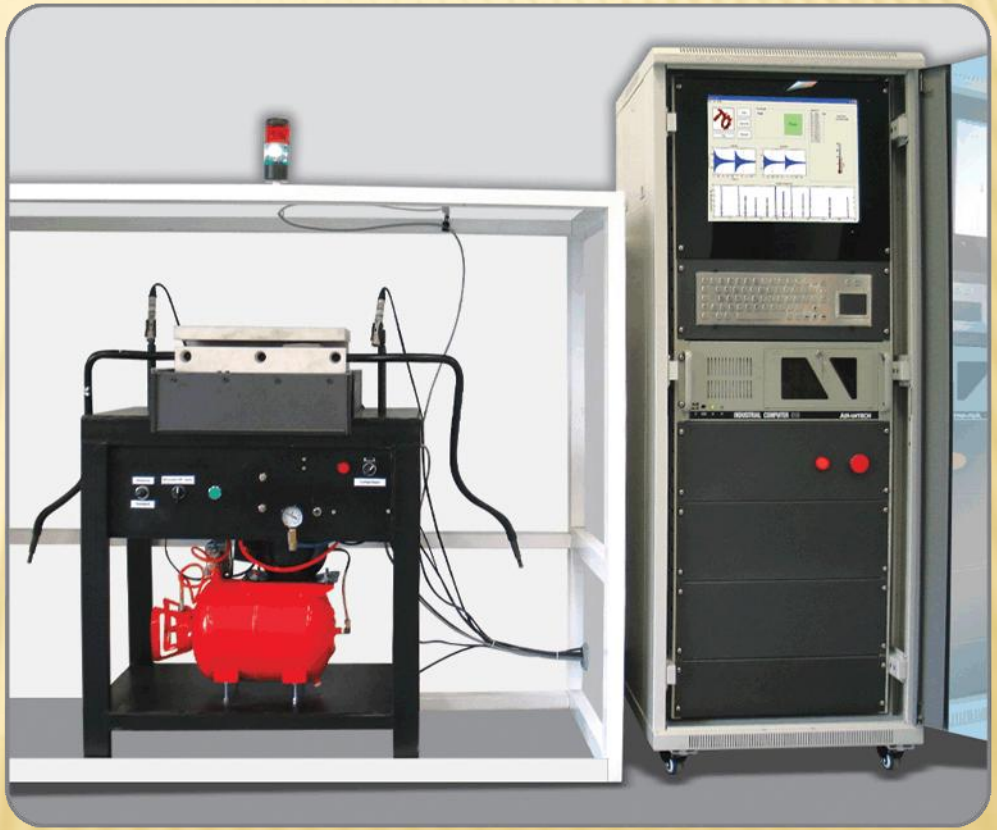
Knuckle Arm Test Line

Knuckle Arm Test Fixture

# Application 2: Hardness Uniformity Test

ARI Equipment to test Stabilizer bar for:

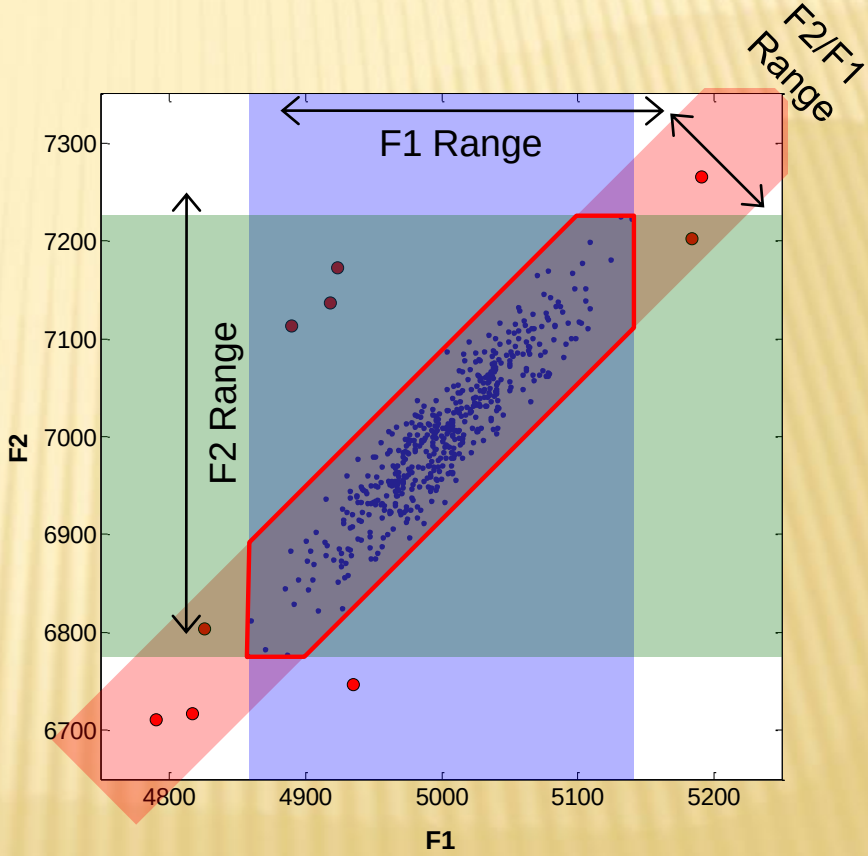
- **Hardness testing**
- **Hardness Uniformity testing**



