CrackMaster™

Non-destructive component testing in mass production by using acoustic resonance testing
CRACKMASTER™ ACOUSTIC RESONANCE TESTING (ART)

You are a producer of series components. A small number of components can show quality-relevant irregularities. Such components occur statistically, quality parts are mainly manufactured.

Typical irregularities are discontinuities (cracks, cavities), inhomogeneity (density, structure, stability), and defects in workmanship.

Acoustic resonance testing (ART) is a technique for non-destructive component testing. The attraction of this method is the possibility to carry out a quick and automated testing by evaluating the merely physical component parameters at relatively low investment and operation costs.

Acoustic Resonance Testing (ART) evaluates the natural vibrations. Natural vibrations are unique physical characteristics of components that describe in their totality the complete component inside and outside regarding material, structure and geometry. Two equal components must obligatorily show the same natural vibration behaviour. If this behaviour differs, the components show physical deviations that can be relevant to quality.

The Saab Medav Technologies (SMT) CrackMaster system measures the natural harmonics of a component by stimulating the resonance e.g. with the help of an impact hammer. By evaluation of the natural harmonics numerous quality features are determined. The measurements are performed quickly and reproducibly, the assessment is performed objectively.

CrackMaster shows a number of favourable aspects compared to competitive techniques and concepts:

- The system is adjusted with parts of the current series production provided that mainly quality parts are manufactured. Any conspicuous components are detected by statistic methods. This approach explicitly does not require pre-sorted good and bad parts.

- The manufacturing process is subject to variations that lead to tolerances of the components. These unavoidable irregularities require regular and extensive readjustment of the feature limits, but this work is done by our "chameleon" method. CrackMaster including the chameleon-method provides the users almost a black box system for their production.

- SMT developed quality criteria based on natural vibrations that are very useful for the detection of slight irregularities.

Acoustic Resonance Testing is especially qualified for in-line application if basic conditions are fulfilled. The most important precondition is that the irregularities to be detected have sufficient influence on the vibration behaviour of the component, also compared to the tolerance-induced manufacturing influences. Thus, prior to any implementation in a manual work place or a fully automated solution, preliminary inspections are necessary. The vibration behaviour of the component should be determined as good as possible, as well as the influence of the manufacturing process. Both are very important for the success of the solution approach.

For successful introduction of a solution that is based on a new technique (being routinely the case for our clients) we expect openness to changes and the nomination of a person in charge. This person is a motivated and computer skilled employee, who is willing to be trained by SMT. SMT supports the required expertise transfer, so that the person in charge is able to carry out all tasks as independently as possible. SMT offers long-term support, e.g. in the development of solutions for further components.
**BASIC INVESTIGATIONS**

For the solution of specific problems, knowledge regarding the vibration behaviour of the test component is required, in order to determine the measuring system and the analysis methods, and to estimate the limits of the detectability of slightly distinctive irregularities like e.g. short cracks.

The calculation of Finite Element Models (FEM) is ideal for the determination of the occurring natural vibrations with related modal parameters “natural harmonics” and “natural vibration forms”. On evaluating the FEM results (list of the natural harmonics and video animations of the related natural vibration forms) physical limits of the error detection can be identified. Furthermore the different natural harmonics are assessed regarding their ability to detect particular defects.

This information combined with the knowledge of the physically motivated effects that cause (quality-relevant) irregularities at the test component are relevant to the definition of the measuring system and of the criteria that have to be determined analytically. At the definition of the measurement setup and parameters physically motivated particularities of the components’ geometry are considered (e.g. rotational symmetry).

The FEM analysis is especially reasonable for the detection of slightly developed irregularities. The detection of major faults is regularly uncritical and does not require an FEM analysis. The same goes for standard geometries that are treated in literature.

Alternatively to the FEM calculation, series of measurements can be performed, e.g. by varying the activating positions with the aim to activate and measure as many natural vibrations as possible. Normally, the approach that delivers the highest number of measured natural harmonics will be applied. In this practical approach, the detectability of special irregularities can be shown by empiric studies with correspondingly faulty components.

Significant results derive from measurement taken on at least 50 items from one production lot, ideal are about 200. We prefer measuring the components in production or machining sequence, which is not always possible. Each data record can be related to the respective component due to numeration of the components or recording of their serial numbers.

