Ultrasonic Identification Techniques of defective Pieces in Hostile Production Environments.

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J.P. Oria; L.A.Rentería; C.Rodriguez; M.Fernández; J.R.Llata

Department of Electronic Technology and Automatic Control Systems. University of Cantabria.
E.T.S.I.I. y T. Avda de los Castros, s/n. 39005 Santander (Spain)
e-mail: [oria, alonso, cristina, monica, llata]@teisa.unican.es

ABSTRACT

We present the results obtained in a defect detection system for foundry pieces, with an industrial application using ultrasonic transducers. Several processing techniques of the echoes coming from the pieces are analysed in order to find the most efficient one. To make the system more reliable, furthermore, we have studied the influence of the conditions of the propagation medium when he environment is industrial with a high concentration of impurities in the atmosphere. We have found the effect on the propagation and its influence on the identification of defective pieces. The system has sufficient flexibility to operate in changing atmospheric conditions and it is an attractive alternative in certain production processes.

1. INTRODUCTION

The most commonly used and widespread technique for identification of defects in automatic production processes is through artificial vision cameras and image processing. The developments achieved in this field make it and essential tool. However, in some industrial processes with low or null visibility due to the environmental conditions, it becomes virtually useless. This is the case of foundry piece process. In this conditions, systems using ultrasonic sensors without great hardware requirements, become very useful for defect detection in foundry pieces, warning the automatic system of the presence of defects. Analysing the morphology of the echoes coming from the foundry pieces, through a suitable processing, the system provides sufficient information to identify any irregularity in the pieces.

The effect of the industrial environments an its influence on the recognition and defect detection
In quality control processes, has normally been considered of little importance and its effects have been ignored. However, this is no valid in certain industrial production environments and the result obtained in the laboratory can be invalid in the industrial application.

The effects of the dependence on temperature of the medium on the propagation have been analysed well by different authors [1] and the existing compensation techniques provide good results. Is should be highlighted that in the foundry piece part process, of interest in this work, although the environmental temperature is high, it is maintained quite constant, making it unnecessary to compensate for it.

In previous work [2], we analysed the problems of industrial noise in ultrasonic propagation and its effects on automatic piece identification systems, finding that up to the industrial permitted level, that it did not affect in a notable way the defective piece detection process.

When the density of particles in the industrial environment is high and moreover non homogeneous the shape of the received echo coming from the pieces to be identified is greatly altered. Some of the characteristics, such as the area under the envelop, peak time, etc. undergo a variation depending directly on the degree of concentration of impurities, and to a lesser extend on the type of impurities present in the medium.

2.SYSTEM DESCRIPTION

For this work we have used a sensorial structure made up of a pair of Massa sensors, one working a an emitter and the other as a receiver, with a excitation frequency of 220 KHz. To produce the ultrasonic wave of the piezoelectric sensor it has been excited with an alternated signal and them modulated by a train of pulses in order to avoid the existence of stationary waves.

Given that there are two zones in the direction of the ultrasonic wave, the near field zone, with interference, and the interference free far field zone, the excitation of the receiver sensor is produced by echoes coming from pieces situated in this zone in the direction of the propagation axis at least 10 cm all.

As is well known, the greater the diameter of the sensor the bigger the near field interference zone or dead zone of work. Besides, the higher the sensor excitation frequency the greater precision although the attenuation also increases. In the developed system we chose a sensor with reduced dimensions working at a high frequency since at the observation distance the attenuation is not a problem.

To carry out measurements in conditions similar to the real ones in the plant, a cubic metal structure has been built, Figure 1, which has a simple linear displacement mechanism in the upper part enabling the precise positioning of the sensors at different distances. The structure is totally closed in by transparent panels in order to carry out the experiments in adverse environmental conditions, such as the presence of dust, smoke or ash. Some fans enable the agitation of the impurities creating different concentrations of contaminants in the atmosphere.