# Application 2: Hardness Uniformity Test

In many cases **intersection** of some simple **criteria** can separate Good parts from Defective parts:

- Range of individual frequencies (*Fx*, *Fy*, …)
- Range of Ratio or Difference between two frequencies (*Fy/Fx* or *Fy-Fx*)




- Blue: Good parts
- Red: Defective parts

# Application 3: Crack Detection

Traditional methods of crack detection such as MP or PT are based on visual scanning of the part. However, theses methods have some problems that doesn't allow to test 100% of parts in mass production:

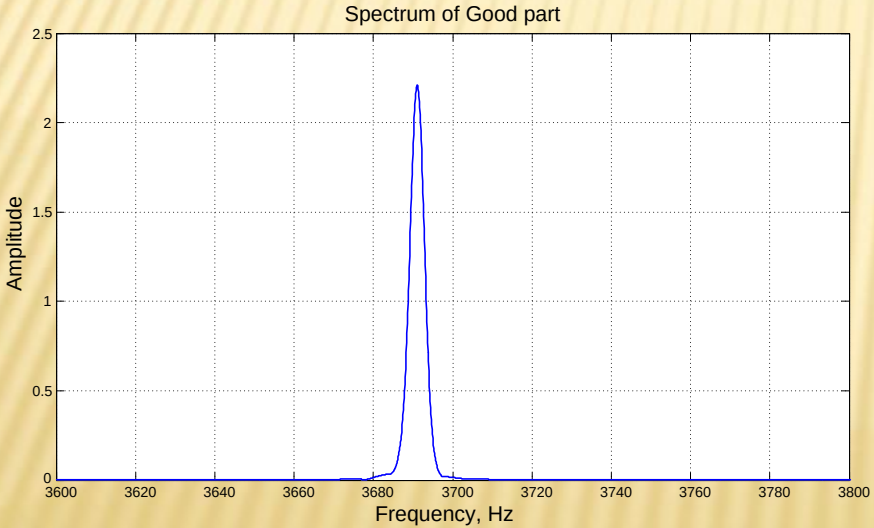
- Very expensive
- Contaminative
- Requires part preparation and cleaning
- High electrical power consumption (MP)
- Requires a well trained operator, and still the result is subjective

Nowadays there is a trend toward replacing the traditional crack detection systems with more energy saving and economic systems. ARI is a promising method that can overcome the existing problems.

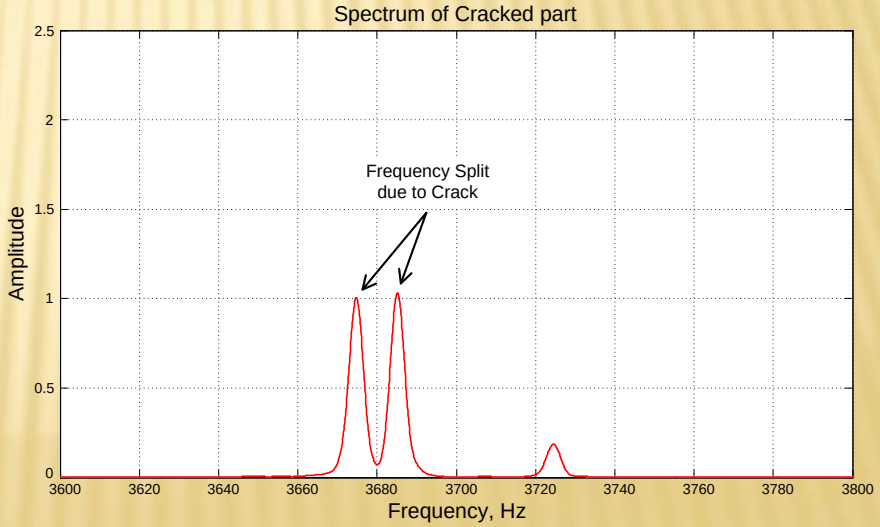
# Application 3: Crack Detection

A crack **shifts** some resonant frequencies, increases their **damping factors**, or causes non-linear effects such as **frequency split**.

