The resonant acoustic method offers the capability of 100% part inspection in a high-volume production environment.

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The resonant acoustic method is a “whole part” inspection technique that measures the structural integrity of each part to detect flaws on a component level. Capabilities include materials ranging from ductile iron to powder metal to ceramics, and part sizes ranging from less than an ounce up to 50 lb (23 kg). The technique is easily automated to eliminate human error, with fast throughput providing cost-effective 100% inspection with minimal disruption to production.

The nondestructive testing — resonant acoustics method (NDT-RAM) is now the standard in-line inspection on production lines for powder-metallurgy and cast parts. It is a simple, effective solution to the challenge of achieving zero parts per million defects.

Resonant inspection principle
The principle of resonant inspection is simple: every part has a unique resonant vibration signature, or pattern, that reflects its structural integrity. A deviation from the expected signature of resonances can indicate the presence of a flaw. For example, consider a bell or tuning fork. When you strike either part, it vibrates and emits a sound. An instrument that “rings true” produces a consistent sound, which correlates to the structural integrity of the instrument.

This is the basis for NDT-RAM technology. When struck by an impactor, parts such as gears, brake anchors, and rotors emit many resonant frequencies as part of their structural response. This unique, measurable signature of resonances is compared with and analyzed against both a good and bad product. Just as a cracked bell will not ring true like a structurally sound bell, if a part such as a gear is cracked, lacks the correct density, or misses other characteristics of a structurally sound product, the flaw will be exposed when its resonant signature deviates from what has been identified as good product. Figure 1 graphically shows the steps in the RAM inspection process.

The resonances of a structure are a function of part geometry and material properties, and are defined by mass, stiffness, and damping ability. These resonant frequencies can be measured in most rigid materials, including most metals and ceramics. NDT-RAM systems detect frequency shifts that can be caused by imperfections such as cracks, porosity, and voids, as well as variances in nodularity (ductile cast irons), dimensions, geometry, weight, density, and manufacturing processes. Typical flaws and defects adversely affecting structural characteristics are given in the table for powder metallurgy, ductile iron, and ceramic parts.

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Quantitative analysis
RAM tests the entire part for both external and internal flaws. It provides an objective, quantitative analysis that eliminates errors involving human interpretation and judgment through proven dynamic measurement equipment.

In operation, a dynamic sensor captures the sound waves, and a high-speed analog-to-digital converter translates the sound into measurable data. The structural resonance of a defective part shifts,
and the shift is identified when compared with predefined
data. In effect, NDT-RAM listens to the structural response
of a part and evaluates it against the statistical variation from
a control set of good parts to screen anomalies.

The criterion for the predefined data is established by ex-
perimental analysis of a statistically significant sample set.
The resonant signatures of both good and bad products are
captured to provide objective, measurable variables for com-
parison. Templates are established for each part type. An
example of a template is shown in Fig. 2. The NDT-RAM
system is programmed with these templates, and requires
minimal human interaction for operation or maintenance.
Because no special part fixturing or preparation is needed,
parts can be tested as fast as one per second, keeping pace
with automated production lines.

Comparison with other methods
Traditional NDT techniques focus on detecting and diag-
nosing defects. They are based on visual techniques or im-
aging to scan for any indication of defects. Scanning methods
include magnetic particle testing (MT), ultrasonic testing
(UT), eddy current/electromagnetic testing (ET), dye-
penetrant testing (PT), and X-ray/radiographic testing (RT).
These methods often are manual and require subjective
interpretation by an operator. Although diagnosing and/or
imaging specific defects are applicable when evaluating an
individual part or system, they are not appropriate for high-
volume, 100% manufactured part inspection. In these cases,
it is of primary importance to detect whether a part is non-
conforming, rather than why. Identifying the type of defect
itself is secondary to identifying the nonconforming parts.
Therefore, an end-of-line “go/no go” objective inspection
such as by NDT-RAM is preferred over that of a slower sub-
jective diagnosis.

After defective parts have been sorted with NDT-RAM,
complementary visual or imaging nondestructive testing
techniques provide a means for subjective diagnosis on the
smaller subset of parts. This is useful to determine the root
cause of a defect and ultimately improve the product de-
sign or production process.

