

Resonant Inspection Applied to 100% Testing of Nodularity of Cast Ductile Iron

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ABSTRACT

Worldwide emphasis on defect-free manufacturing within the automotive sector has driven manufacturers to seek out cost effective methods of 100% inspection. To achieve zero defect output cost-effectively, manufacturers are making the commitment to move to online, automated nondestructive testing (NDT) methods. This type of online inspection requires accuracy, reliability, and high throughput. The Resonant Acoustic Method of Nondestructive Testing (RAM-NDT) is emerging as a type of resonant inspection that is a very efficient method of structural defect discrimination lending itself well to automated online implementation. This paper presents the fundamental principles of the resonant acoustic method and how it is been applied to testing nodularity in ductile iron brake calipers, rotors and anchors.

INTRODUCTION

Due to the high expectations of automotive manufacturers and their end consumers, there is a growing requirement for zero defect supply chain commitments. To achieve zero defect output, manufacturers are making the commitment to move to online NDT. This type of online inspection requires accuracy, reliability, and high throughput. Resonant Acoustic Method NDT (RAM-NDT) provides a proven technique exhibiting these pivotal performance requirements and automates economically. RAM-NDT tests, reports and screens for most common part flaws in a manner similar to the way NASA tests flight hardware and automotive manufacturers validate their new car designs. Utilizing structural dynamics and statistical variation, RAM-NDT provides mature, laboratory proven technology in a robust, economical, process-friendly manner.

FUNDAMENTALS OF RESONANT INSPECTION

RAM-NDT [1] is a volumetric resonant inspection technique that measures the structural integrity of each part to detect defects on a component level. This technique is easily automated to eliminate human errors with fast throughput, providing cost effective 100% inspection with minimal disruption to production. With a large number of successes on the production lines of powdered metal and cast parts, RAM-NDT is the simple and effective solution to manufacturers' zero PPM challenge.

Traditional NDT techniques, for example ultrasonics or magnetic particle testing, focus on detecting and diagnosing defects. They use visual or imaging techniques that scan for indications of specific defects. For production line quality inspection, identifying the type of defect itself is secondary to identifying the defective parts. While diagnosing specific defects is applicable when evaluating and inspecting some systems, such as using ultrasonics to inspect gas pipelines, it is not appropriate for high volume 100% inspection of manufactured metal parts. For these production lines it is of primary importance to detect *if* a part is non-conforming rather than *why*. Therefore, an end-of-line "go/no go" objective inspection, such as by RAM-NDT, is preferred here to a subjective diagnosis, perhaps useful in defect root cause analysis.

Resonant inspection (RI), the general classification of RAM-NDT, measures the structural response of a part and evaluates it against the statistical variation from a control set of good parts to screen defects. Its volumetric approach tests the whole part, both for external and internal structural flaws or deviations, providing objective and quantitative results. This structural response is a unique and measurable signature, defined by a component's mechanical resonances. These resonances are a function of the part geometry and material properties and are the basis for

RI techniques. By measuring the resonances of a part, one determines the structural characteristics of that part in a single test. Typical flaws and defects adversely affecting the structural characteristics of a part are given in Table 1 for powdered metal, cast and forged applications. Many of the traditional NDT techniques previously discussed can detect these flaws as well, but often only RI can detect all in a single test, throughout the entire part (including deep sub-surface defects), in an automated and objective fashion.

Table 1. Typical structural defects detectable by resonant inspection.

Cast	Forged	Powdered Metal
Cracks	Cracks	Cracks
Nodularity	Missed or double strikes	Chips
Porosity	Porosity	Voids
Hardness/density	Hardness	Hardness/density
Inclusions	Inclusions	Inclusions
Heat treat	Heat treat	Heat treat
Compressive & residual stress	Quenching problems	Decarb
Cold shuts	Laps	Oxides
Raw material contaminants	Raw material contaminants	Raw material contaminants
Missed processes/operations	Missed processes/operations	Missed processes/operations

After defective parts have been sorted with RI, complimentary traditional NDT techniques may provide a means for subjective diagnosis on the smaller subset of parts. This is useful for determining a defect's root cause and ultimately improving the production processes.

