B-scan ultrasonic image analysis for internal rail defect detection

H. Cygan, L. Girardi,
SNCF Exploitation-Maintenance IEM-RM

P. Aknin,
INRETS Institut National de Recherche sur les Transports et leur Sécurité

P. Simard
UTC Université Technologique de Compiègne

Abstract

In this paper, advantages to work on an ultrasonic image, called B-scan image, are presented to improve the detection of internal crack in rail. First, methods usually used and based on A-scan signal analysis are presented. Then we show what B-scan images analysis bring. Finally, after presenting some simulations on acoustic waves in the rail, an example is given of the efficiency of B-scan analysis for a typical defect, a transversal crack under a Head-Checking, in a real case.

1. Introduction

SNCF transports more than 800 million people a year through 31385 km of lines. To increase the satisfaction of theirs customers, SNCF leads several research projects to improve the transport comfort and security. In this purpose, both the new technologies and the evolutions of existing systems are interesting. Among all the existing systems, many of them are dedicated to maintenance of ground installations. Curative maintenance and preventive maintenance have to be distinguished. Curative maintenance restores the network in its original configuration after having discovered a flaw, whereas preventive maintenance tries to avoid a problem thanks to a forward and planned intervention of maintenance service. For fifty years, the railway industry has developped ultrasonic inspection in order to detect internal crack, whose fast evolution phase could lead to rail break. The large size of the railway network requires the use of an automatic inspection system. With the help of new real time electronic facilities, the ultrasonic detection process can be improved by signal and image processing.

2. Industrial context

2.1 Current inspection

In fact the rail control is realized in two separate steps. The first one tries to make an inventory of defects on line with an ultrasonic inspection train (fig. 1) going at a maximum speed of 60 km/h.

Figure.1: Ultrasonic inspection train V5

The aim of this step is to locate geographically the defect by noting the kilometric point of detection and by painting the rail at this point. In the second step, a maintenance team is sent out and initiates a precise analysis of the defect to give it a gravity rating.

2.2 Ultrasons

The detection system is based on three ultrasonic probes. Theses probes are used to detect two families of cracks in the rail head. One probe, called 0° probe, is intended to find horizontal cracks and two probes, called 68°

probes, are intended to find transversal cracks with a 68° theoretical mean orientation of running surface. The probes are mounted under the train, protected in a carrying shoe and set onto the rail. Figure 2 shows the ordering of probes in the carrying shoe during the control by the ultrasonic inspection train.

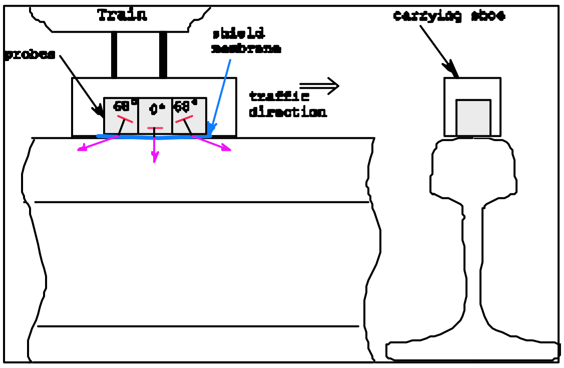

Figure. 2: Ordering of probes in carrying shoe

Ultrasonic probes emit an acoustic wave which propagates in the rail in a specific direction. The wave flows without reflection until the material is homogeneous. In case of break of the homogeneity, due to the geometry of material or the presence of a crack, a reflective wave is created. The direction of this wave follows Snell-Descartes laws [BLI 96]. So if the crack is perpendicular to the direction of wave propagation, the reflective wave comes back to the probe which records an ultrasonic echo called A-scan. Most of industrial non destructive control systems are based on this kind of visualization. All the detection procedures of the automatic inspection train are based on this signal.

Indeed, each probe works both in emission and reception mode. They allow to have an ultrasonic signature of the area where the cracks are seeking. Figure 3 shows two A-scan signals recorded on a 68° probe with or without a transversal crack in the head of the rail. X-axis represents the propagation time of the wave. Knowing the sound velocity in the material, it also represents the depth in the material along the propagation direction. Y-axis gives the amplitude of the reflective wave. The echo at the beginning of the signal is called surface echo. It results from the interface between the probe and the rail. Unfortunately this echo hides the presence of cracks near the surface.

