ACOUSTIC RESONANCE ANALYSIS FOR SAFETY PARTS IN MASS PRODUCTION

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Abstract: Acoustic sonic and ultrasonic resonance analysis is a new non-destructive testing technique that allows 100% testing of a wide range of test objects quickly and at low cost. After an impact, a specimen vibrates in certain characteristic modes and frequencies that can be measured by a microphone or laser vibrometer. Typical faults that can be detected are cracks, cavities, detached layers, material inconsistencies, hardness deviation and nodularity in iron castings. This test method supplements the volume-oriented NDT methods and possesses some important advantages.

Introduction: Sound testing by tapping a specimen is said to be one of the oldest NDT methods and still used in many applications, not only with chinaware or glassware. In all cases human beings evaluate the sound subjectively on the basis of their experience. In mass production this procedure is

- far too costly,
- not reliable, especially with safety parts and in loud environments,
- not reproducible and cannot be documented,
- too rough, because the human ear cannot distinguish between fine sound differences,
- stressful for the worker who has only a limited concentration.

Acoustic resonance testing (ART) – applied to industrial needs – is, in comparison to well-established testing methods such as ultrasonic, eddy current and x-ray, a relatively new non-destructive technique for a fast and cost effective 100 % testing of a wide range of specimens. To deal with these challenging requirements, this paper focuses on three major areas: firstly, how sound testing works even in harsh industrial environments; secondly, the properties (and limitations) of resonance testing within the context of other NDT methods; thirdly, and finally, the test system structure and some applications from the automotive industry for safety components.

One of the possibilities of grouping NDT methods is the differentiation into (Fig. 1)

1. volume-related methods and
2. surface-related methods.

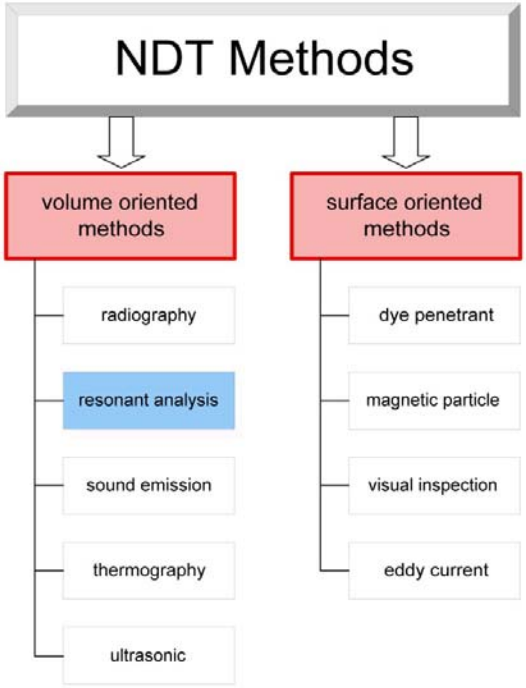


Fig. 1: Classification of NDT methods

The acoustic Resonance Analysis uses acoustic waves which can propagate through a physical medium. Sound in the narrow sense is understood as elasto-dynamic vibrations and waves in the medium of air, in the frequency range audible to humans, i.e. approximately 20 Hz to 16 kHz.

Mechanical vibrations in a structure (structure-borne sound) and radiated vibrations in the surrounding air (audible sound) carry information. Nearly all objects will vibrate when they are hit or excited or somehow disturbed. The mechanical deflections are called elastic waves. The velocity of propagation c is within a stiff material higher than within a soft medium and mainly a characteristic material constant (density, Young´s modulus of elasticity). The sound propagation is a directional quantity (vector) and depends upon the shape of a body (reflection). In solid-state devices, the sound propagation is different to that in gases and liquids, since in addition to compressional waves, transverse strains and transverse deformations can also exist. The following wave types may occur (Fig. 2):

Longitudinal wave	Direction of vibration similarly as in gases and liquids, i. e. parallel to the direction of propagation. No transverse deformations. Local compression zones und zones of lower density occur.
Transverse wave	The particles of the body vibrate perpendicularly to the direction of propagation around their resting position. Only transverse deformations, no volume variations.

