

# 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 ultrasonic 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 ultrasonic 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.

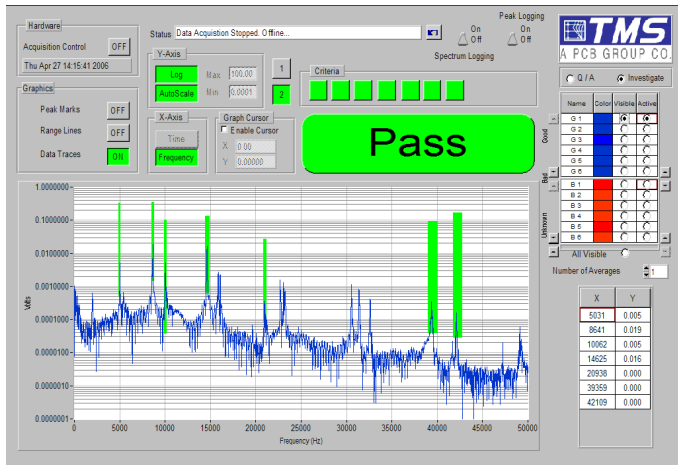
Resonant inspection (RI), the general classification of RAM-NDT, measures the structural response of a part and evaluates it against the statistical variation from a control set of good parts to screen defects. Its volumetric approach tests the whole part, both for external and internal structural flaws 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 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	Powder 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.

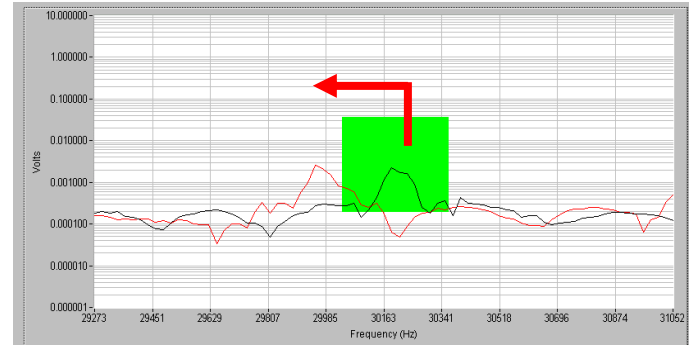
The Resonant Acoustic Method technique performs resonant inspection by impacting a part and "listening" to its acoustic spectral signature with a microphone. The controlled impact provides broadband input energy to excite the part and the microphone allows for a non-contact measurement of the part's 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 made as a part is moving down a conveyor, often as fast as a part per second. The parts do not need to be physically stopped; nor are they required to be precisely located with expensive robotics on contact actuators and vibration pickups. Simple guides are typically adequate to rotate/position the part for impact and allow flexibility to test many different types of parts or geometries. Given this capacity for automation and throughput, and its quantitative analysis with objective results, RAM-NDT is ideal for plant floor, high volume quality control test applications. A typical production line installation is shown below in Figure 3.

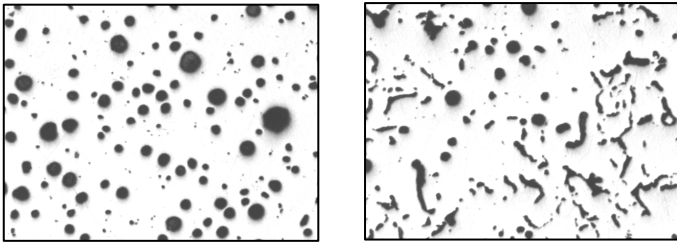


**Figure 3. Fully automated system on plant floor, shown testing parts through acoustic chamber.**

## DUCTILE IRON CASE STUDY – TESTING NODULARITY

One common application for RAM-NDT is testing ductile iron for acceptable levels of nodularity. Cast iron is a metal alloy characterized by relatively high carbon content. During the metal's solidification, this carbon content can form graphite, with tiny, irregular flakes that disrupt the crystalline structure, causing cracks and unwanted brittleness. In ductile iron the graphite forms spherical, rounded nodules that inhibit the formation of cracks and provide enhanced ductility and machinability.

ASM defines nodularity as “the volumetric proportion of spheroidal or nodular graphite to total graphite in a ductile iron or a compacted graphite iron matrix.” In other words, it's the total number of rounded graphite nodules as a percentage against the total number of graphite particles – the higher the nodularity, the higher the ductility. Figure 4 illustrates the difference in microstructure of ductile iron with high nodularity (93%) and poor nodularity (just 55%).



**Figure 4. Difference in microstructure of ductile iron with high nodularity (93%) on the left and poor nodularity (55%) on the right.**

Very often, part designers specify a minimum level of acceptable nodularity (typically >80 to 85%) to ensure proper ductility. The traditional inspection technique for testing this is ultrasonic (UT) [2]. UT measures the velocity of sound waves passing through material. Basically, rounded graphite nodules do not impede the acoustic energy while flaky graphite particles do. Thus, higher ultrasonic velocity correlates with higher nodularity.