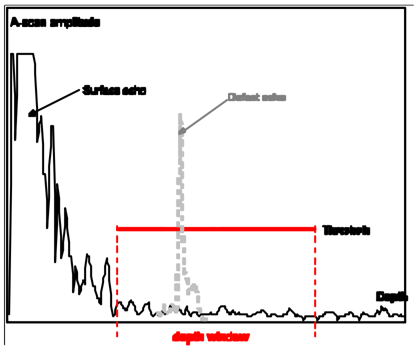

Figure. 3: Example of A-scan signals and threshold

2.3 The detection

During the inspection, an ultrasonic shoot is done each two millimeters. To detect the defect, the procedure is based on a threshold applied to the A-scan signal through a depth window. To avoid false alarms, this threshold must be reached several times successively. Adjusting the threshold and the depth window are the crucial points which require a great experience. If the threshold is too high some defects may be missed and if it is too low a lot of interferences may affect the results. The major drawback of this control is that it is a binary technique. The non detection probability can be estimated around 20%.

3. Advancement for the control

3.1 B-scan

A new idea is to work on an accumulation of successive A-scan signals which form in fact an image (cf Figure 4). This image is called B-scan. It keeps the geometrical coherence of the defect taken advantage during the processing and leads to a better noise immunity. So the crack is seen in its whole structure and none as a limited signal reaching a threshold. The X-axis represents the displacement of the inspection train during the control with a constant spatial sampling and the Y-axis represents the depth into the rail. Figure 4 shows how is built from several A-scan signals a B-scan image.

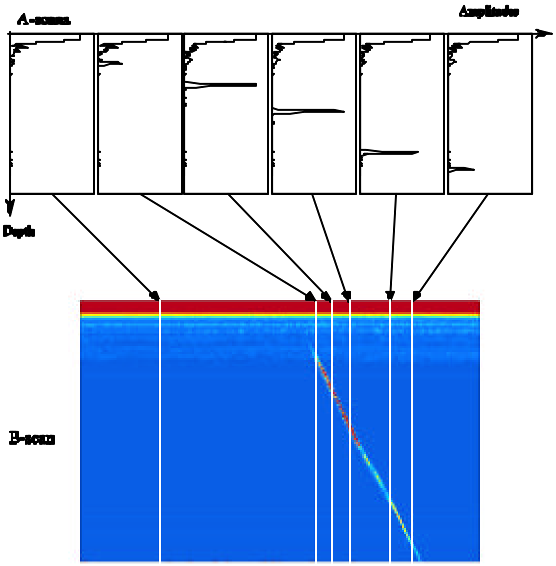

Figure. 4: B-scan construction from A-scan signals

3.2 Image processing

[CYG 01] details the implementation of a procedure to detect a transversal crack in a B-scan image. In fact, in the B-scan image, only the echo of the defect is interesting. It will be advantageous to eliminate the surface echo and the associate noise that presents a horizontal structure in the image. Thanks to wavelet decomposition [MAL 98], the defect echo can be separated from the noise by choosing a reconstruction phase that suppresses the horizontal structures. Figure 5 shows the B-scan image of a transversal crack and the processed image, denoised by the wavelet transformation.

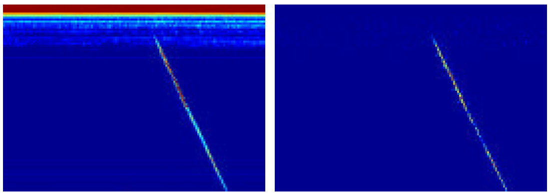

Figure.5: Wavelet-denoised B-scan image

Edge detection processing can still improve the result [COC95]. The Radon transform is a process adapted to detect lines in an image. It proceeds by projecting all the pixels onto a turning axis centred in the image. A transform image is built where X-axis is the angle of the turning axis rotation and Y-axis represents the result of the projection. By seeking the maximum value in this image, the preferential orientation of energy in the denoised B-scan image directly linked to the angle of the defect echo can be known. Figure 6 shows the Radon transform of the denoising B-scan image presented in figure 5.

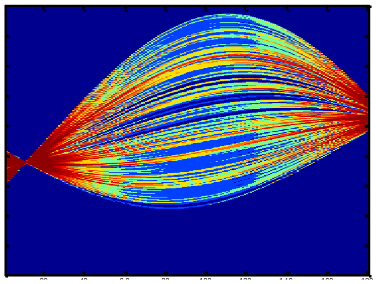

Figure 6: Radon transform of B-scan after processing

The following section shows the advantage of this processing on a more complicated real defect.

4. Processing of a transversal crack under Head-Checking

4.1 Probe positioning

The probes on ultrasonic inspection train should be centred on the top of the rail but the geometry of the line presents some characteristics that could disturb this positioning as switches and curves. So a special system must be used to steer the probes. This system can be mechanical as sensor wheels or electronic using technology as eddy current [AKN 92]. However, a decentring of the probes of few millimetres occurs. So the part of rail sounded is different of the part that should be. The geometry of the rail is also different. It has a consequence on the acoustic field emitted into the rail.