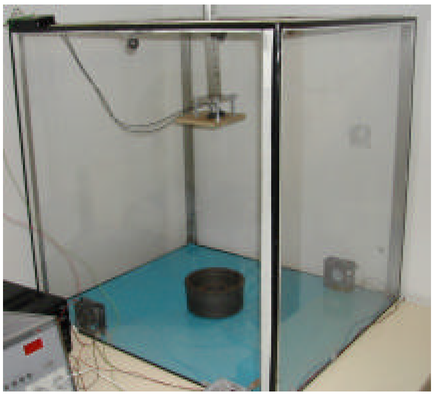

Figure 1

In this defect detection system, a high-speed data acquisition card has been used with powerful signal processing software. The signals of the echoes coming from the pieces have been sampled at a frequency of 1 MHz. Figure 2 shows one of these echoes in the zone containing most information, where, once the envelope has been found, flight time can be obtained as well as parameters such as the gradient, the maximum amplitude, etc. which have been used in defect detection techniques.

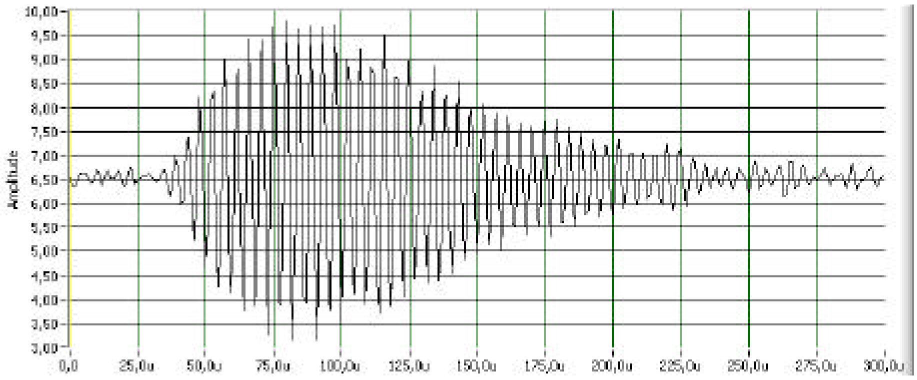

Figure 2

The first phase of the work consists in establishing a reliable foundry piece defect detection method in laboratory conditions that are normally very different to industrial conditions. Then, the influence of the industrial environment on the propagation of the ultrasonic waves is analysed, with the presence of impurities in the air.

3.DETECCION OF DEFECTS IN FOUNDRY PIECES

The pieces for defect detection are brake drums for vehicles that can have defects such as flash on the outside edges, which if not detected can pass on to the machining stage provoking important problems and the corresponding delays in the process. Figure 3 shows one of these pieces with one of the possible defects.

Figure 3

To achieve the discrimination between defective and non-defective pieces, several techniques are used, with different relative positions among the piece and the ultrasonic sensors. Moreover, for each position, several distances were tried until the best discrimination between good and bad echoes was found. The best results were achieved by illuminating the piece part by part with a distance of 20 cm between the sensors and the upper edge of the piece, in such a way that only the area around the defect is illuminated. In this way, the ultrasonic echo incident only on an irregular surface instead of a smooth one, has different characteristics with respect to the echoes from a defect-free piece. This is probably due to the dispersion.

The first strategies used are based on the temporal study of the echoes. A typical echo was obtained from several echoes from non-defective pieces and it was compared with all the echoes obtained from both good and bad pieces. This comparison was carried out both with the unprocessed echoes and with their envelopes. For this, several error indices were calculated such as the mean absolute error.

$$\frac{1}{n}\sum |x_i - p_i| \qquad [1]$$

or the mean square error:

$$\frac{1}{n}\sqrt{\sum (x_i - p_i)^2} \qquad [2]$$

and indices related to the energies:

$$\frac{1}{n}\left(\sum x_i^2 - \sum p_i^2\right) \qquad [3]$$

where $\mathbf{x}_i$ and $\mathbf{p}_i$ are the i^{th} samples of the envelopes of the unknown echoes and typical echoes respectively, and **n** the number of samples used

The samples obtained were not satisfactory since the calculation of the average in order to obtain the pattern implies an inherent filtering, which makes the amplitude of the typical wave pattern bigger than those of each of the echoes used in order to obtain it. Thus the error obtained from the defective pieces is not significantly different to the one obtained from the defect-free pieces.