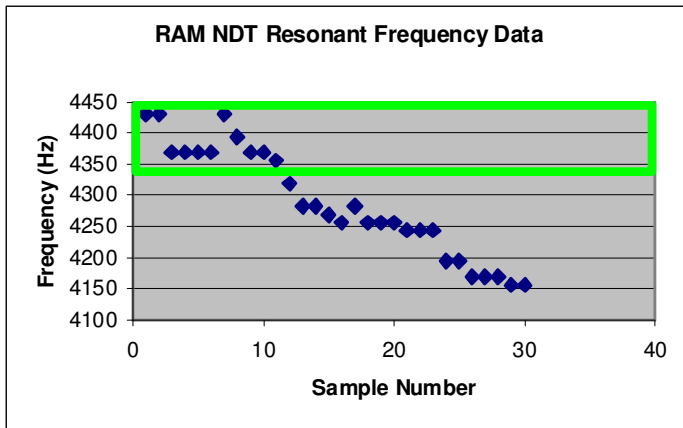
In order to evaluate the effectiveness of RAM-NDT for inspecting ductile iron for nodularity, a controlled set of brake anchors were manufactured as shown in Figure 5. The anchors were 100% tested using ultrasonic, and 100% tested using RAM-NDT. The ultrasonic velocities and resonant frequencies were recorded. The parts were also sectioned and the microstructure was analyzed to quantify the percentage nodularity. The resulting data is tabulated below for 30 samples, with graphical correlation between RAM NDT and nodularity shown in Figure 6.



**Figure 5. Ductile iron brake anchor on automated conveyor system.**

**Table 2. RAM NDT and UT data for nodularity testing**

Sample	Velocity (m/sec)	Frequency (Hz)	Pass/Fail	% Nodularity
1	5600	4431	P	95
2	5600	4431	P	95
3	5600	4369	P	95
4	5600	4369	P	95
5	5620	4369	P	95
6	5620	4369	P	95
7	5600	4431	P	95
8	5620	4394	P	95
9	5620	4369	P	95
10	5620	4369	P	95
11	5570	4356	P	85
12	5540	4319	F	80
13	5570	4282	F	80
14	5550	4282	F	80
15	5550	4269	F	80
16	5550	4256	F	80
17	5560	4282	F	80
18	5510	4256	F	70
19	5510	4256	F	70
20	5510	4256	F	70
21	5470	4244	F	60
22	5430	4244	F	60
23	5460	4244	F	60
24	5370	4194	F	40
25	5350	4194	F	40
26	5370	4169	F	40
27	5350	4169	F	30
28	5320	4169	F	30
29	5300	4156	F	20
30	5280	4156	F	20



## REFERENCES

1. Gail Stultz, Richard Bono and Mark Schiefer, "Fundamental of Resonant Acoustic Method NDT", [www.modalshop.com](http://www.modalshop.com)
2. Mark Willcox, "Ultrasonic Velocity Measurement Used to Assess the Quality of Iron Castings", [www.insightNDT.com](http://www.insightNDT.com)

**Figure 6. Correlation between RAM NDT resonant frequency test at approximately 4k Hz and nodularity. Green box indicates accepted criteria range for samples 1-11 with >85% nodularity. Samples 12-30 show nodularity ranging from 80% down to 20%.**

The results clearly show that RAM NDT accurately inspects ductile iron parts for acceptable levels of nodularity, with the capacity to sort samples with finer % resolution than UT velocity measurements. With RAM NDT, even the samples that are in the 80-85% range show clear separation, yet would not be clearly sorted using a velocity measurement – note the mix of velocities around 5550 m/sec in Table 2 above.

Additionally, RAM NDT boasts numerous advantages over UT. Ultrasonics test only one section of a casting – typically the most likely spot to detect poor nodularity. Low nodularity localized in other areas of the casting would not be detected. Since RAM NDT is a volumetric technique, it tests the entire casting for acceptable levels of nodularity. RAM NDT is a dry test eliminating the need for fluid coupling and cleaning, and preventing potential rust contamination. Finally, RAM NDT is a fast and efficient test, which automates very economically.

## CONCLUSION

The RAM NDT technique has grown to broad utilization in the last 5 years at some of the world's largest automotive manufacturers and Tier One suppliers. The technique itself has been favored in recent years by manufacturing and quality professionals, dissatisfied with low, subjective traditional inspection methods. Unlike complex engineering workstations found in metrology labs, RAM NDT is a fast, objective 100% whole part test. The RAM NDT system is online for simple, reliable and affordable inspection, which drives improved quality and increased profits.