One of the benefits of RAM is that it is easy to justify fi-
nancially. It has a low overall cost of ownership because it
does not require additional materials to operate; no solu-
tions, chemicals, or films are needed. It aids in profitability
by achieving zero defects and lowering overall production costs
by reducing variances in the production process.

Because it is fast enough to test 100% of the parts, the
system works as a process monitor in addition to part quality

Fig. 2 — Parts template in NDT-RAM software used for evaluating
parts against known good samples.
inspection, and insures against quality-related expenses while functioning as a process control monitor. If the system starts failing multiple parts, it allows manufacturing personnel to adjust the upstream process before a large number of faulty parts is produced and must be scrapped.

**Nodularity testing**

One common application for NDT-RAM is testing ductile iron for acceptable levels of nodularity. Cast iron contains a high carbon content, and during solidification of the metal, the carbon content can form irregularly shaped graphite flakes that disrupt the crystalline structure, causing cracks and brittleness. In ductile iron, the graphite forms spherical, rounded nodules that inhibit the formation of cracks and provide enhanced ductility and machinability. The higher the nodularity, the higher the ductility. Figure 3 illustrates the difference in microstructure of ductile iron with high nodularity (93%) and poor nodularity (55%).

Very often, part designers specify a minimum level of acceptable nodularity (typically >85%) to ensure proper ductility. This can be especially important in safety-critical automotive parts such as brake and suspension components. The traditional inspection technique for testing this is ultrasonic (UT), which measures the velocity of sound waves passing through material. Rounded graphite nodules do not impede the acoustic energy, while flaky graphite particles do. Thus, higher ultrasonic velocity correlates with higher nodularity. However, UT is a localized test that looks only at one specific section of a part, and it requires a coupling liquid bath for testing.

With NDT-RAM, resonant frequency correlates directly with nodularity, and no coupling agent is required. Lower nodularity levels result in reduced resonant frequency characteristics. Resonant inspection detects these shifts in resonant frequency characteristics, resulting in cost-effective, reliable, high-volume automated inspection. Additionally, because resonant acoustic inspection is a volumetric technique, it checks the entire part for nodularity (as well as for other flaws such as cracks and voids).

**Sinter brazing**

Sinter brazing is a common joining process for powder metallurgy parts, as it allows production of complex components via conventional PM technology. The technique involves assembling multiple parts prior to sintering, adding a braze compound, and sintering at temperatures above the melting...
point of the brazing alloy. When processed properly, sinter brazing is very cost-effective and produces a very strong joint. Several examples of brazed powder metal parts are shown in Fig. 4.

Certain defects are common among sinter-brazed PM parts, including subcomponent misalignment during initial assembly and incomplete braze material infiltration. Inadequate infiltration is typically caused by an improper braze alloy or damaged braze pellets (for example, a slug with 50% of its material chipped away).

Another root cause of poor sinter brazing is missing the braze pellet altogether. Other process variances that can lead to inadequate braze joints include improper furnace settings and dwell point. All of these defects can result in poor joints, reduced part strength, and ultimately part failure. With RAM, resonant frequency shifts are measured for an accurate, reliable 100% inspection. By comparing these measurements to visual and destructive separation pull-force evaluations, it can easily and reliably detect poor sinter-brazed joints. The capability of automating NDT-RAM makes it superior to subjective visual inspection or inefficient separation-force testing.

Ceramic parts

Ceramic parts ranging from ceramic washers and filters to personal body armor plates are also suitable for NDT-RAM. Typical structural defects in these components include cracks, chips, and delaminations.

Ceramic parts are manufactured in a similar manner to powder metallurgy parts. Ceramic powders are pressed into a green compact and then subjected to a sintering process. Density gradients and non-uniform shrinkage can cause distortion or stresses that can lead to fracture or other structural defects during the process. Shock or vibration to green parts during handling prior to sintering can also lead to significant structural defects.

As a result, 100% part inspection via resonant inspection is often necessary, particularly with safety-critical parts or in medical equipment components. In the case of personal body armor, plates are often destructively tested by shooting them with a projectile. If a sample set from a production lot stops the bullet, then the samples are discarded and the remaining production units from that lot are accepted. On the other hand, if just one of the lot sample plates is damaged by the projectile, the entire lot is rejected.

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