With our measurement setup noise or vibration signals are recorded from which spectra are calculated. In the spectrum the frequency detection windows for the selection of the resonance frequencies are defined in such a way that the resonance frequency can be detected for all samples (at least for all good parts) despite of its scatter.
Subsequently, assessment features are defined using the physical quantities maximum position, signal level and damping of the resonance frequencies. For this we use our wide expertise in order to take advantage of all potentially relevant quality criteria. From twenty selected resonance frequencies up to several thousand assessment features can be obtained.

For this purpose, statistical values for each assessment feature are calculated. In this process outliers can be neglected in order to avoid distortion of the feature values caused by faulty parts.

Under the postulate that mainly faultless parts are produced in our batch and under assessment of all calculated features CrackMaster determines a ranking of all test results according their conspicuousness.

On top of this table you will find the most striking component related to its vibrational behaviour, and at the bottom of the table the most homogenous component related to our resonance frequency measurement – definitely a faultless part according to the requirements.

It is a fact that the components detected by the CrackMaster System as abnormal are physically “irregular”. It is to be clarified if these irregularities are quality-relevant according to the standards of the factory. This factory-sided evaluation of the components that were pre-selected as being conspicuous by the CrackMaster system is decisive for the reliability of the sorting. For this reason, our customer applies non-destructive and destructive techniques in order to achieve the maximal safety of an approved quality rating for selected components.

Assessment features and their tolerances are checked by this tuning process, and - if necessary - adapted. In this way a “formula” for the abnormality limits of each assessment feature is determined, which uses statistical units.

CrackMaster is now set. A validation of the results is carried out by further measurements, preferably about 1,000 - 2,000 items from two or three different production lots.
SERIES TEST AND QA CONTROL CYCLE

The CrackMaster is set according to the results of the basic investigations. Typically several hundred or thousand criteria are active and applied for the series test - performed by our customer either by a hand-work place or by a fully automated system. At the hand-work place the handling of the component is carried out manually, the measurement is started manually; the test procedure itself is carried out automatically.

The CrackMaster system can be adjusted and optimized with regard to process safety during ongoing serial operation by checking independently sorted out abnormal items, limiting samples, and faultless parts. SMT named this method to adjust the system the QA Control Cycle.

Abnormal items are detected by the CrackMaster system and sorted out over a separate belt that classifies the components non-interchangeably, so that the respective measured data record at the CrackMaster system can be assigned to the component. The quality assurance “occasionally” takes out the sorted out components and carries out a supplementary quality control applying non-destructive or destructive techniques. These results are documented and entered into the CrackMaster system, which checks the data and - if the assessment diverges - adapts its limits for abnormalities so that the assessment of the prior recorded data leads to results in agreement to that of the supplementary quality control. From this stage on the series is tested with the new "formula" for abnormality limits. The adaption of the limits and also their update is performed automatically in a few minutes or correspondingly on specified clearance routine. The systems includes a safeguard in order to keep unaffected formerly pre-set tolerance limits which showed to be important for the detection of faulty parts. The same method is applicable to limiting samples and quality test samples.

On serial operation the values measured for each assessment criterion can vary due to fabrication variability and environmental influences. Our “chameleon” method automatically adapts the absolute position of the irregularity limits for all assessment criteria. In this way it is guaranteed that the closest tolerance is applied for the criteria, being decisive for the detection of slight irregularities. Our ambition is to detect conspicuous (i.e. untypical) parts within a series of items. This is why it is so important to permanently compare the respective component with reference parts that are as comparable as possible – to each other and to the part under test. This explains why the parts should preferably be tested in the order of the production and processing. There are various strategies for adaptation to the current production lot and definition of tolerance limits.

Lots and tool changes can lead to abrupt changes in the feature values causing comparable or even larger differences than between faultless and faulty parts. For this reason it is important to update the CrackMaster in case of process alterations. By help the subsequent measurements CrackMaster will then calculate a new standard for the feature values and continue testing. The components that had not been tested thereby are lead back on short term or evaluated offline.
Saab Medav Technologies is a system supplier for solutions, components and tools. For tasks related to machine building SMT cooperates with the partner of customer’s choice. It is certainly possible that the customer contributes with internal services. SMT contributes its expertise in vibration-relevant aspects to the construction of the testing device. SMT offers a wide range of modular system components that are very useful for a cost-efficient installation of hand-work places and automats:

**Example 1:**

*Universal test station with impact device* for components of size up to 400 x 400 x 300 mm.