The Resonant Acoustic Method technique performs resonant inspection by impacting a part and "listening" to its acoustic spectral signature with a microphone. The controlled impact provides broadband input energy to excite the part and the microphone allows for a non-contact measurement of the part's structural response. The part's mechanical resonances amplify the broadband input energy at its specific natural frequencies, indicated as peaks in the frequency spectrum and measured by the microphone above the background noise in the test environment. "Good" parts (structurally sound) have consistent spectral signatures (i.e. the mechanical resonances are the same among part samples) while "bad" parts (structurally different) are different. Deviations in peak frequencies or amplitudes constitute a structurally significant difference that provides a quantitative and objective part rejection. An example of a typical spectrum from 0 to 50 kHz is given in Figure 1.

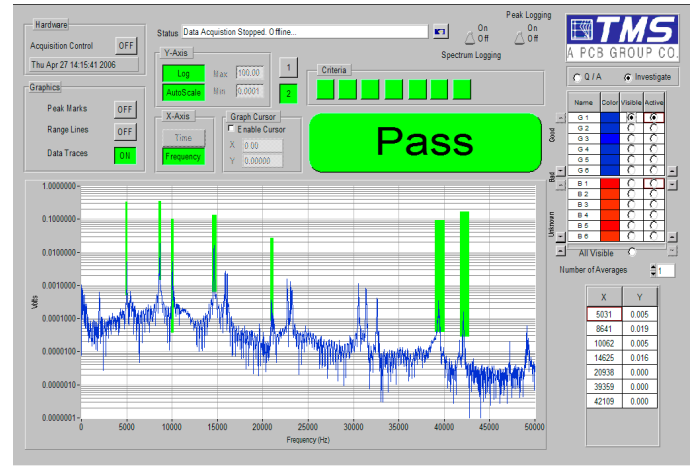


Figure 1. Typical acoustic signature, power spectrum to 50 kHz, for a metal part, shown as processed by NDT-RAM with criteria ranges (indicated with green "boxes") at seven natural resonant frequencies.

Gross defects can often be distinguished directly by the human ear, but human hearing is subjective and limited to approximately 20 kHz maximum. By analyzing data beyond 20 kHz, to upwards of 50 kHz, much smaller defects can be detected, even across production lots given reasonable process control. Typically, these defects cause frequency shifts as shown in Figure 2. These shifts are a function of how the specific defect affects the mechanical resonance, which is dependent upon the specific defect location with respect to the deformation pattern of the resonance. Fortunately, mechanical resonances are global properties of a structure, and generally a defect will alter at least one resonant frequency. For this reason, it is good practice to set up multiple criteria ranges for analysis.

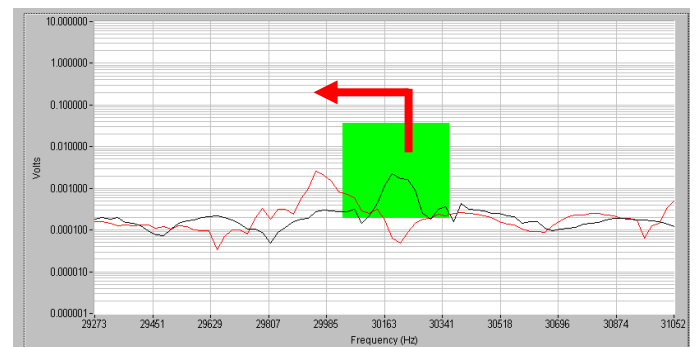


Figure 2. Data showing frequency shift due to structural defect in part.

RAM-NDT's basic measurement procedure allows for easy automation and very high part testing throughput. There is no part preparation required – no magnetizing, cleaning, immersion, etc. Expendable costs associated with such preparation, such as chemicals and waste removal, are eliminated. The single impact and non-contact response measurement (via microphone) can be