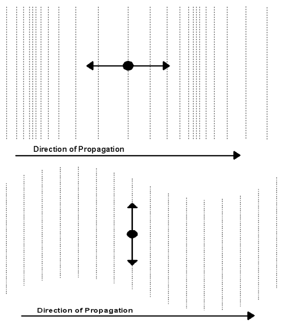


Fig. 1: Basic wave types

The vibrations represent the “language” of the test specimen, its “fingerprint” that can be detected with a sensor and then analysed digitally. A body contains numerous acoustic modes, the so-called natural frequencies or resonances, which depend uniquely on the object's material, geometry and condition.

Work pieces with a rather simple geometry like a rod, bar, ring or tube can be described by a set of mathematical equations. By means of the FEM (finite element method) and modal analysis, the natural frequencies and their variations can be calculated on the basis of the geometrical data. Defects can be inserted and their effects, which induce spectral shifts, calculated. Fig. 3 shows some of the different modes of an airbag cap.

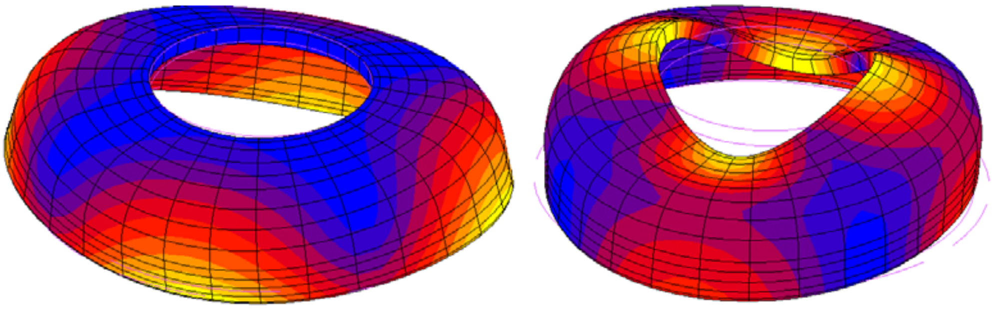


Fig. 3: FEM of an airbag cap (left: 3.3 kHz, left: 18.260 kHz)

In practice, a work piece is excited by an impact and the different modes are measured with appropriate sensors and devices. This requires consideration of different influences of the excitation, fixture bed, sensor technology and acquisition of the resulting signal. It also requires engineering and a stepwise approach for the variation of different conditions in order to observe their effects. The results from the above-mentioned theory can help to interpret the measured resonances and to identify the modes.

Acoustic Resonance Testing Technology

Resonance analysis can be applied for non-destructive testing of workpieces for several properties and defects within the body. They can be used to detect defects such as cracks, defective microstructure, shrinkage cavities, exfoliation, material spalling and fluctuations in density. One assumption is, amongst others, that the workpiece can be stimulated to vibrate and that the vibrations are not too strongly damped. Fig. 4 shows the time signal and adjacent resonant spectrum of a sample test subject. The peaks are the resonances of the part.

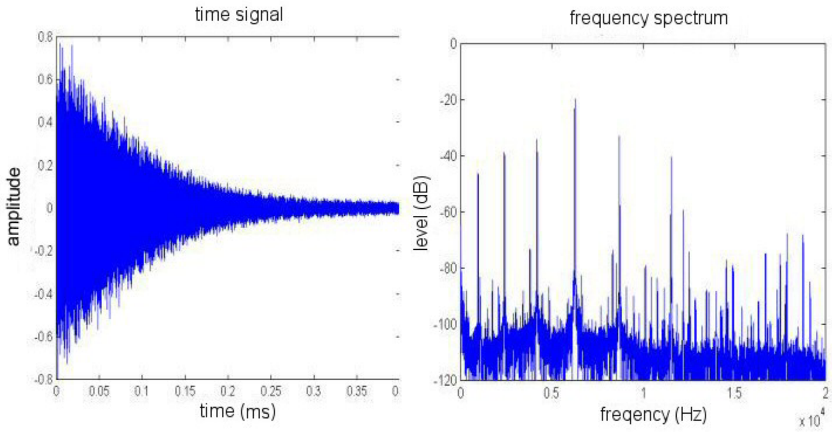


Fig. 4. Time signal (left) and adjacent resonances (right)

