Title: Crack Detection in Cast Stainless Steel Valve Utilizing Nonlinear Acoustics

ABSTRACT

Many structural system parts are today subjected to critical loads and the presence of damage is inspected in a variety of ways. Some of these parts are made of CAst Stainless Steel (CASS), a material commonly used in nuclear power plants. One way to verify the damage status of these parts is to use ultrasonic inspection. These inspections are very challenging to perform and, in general, success in the detection of damage remains uncertain.

However, the techniques can be improved, even for materials known to be challenging for ultrasonic inspections.

A study of crack detection in cast stainless steel utilizing a nonlinear acoustic method is reported in this work. The technique is briefly described, and is exemplified by carrying out a fingerprint measurement.

The specimen was a test block made of a valve provided from Ringhals AB which was cut in three pieces. One of these pieces is evaluated in un-cracked condition as initial reference. Subsequently, cracks are introduced and new evaluations are made.

The results show clear indications of presence of damage, and the technique's localization capability is shown.

INTRODUCTION

Sensitive nonlinear methods are in strong progressive development. High sensitivity gives the opportunity to find defects and characterize the material in a increasingly careful manner. A nonlinear acoustical modulation technique was used to detect damage in a cast stainless steel part.

Cast stainless steel is like the majority of the cast iron an anisotropic and coarse grained material. For this type of material ultrasonic inspection has known limitations because of low transmission of sound and because of high amount of signal noise are present [1]. The structure raises difficulties to inspect objects manufactured in this type of material using ultrasonic inspection techniques [2].

That kind of inspection problems occur also for different metal welds. Because of the large grain size in these materials the acoustical waves propagating are strongly attenuated and severe scattering occur. Waves received from flaws can be difficult to recognize among the scattered waves.

The specimen is a test block made of a valve provided from Ringhals AB which was cut in three pieces. The inspected object is one of these three and had the approximately dimensions of 600x600 mm and the weight was about 300 kg. The 1/3 of the valve is shown in figure 1.

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Figure 1, The 1/3 valve on pallet.

A fingerprint measurement of the valve has been carried out. Firstly the part was measured in its undamaged state in order to investigate any damage due to the manufacturing and cutting processes. Subsequently, at another laboratory cracks were introduced into the valve and then the valve was measured again to investigate the increase of damage.

Calculating the modulated nonlinearity for the undamaged and damaged states and then comparing them showed a high difference in values.

The introduced damage consisted of two cracks in two different locations inside the valve. The cracks had the size of 50mm and 70mm respectively and were located in the middle of the valve's thickness. Both cracks were decided to be located in the right half of the valve as shown in figure 1 and in the left half as shown in figure 5. The locations in this half of the valve were unknown prior to this fingerprint measurement.

EXPERIMENTAL METHODOLOGY

The experimental technique used in this work is a nonlinear acoustical modulation technique. It is based upon introducing two or more waves are propagated in the object and they are modulated if damage is present. Conceptually this technique was introduced in the 1960's [3, 4], and has previously been used to detect damages in cast iron [5].

Two different measurement approaches were used to evaluate the possibility to detect the presence of damage. The first one is an automated testing approach in order to be used as an inservice inspection technique, while the object being measured is in use and operational. The second one can be used for manual testing in laboratory or manual testing on site. This approach can also be used to determine the location of the damage.

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These experiments were conducted using piezoceramic transducers (PZT) glued with epoxy. Two of the PZTs acted as actuators to generate the acoustical waves in the valve and the other two acted as acoustical wave sensors.

The locations of the transducers and receivers are shown in figure 2. The transducers were located at T1 and T2 and the receivers were located at R1 and R2. For the manual measurement approach eight additional excitation poins are added. Three between receiver R2 and transducer T2, two in the waist of the valve and three to the right of receiver R1.