4.2 Ultrasonic Simulations

Simulations in laboratory have been done to evaluate the impact of decentring a probe on the rail. The purpose is to quantify the acoustic field attenuation into the rail. The simulations have been done with the CIVA software by CEA (French Atomic Energy Commission). The software inputs are the geometry and characteristics of a rail (here it is a UIC 60 rail) and the probes characteristics.

Calculations are based on the reciprocity principle and the Kirchhof-Helmholtz integral calculation [PET 00]. Figure 7 shows relative acoustic pressure into a rail with three different lateral positions of a 68° probe. In the first case, the probe is centred on the rail, in the second one, it is placed at five millimeters from the center and in the last case, at ten millimeters. The calculations are done in the control plan perpendicularly to the propagation direction.

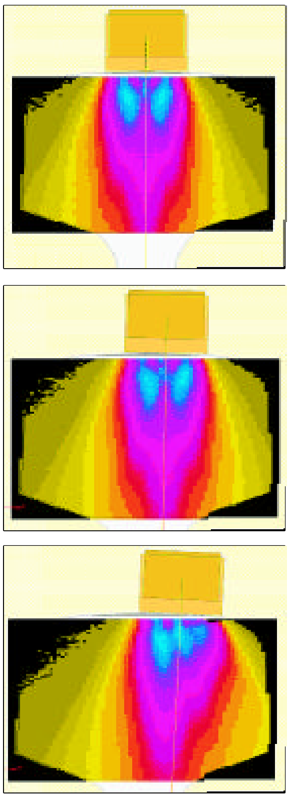

Figure. 7: Acoustic pressure in a safe rail (centred, 5mm decentred and 10 mm decentred)

The ultrasonic response of a crack depends of its size, its depth and its orientation: the figure 7 shows that the probe position is also important. A decentred crack below an inversely decentred probe (Head-Checking is typically a decentred defect) could produce a too low reflective wave to reach the threshold used in the A-scan processing. Increasing the number of probes and disposing them volontarily decentred onto the rail could be a solution. Nevertheless, the configuration of the probes would be changed for each type of rail and moreover the state of surface on running contact zone of rails is often too rough and the multiplicity of probes leads to a weak apparatus.

4.3 Analysis of a crack under **Head-Checking**

Crack under Head-Checking is a defect which generally appears in curves and which is decentred towards the active flange of the rail. The SNCF testing track is equipped with this kind of defect. This special track is used both for ultrasonic materials calibration and for research projects that try to increase the detection capability. This crack under Head-Checking is classified “X1” what means that it should have been removed from track in the following six months. Several runnings have been done on this defect, in first time with centred probes, and in second time with probes placed at ten millimetres from the center.

4.3.1 A-scan method

During the test with the centred probe, the defect is not detected with the ultrasonic inspection train usual system. The reflective wave is not enough energetic to allow the reaching of the threshold several times successively. Figure 8 shows the successive A-scan signals during the passage on the crack under Head-Checking.

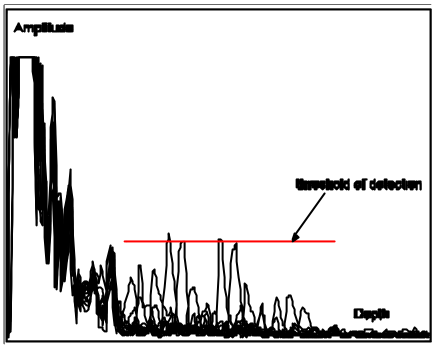

Figure. 8: Crack under Head-Checking A-scan signals with centred probes

This defect is at the detection limit of inspection train in the case where the probes are centred.

If the probes are volontarily placed at ten millimetres from the center, on the same side than the defect, the incidente wave is more powerful. Then the reflective wave is strong enough to permit the detection of the crack under Head-Checking by the inspection train. Figure 9 shows the successive A-scan signals during the passage on the crack under Head-Checking.

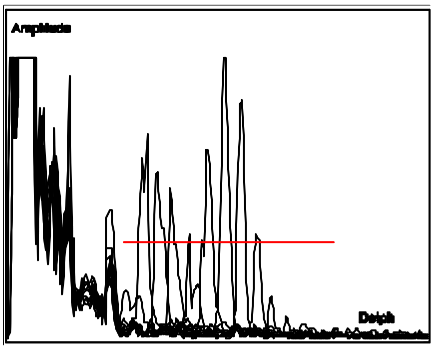

Figure.9: Crack under Head-Checking A-scan signals with probes placed at 10 mm from the center on the same side.

The threshold is reached several times by echos with high amplitude. At that time, the presence of the defect is validated.