Mainly microphones or laser vibrometers are used. Measuring with a microphone has the advantage that this is an integral signal acquisition of the specimen. A microphone measures the sound pressure within a near field of the specimen, that means at a distance of about 5 to 15 cm. The distance depends on the size of the object. The frequency range is typically linear within 80 - 24.000 Hz. It is self-evident that the microphone must be suitable for harsh production environments, which are often dusty and oily.

The resonant frequencies, the spacing between them and the modulus of elasticity are characteristic parameters of the component and depend on the material as well as on its internal structure and geometry. Even very small material defects already influence the acoustic pattern of a body. For example, a crack in a component results in certain resonances being displaced to low frequencies whilst others remain the same.

Results: Applications presented in this paper are derived from various installations of the acoustic materials test system SR20AT (see below) in different branches: foundries, forges, sintered metal productions, metal forming and ceramics. Resonance analysis has passed its acid test in use in different branches of industry to detect

- cracks inside the part,
- nodularity (of cementite or graphite),
- inclusions,
- density differences in sintered metal products,
- hardness differences (heat treated or aged),
- bonding (welding, friction welding).

Table 1. Application areas of resonance testing

Material	Test of	Products (examples)
Castings		
Nodular cast iron	nodularity (cracks, inclusion)	Brake calipers, stub axle
Grey iron casting	structure	Camshafts
	cracks, casting defects, natural frequencies	Brake discs and drums
Diecasting	cracks, casting defects	Pedals, steering wheels, housing covers
Ingot mould casting	cracks, casting defects	Chassis parts, cylinder heads

Sintered parts	cracks, density	Transmission parts, toothed wheels
Steel	cracks, natural frequencies	Steering rods, drag link, airbags
Forgings	cracks	Synchronous rings, conrods
Steel / castings	bonding quality	Rotors, turbocharger shafts

Spherical-cast Brake Calipers

Spherical-cast brake calipers are safety parts. Structural and casting faults, cracks and cavities should be reliably detected as part of the components' total quality assurance tests. Of special interest is the structure of the material to make sure that the iron cast has not changed to grey cast.

100% production line testing is performed on a revolving transfer table, installed specially for the final tests (Fig. 5). The measured parameter is sound, with the specimen excited to oscillate in a defined way. Recording and analysis occur in a few hundred milliseconds. To achieve maximum reliability, all parts are sequentially tested by eddy current and resonance testing. Whereas eddy current checks the surface, the resonance analysis looks more into the volume.

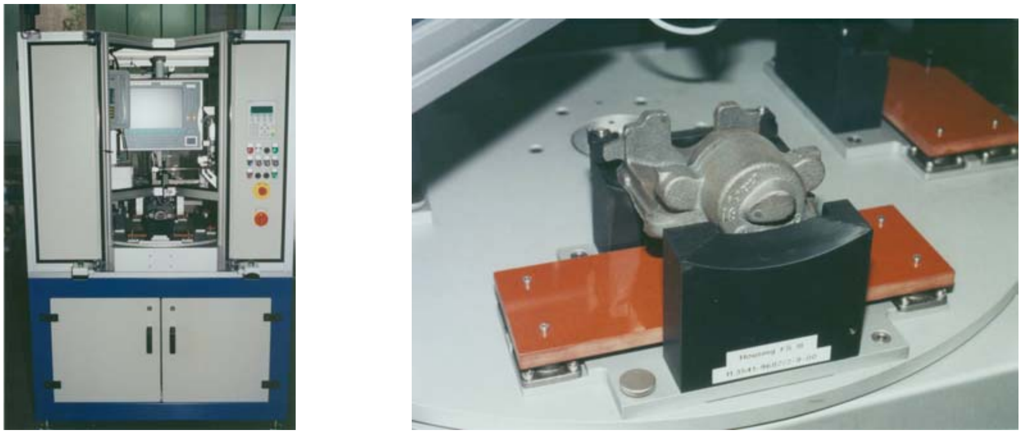


Figure 5. Integrated test bench with eddy current and resonance testing for brake components

Monitoring by the test system of all the parameters relevant to the acoustic test leads to high system availability and test result reliability. Parameters can be changed by authorized personnel by using the "online parameter setting" function. Inputs are checked for physical plausibility, so as not to endanger the testing process.