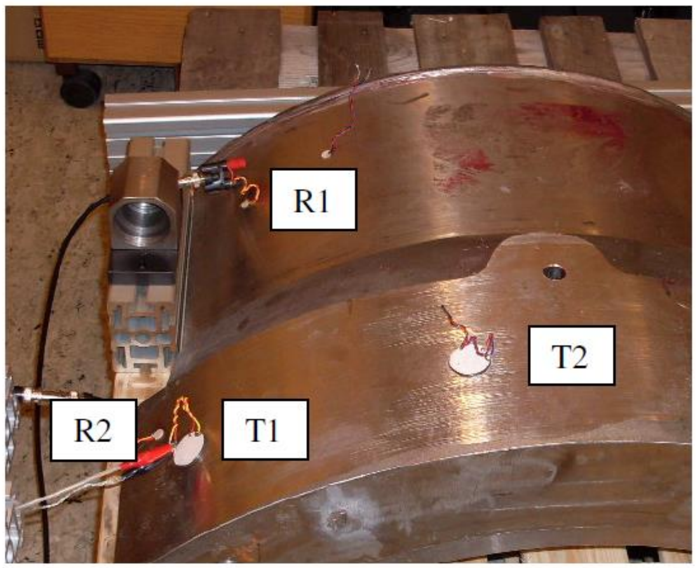

Figure 2, Transducer and receiver locations.

The measurement system used in this work is a system developed by AcousticAgree AB. The measurement system is shown in figure 3. The damage evaluation is performed directly in this system resulting in a fast measurement process.

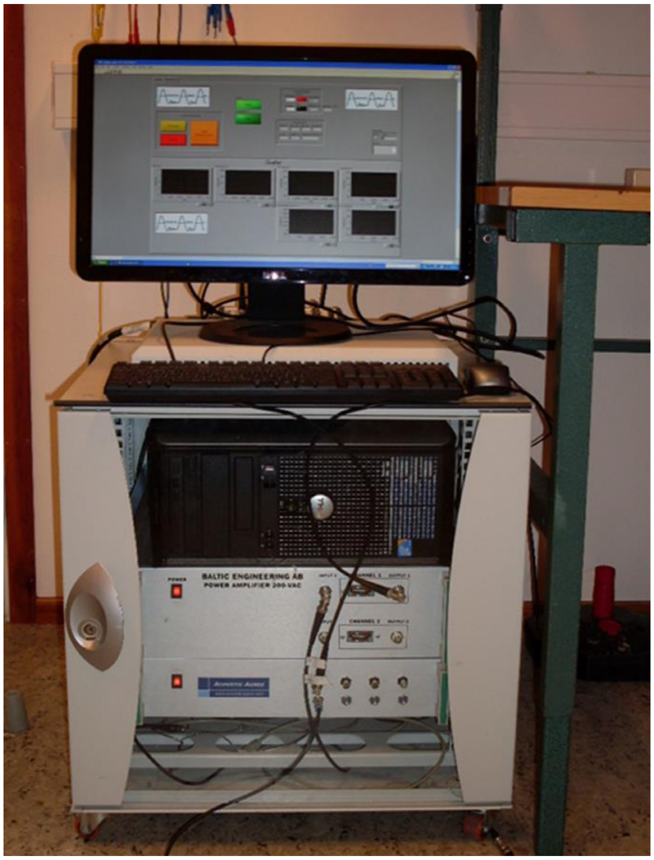

Figure 3, The measurement system used from AcousticAgree AB

RESULTS

The results presented here have been calculated with respect to the damage response for the initial condition of the valve, where no crack is present. This makes it possible to determine the increase of damage introduced by the cracks. This is an expected result because casting iron is a complicated process and inhomogeneities and inclusions can be problematic to avoid in the manufacturing process and wherefore the cast iron might contain cracks from the beginning.

The result produced utilizing the automatic method is shown in figure 4. The notation in the graphs follows the example T1R1, referring to the positions of the transducer (T1) and the receiver (R1). The graphs show the results for all the combinations of each transducer combined to each receiver. The bars filled with black are the results from the initial measurement, without the cracks introduced. The bars filled with white are the result from the measurement when cracks are introduced.

The numbers on the y-axis are normalized values. The normalization is due to the highest damage level measured without cracks, and was then set to 100. All other numbers are related to that number.