We have also used techniques based on frequency treatment of the echoes in this work. We have applied the fast Fourier transform (FFT) for the comparison among the echoes from defective and defect-free pieces, and the comparison of their power spectra. Although representative results were achieved, the necessary degree of reliability was not reached. In this system, artificial intelligence methods were not used, which were used in previous work [3] specially through the use of neural nets enabling the learning of good pieces and allowing the distinction of defective ones. This is because the objective was to study the influence of environmental contamination on the ultrasonic propagation in an open way, which neural nets would not have permitted.

The technique showing the best results was based on the calculation of the area of the envelope of the echo. Furthermore, it was found that the maximum amplitude of the echoes of defective pieces was significantly less than that of the defect-free pieces. Figure 4 shows the envelopes of a defect-free piece, wide trace, and another defective one, narrow trace, in which it can be observed that the difference in intensity and energy is quite significant.

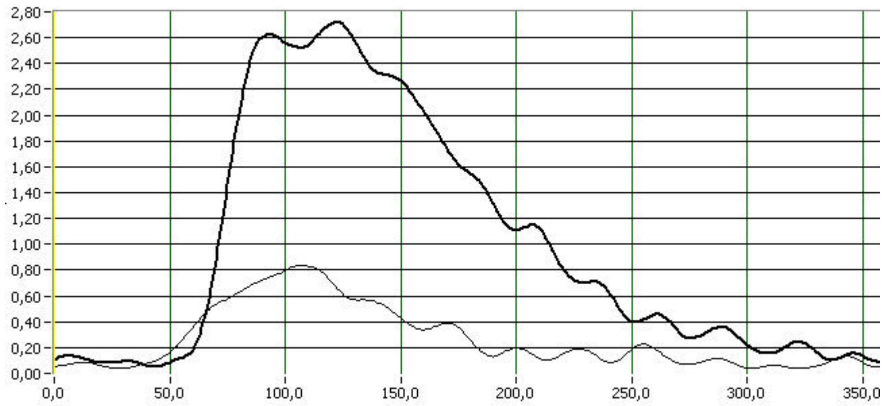

Figure 4

Therefore, this was the technique chosen for the automatic system for detection of surface defects in foundry pieces.

4.PROPAGATION IN INDUSTRIAL ENVIROMENT

Once the method has been proved in clean environment we have proceeded to create an industrial environment with the presence of impurities in air to simulate in the most similar way the atmosphere in which the system had to work. In this conditions the technique developed has been tested. The first step consisted of the characterisation of ultrasonics wave propagation by putting in the testing room a mixture of foundry dust, ash and smoke, where the mixture proportion was near to a real industrial environment. To reach an homogeneous mixture in the air we have used ventilators. In this same way, as well as particles in hanging, we have also bearded in mind the effect of turbulence and air currents presented in the production process.

In this conditions, the echoes from the bottom container in different heights has been compared with the echoes gathered in free impurities environment. The results obtained indicate that the impurity effects have influenced in any echoes envelope characteristics like maximum amplitude and energy, besides an small advance because of the propagation speed in this environment has increased. When we have increased the distance, the effects have been more accused, as it can be observed in figures 5 and 6, in which have represented in thick line the echo in clean environment and in fine line the echo in industrial contaminated at 56 and 24 cm respectively.