The test station includes the following modules:
- A vibration isolated base plate including a mounting area for the component-specific part settlement,
- A portal for positioning of the impact device,
- And a holding device for the sensors (microphones, probe tip).

The positions of all test bench components for a concrete test setup are documentable via scales.

Control and supervision of the impact device result electronically. The control electronics is part of the CrackMaster system.

The impact device fits for horizontal and vertical impact. The distance to the component under test is adjustable precisely.

**Example 2:**

*Universal slide device* for particularly small components or special geometries which are not suitable for sound excitation via impact device.

In this process the component is introduced individually and in correct position from above into a guide rail. An electronically controlled stopper activates the testing process. The component drops on an anvil, rebounds releasing a characteristic noise signal and falls onto the soundproof collection container. This noise signal is recorded by a microphone and then evaluated. Device and anvil are vibrationally isolated. All setups are documentable by scales.

**Example 3:**

*Half automated testing device* for rotation symmetric components including acoustic hood and external control.

Rotation symmetric components like gear wheels and brake disks need to be activated at different positions. A motor powered turning device can be used for this. An acoustic hood is used for reduction of distortions by ambient noise.

The external control is qualified for control of the acoustic hood and activation of the turning device.
APPLICATION EXAMPLES

Example 1:
Testing of rotationally symmetric sintered (PM) components for the detection of small cracks and other discontinuities. The customer conducted an FEM analysis and provided the results.

Hand-work places and fully automated systems were delivered.

The cycle time for testing of rotationally symmetric components is about 10 seconds due to the requirement of multiple impacts with turning of the component. The cycle time for testing of parts with one impact is approx. 1 - 2 seconds (this is also the case for testing facilities using the slide device for sound excitation).

SMT has large experience on standard sintering techniques (powder metallurgy) and metal injection molding (MIM).

Example 2:
Crack-tests of car body parts. Drawing cracks, thinning, doubling and cut defects can be detected.

Body parts are automatically tested in the press line according to the press clock. The component handling is carried out by robots or transfer units.

The measurement instrumentation and evaluation software were delivered.

Example 3:
Testing of forged unbalance shafts concerning cracks and hardness differences.

The testing time is about two seconds.

A hand-work place and a fully automated system were delivered.

SMT provided systems for crack and microstructure testing for different industries: Foundries, extruding presses, and others.
SYSTEM OVERVIEW, TECHNICAL DATA

System overview

A CrackMaster system must include:
- signal recording device with control module for impact device or slide device
- PC for data evaluation (Windows based)
- online and offline analysis software including chameleon module

Depending on the application a CrackMaster system can include:
- the automation interface (TeCo), alternatively via TCP/IP, PLC, field bus, …
- engineering components:
  - impact or sliding device
  - part settlement (for testing of different components, a changeable part settlement is recommended)
- sensor system: measuring microphones to 75 kHz, laser Doppler vibrometer, probe tips (accelerometers)
- control cabinet with UPS and ventilation/cooling
- noise reduction measures

Optional modules:
- remote maintenance
- offline software for the optimisation of setups, statistics (reporting)
- connection to QDAS (data handling in the QDAS-data format)
- calibrators for the implemented sensors

Environmental conditions

Measuring signals have to be protected against disturbing noises and vibrations in order to guarantee process safety. This can require noise protection (enclosure and acoustic insulation using commercial isolation modules) and structure-borne noise damping measures (using commercial tilger modules).

Application temperature for CrackMaster hardware: 10 °C to 40 °C.

Clock cycle

The typical cycle time for the testing of a component is between one and two seconds and slightly depends on the number of the setup criteria. On applications that require multiple impacts, a cycle time of between 4 and 10 seconds is expectable.

Master part

For a functional check of complete testing device, it is recommended to produce a long run stable master part. The master part should basically meet the geometry of the testing component, so that it fits into the part settlement supporting the impact and sensor measuring system. The master part helps to detect any irregularities in the complete measurement chain by comparing a test measurement to the result history.

Languages

User interface and handbooks are alternatively available in German or English language. Other languages are available on request.

Industrial property rights

Patent protection is applied for parts of the CrackMaster system, applications, and measuring devices.