A difference of amplitude on A-scan signals can be noted in function of the lateral position of probes. Although probes are supposed to be centred, sometimes their lateral position can be uncertain in curves. The use of B-scan image analysis allows to forget the adjustment of the threshold which is here not adapted for the detection of the crack under Head-Checking with centred probes.

4.3.2 B-scan method

B-scan processing has the advantage to keep the geometrical coherence of the defect during the inspection although an A-scan signal is only a part of the global response of the defect. Figure 10 shows the B-scan image during the inspection with centred probes. Cracks appear as a line in the image with different intensities, the angle corresponds to a 68° transversal crack.

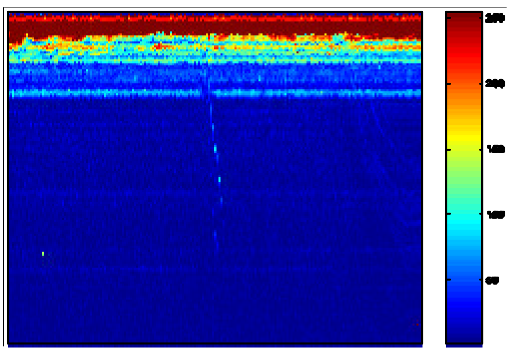

Figure. 10: Crack under Head-Checking B-scan image with centred probes

The image in this version is hardly exploitable because of the surface echo energy which is too important. The denoising technique with wavelet allows to isolate the crack into the image. Then it is easier to detect the defect. Figure 11 shows the results obtained after the denoising

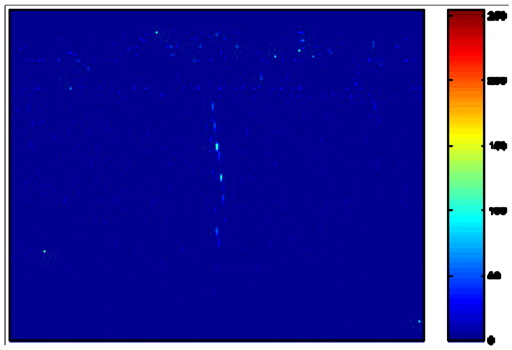

Figure. 11: Denoised crack under Head-Checking B-scan image with centred probes

If the defect exists, its energy represents the most part of the image total energy. The only remaining thing to study is the direction in which the image energy is mainly concentrated. To reach this objective, the Radon transform is used. If this angle matches with the theoretical angle of defect appearance, the defect is confirmed. In the previous example, the defect has been detected. Figure 12 shows the Radon transform of the denoised B-scan image. The pixel with the maximum value is sought.

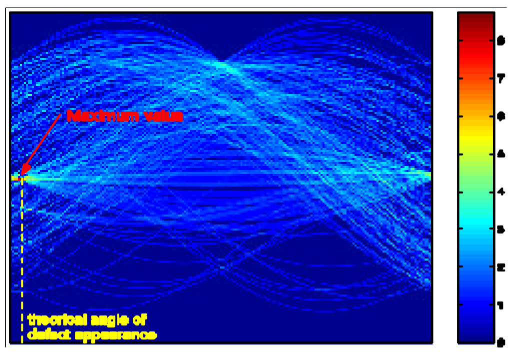

Figure 12: Radon transform of previous B-scan after processing

5. Conclusion

We have presented in this article the advantageous to work on B-scan images in a real case thanks to image processing. We show we can increase the rate of good detection and decrease the false detection one, especially for decentred defects.

Working with only one probe does not permit to estimate all the characteristics (size and depth) of a detected defect. The signals from the two others probes contain some information which could complete the diagnostic of the defect. So a data fusion phase between the three probes is planned

To realize a full automatic system, a neural network will be created in the purpose to give a first diagnostic of the defect. So the maintenance team will be sent in priority where the defect seems to be the more dangerous.

Bibliography

[AKN 92] P. Aknin, D. Placko, J-B Ayasse. *Eddy currents sensor for the measurement of a lateral displacement. Applications in the railway domain*. Revue Sensors and Actuators : Physical. Vol 31 n°1-3 pp.17-23. Ed. Elsevier. 1992

[BLI 96] BLITZ J., SIMPSON G., *Ultrasonic methods of non destructive testing*, Non destructive evaluation series**,** Edition Chapman & Hall, 1996.

[COC 95] COCQUEREZ J-P., PHILIPP S., *Analyse d'images : filtrage et segmentation*, Edition Masson, 1995.

[CYG 01] CYGAN H., Détection des défauts internes de rail, rapport de DEA, UTC, 2001.

[MAL 98] MALLAT S., *A wavelet tour of signal processing*, Edition Academic Press, 1998.

[PET 00] PETILLON O., *Contribution of Modelling Tools to aeronautics NDT,* 15th World Conference on Nondestructive Testing Roma (Italy) 15-21 October 2000