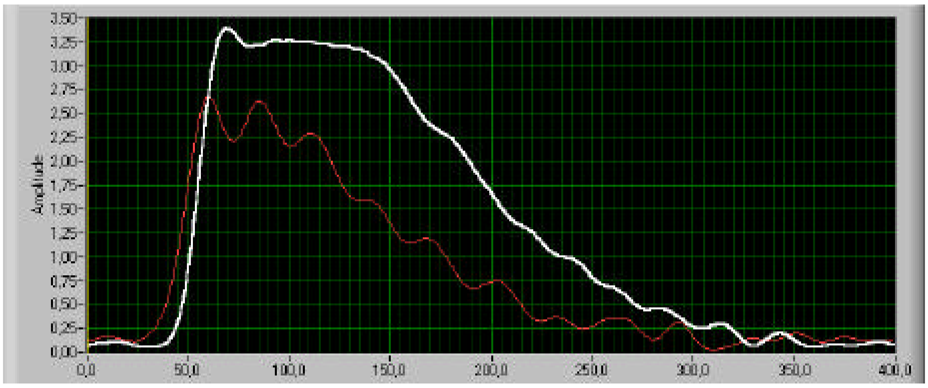

Figure 5. Echoes to 56 cm

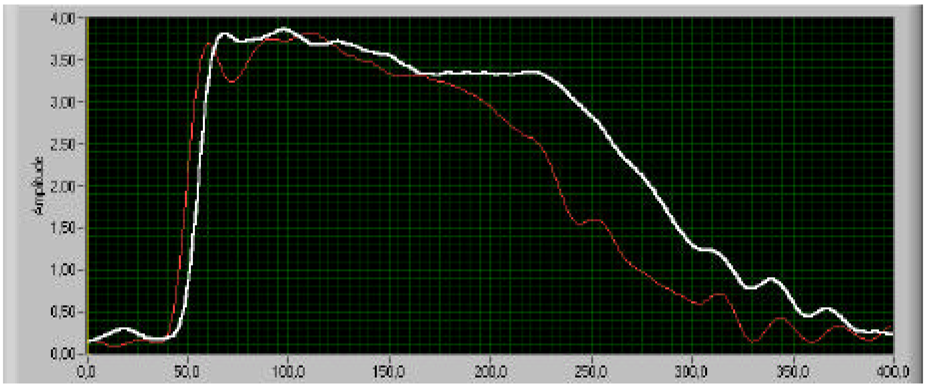

Figure 6. Echoes to 24 cm

Since the echoes are affected by the distance we have worked at a distance near to 20 cm so that the results were independent of environments impurities and turbulence. In this way, we can keep on using the classical echo envelope parameters: energy, maximum amplitude and starting slope to distinguish echoes of defective pieces.

5. INFLUENCE ON THE DETECTION OF DEFECTIVE PIECES

After analysing the influence of the industrial environment on the ultrasonic propagation, we studied its influence on the fault detection system in order to check its reliability. For this, the echoes of valid and invalid pieces were taken in contaminated atmospheres in a similar way to real working conditions and then, the same signal processing was carried out such as when working in clear atmosphere.

In Figure 7 the envelopes of echoes from good and defective pieces, under these conditions, can be seen. The wide line shows the envelope of echoes corresponding to a piece without faults and the fine line shows echoes from a defective piece. Although the amplitudes of both echoes are a little smaller than in clear conditions the discrimination capacity is still maintained since the attenuation provoked by the hostile environment affects both the envelopes in an identical way.

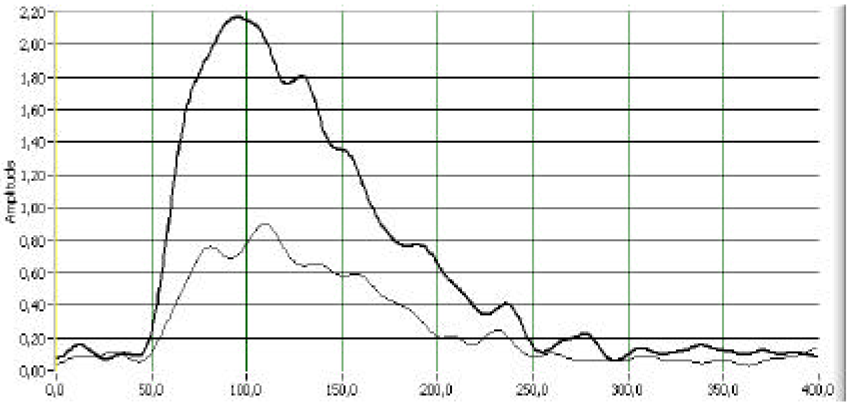

Figure 7

In order to ensure the success of the fault detection process, it is necessary to sweep the whole piece. The discrimination becomes maximum when the irregularity is fully illuminated because the difference of energy is notable. When this is not so, as this characteristic is reduced, it is necessary to use more parameters of the envelope for detecting the fault.

CONCLUSIONS

From the work carried out, it can be deduced that a method such as the one developed here, with a simple ultrasonic sensorial system and a basic positioning element along with real-time capable signal processing, enables the automatic detection of defects in foundry pieces in hostile industrial environments, where systems using other technologies cannot work. Moreover, this is a robust system.

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