We detect frequency split using advanced Eigen decomposition techniques to detect longitudinal hairline cracks.



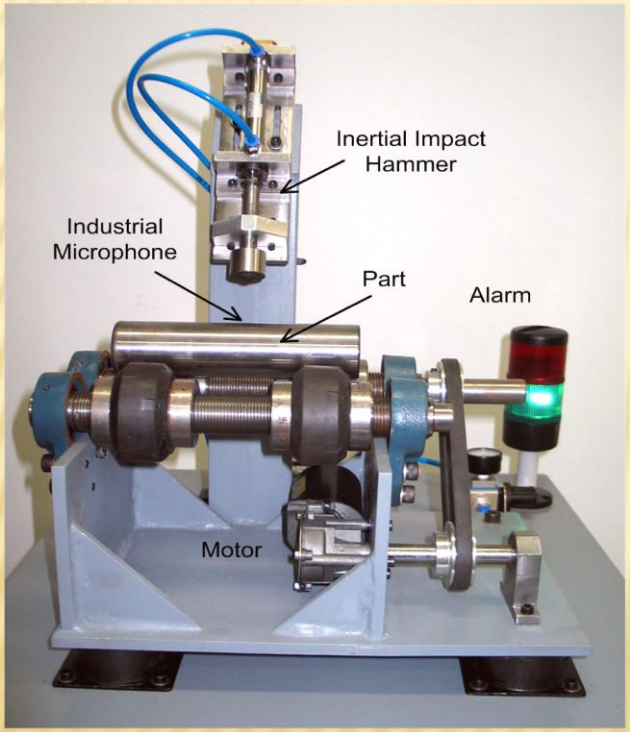

Mode *F3* of a good drive shaft




*F3* Split in a cracked drive shaft

# Application 3: Crack Detection

Examples of crack detection in Axle Shaft and Air & Exhaust Seats:

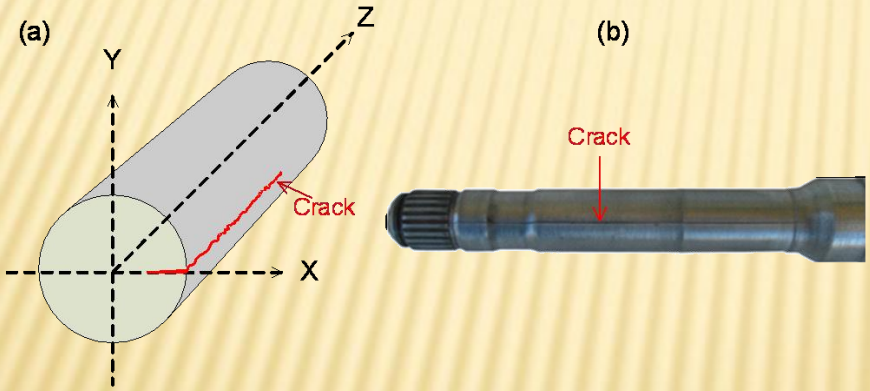



Longitudinal crack detection in axle shaft

Crack detection in air and exhaust seats

# Application 3: Crack Detection

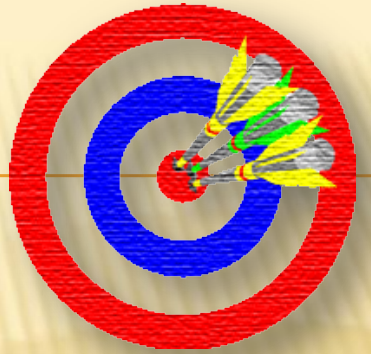
Example of longitudinal crack detection in drive shaft.




Longitudinal crack

ARI equipment for drive shaft test

# ARI 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 and Mass Compensation of resonant frequencies
- Automatic impact using inertial impact hammers
- Input/output control signals for trigger, alarm or other on-line process
- Dust-proof and weather resistant enclosure
- Customized fixture design with optional control for part loading
- Report generation including statistical analysis

# THANK YOU!

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