Sinter metal parts

Sintered parts are widely used in industry. Faults can be cracks, porosity and different density areas within the part. For fast production testing, RTE has developed an automatic test bench for rotary symmetric parts with an incoming conveyor belt, modular test bench with separating, positioning, resonance testing and sorting / marking, and finally an outgoing conveyor belt (Fig. 6). The test bench with a test capacity of 900 parts / h can easily be adapted to different products by changing components. Products and production process are monitored and statistically evaluated.

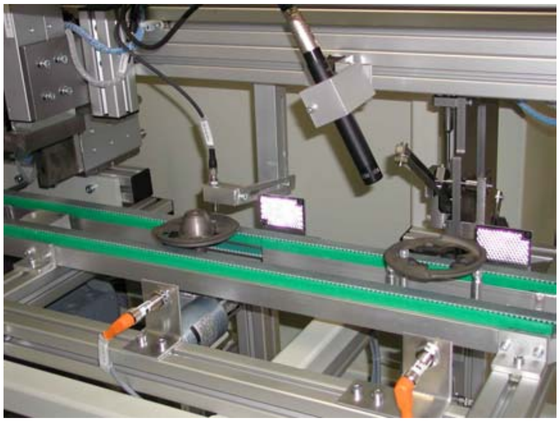


Figure 6: Inline modular test bench for sinter metal components (right: positioning and resonance testing)

Airbag Inner Tubes

Airbags are safety parts and manufactured by a solid forming press. Through this cold metal forming process crinkles (so-called "smilies") and cracks can occur in the material (Fig. 7). When hitting such a rotary-symmetric part one can observe the effect that the level of two adjacent resonances changes in relation to the angle. One of the frequencies has its maximum when the other has its minimum and vice versa.

Fig. 7: Airbag tubes with crack (left) and crinkle (right)

Although the dimensional properties of airbags are quite precise, the hardness may differ between the batches due to the thickness calibration of the material before forming. These hardness differences require a self-adaption of characteristics to preserve the resolution of the analysis.