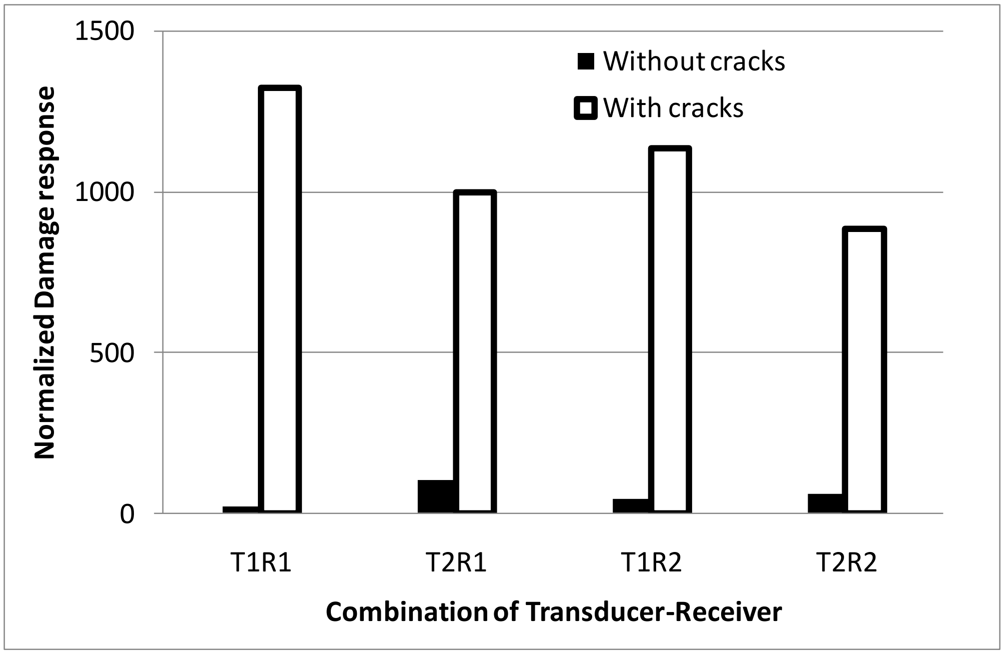

Figure 4, Fingerprint result for all transducer and receiver combinations.

As can be seen, no matter which combination of transducer and receiver used for this measurement a clear indication of the presence of cracks is given. Introducing cracks into this valve gave at least 15 times larger indication value which is a clear indication of damage.

Using a manual technique all the transducer and receiver combination were obtained. By mapping the damage response in relation to each other in space, the physical location of the damage can be determined. This is presented in figure 5. The explanation legend is presented in table 1.

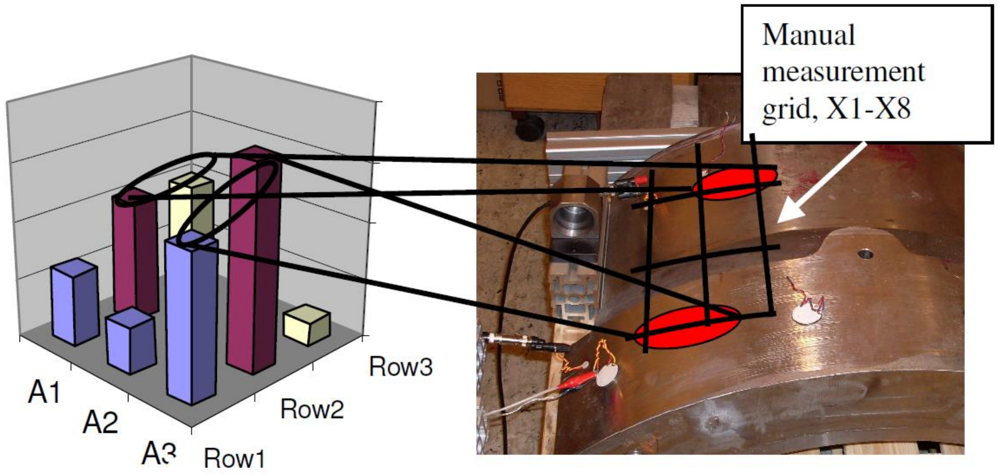

Figure 5, Localization of the damage.

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R1	X6	X7	X8	
	X4	X5		
R2/T1	X1	X2	X3	*T2*
	Row1	Row2	Row3	

Table 1. Legend to figure 5 indicating the position of the damage with respect to position of the transducers (T) and receivers (R).

The graph to the left in figure 5 shows how the damage response is distributed in the valve after the cracks are introduced. The picture to the right in figure 5 shows where the damage is mapped from the damage response to the real valve. These locations were verified by Ringhals AB as being the correct positions.

DISCUSSION

The material itself shows nonlinear response in the undamaged state, but in comparison to the introduced damage, the material itself exhibits a very small damage response and can be considered as undamaged.

The nonlinear modulation approach worked well for the cast iron stainless steel and showed distinctively the presence of cracks.

The automatic approach increased the indication at least 15 times. This technique can be used to monitor the structural health during operation of this valve. The manual approach, suitable for inspections, has even higher sensitivity and adds damage localization capabilities.

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