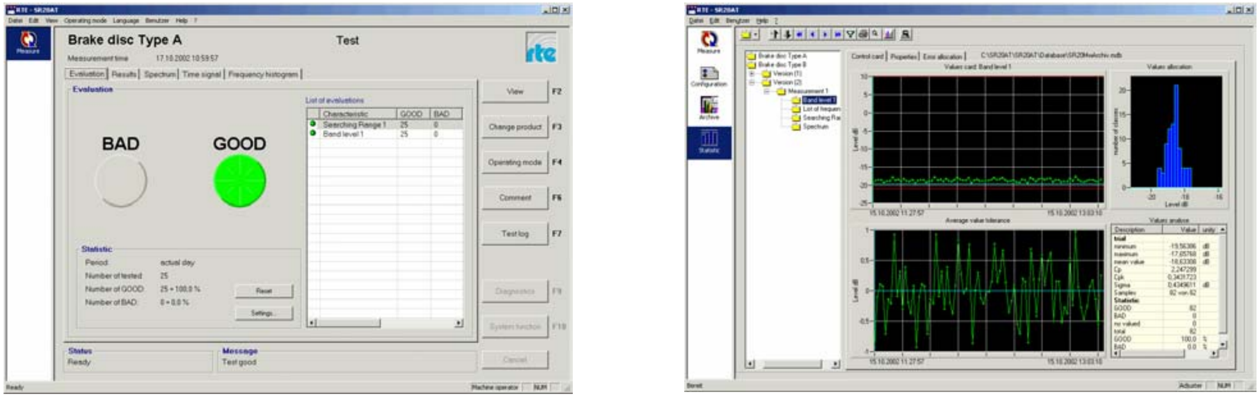
Steering racks

The acoustic resonance method was also applied for inline testing of toothed steering racks. The main focus here is the test for cracks and heat treatment. The racks are transported into the test bench by a lifting unit and then to the test position. Three electro-dynamic hammers excite the steering rack sequentially at different positions. The sound is picked up by a microphone. The computer calculates and compares the resonances with a resolution of 1 Hz and generates the decision for the test bench controller. The PLC forwards the toothed rack into the next position where a lifting unit lowers the specimen to the conveyor or transports it to the deposit station (Fig. 8).

Figure 8: Automatic resonance testing of steering racks

SR20AT Resonance Test System

RTE has developed the system SR20AT for industrial acoustic resonance analysis, which can be used for manual testing as well on a fully automatic test bench with a choice of excitation systems (pneumatic impact, striking in horizontal or vertical suspension) and sensors (microphone for sound range up to 25 kHz, laser vibrometers up to 100 kHz). SR20AT automatically determines the test characteristics by means of a "reference run" with previously classified samples. The high degree of resolution down to less than 1 Hertz also enables detection of very fine defects. Because the acoustic materials testing often takes place automatically in the production cycle, the self-monitoring of the test rig, sensory mechanism, hard and software as well as the calibration capability is particularly important.



Brake disc Type A

Test

Measurement time 17.10.2002 10:59:57

Evaluation

List of evaluations

Characteristic	GOOD	BAD
Searching Range 1	25	0
Band level 1	25	0

Statistic

Period: actual day
Number of tested: 25
Number of GOOD: 25 = 100.0 %
Number of BAD: 0 = 0.0 %

Status: Ready
Message: Test good

C:\SR20AT\SR20AT\Database\SR20Archiv.mdb

Description	Value	unity
trial		
minimum	-19.56306	dB
maximum	-17.65768	dB
mean value	-18.63306	dB
Cp	2.247299	
Cpk	0.3431723	
Sigma	0.4349611	dB
Samples	82 von 82	
Statistic		
GOOD	82	
BAD	0	
no valued	0	
total	82	
GOOD	100.0	%
BAD	0.0	%

Figure 9: SR20AT Test System: result screen (left) and statistical evaluation (right)

The hardware system consists of an industry-standard desk-top case with TFT display, industrial PC with Windows 2000, 8-channel signal card, opto-isolated digital I/O card, sensor system with signal conditioning, network and modem connection for remote maintenance and a test control box.

The modular software comprises components for the test mode, user administration, configuration of test sequences and test specimen parameters, archive and statistic components. These components communicate via the standard interfaces with the SR20AT server, which executes the test steps on the basis of scripts. The components utilize numerous functions, among others, the presentation of results, deviation analyses and trend analysis. The software is available in all common languages including Japanese.

Conclusions: Resonance analysis is a qualitative method, i.e. it can differentiate between defective and non-defective parts, so that it is especially suitable for quality assurance in the series production cycle. It compares the actual oscillatory situation with the target one derived from a learning base. This learning base is established by using defined standard parts. The number of self-resonant frequencies is determined by the geometry of the object under test. For instance a bar has few resonant frequencies, while a complex lattice-type object has many natural resonances. After a systematic engineering approach, the user can benefit from the following predominant features of the resonance analysis:

- High reproducibility: you will get exactly the same frequencies when you hit the part again!
- High resolution down to less than 1 Hertz possible - linear in the whole frequency range (!),
- Non-destructive, dry and clean,
- Fast analysis (within a second!),
- Simple to automate in comparison to other methods like x-ray and ultrasonic,
- The entire part is involved independent of the defect position,
- Documentation, storage and traceability of each or selected parts,
- Excellent cost-value ratio.

References:

Hertlin, Ingolf: Acoustic Resonance Analysis. Castell Publication Inc., Wuppertal 2003. ISBN 3-934 255-21-3