POD GENERATOR, Development of numerical modeling tools for quantitative assessment of the performance of non-destructive inspection techniques.

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Abstract

Risk based inspection strategies rely on detailed knowledge of the performance of inspection techniques. It is well known that every inspection technique has limitations in terms of reliability and effectiveness. Moreover, these are influenced by many factors. e.g., it depends on operator skills, inspection procedure, defect and object geometry, inspection technique.

The objective of the “POD generator” project is to develop a numerical modeling approach to assess inspection effectiveness for a specific technique and situation. This approach enables a flexible and reliable quantitative assessment at acceptable costs.

Besides the models to simulate various degradation mechanisms, numerical models have been developed and validated for accurately simulating the physics of inspection techniques. Also the human factor is taken into account. These numerical models are then used to generate probability of detection (POD) curves. In this paper this approach will be illustrated for ultrasonic TOFD inspection.

The POD generator will help asset owners to rationalize their inspection and maintenance strategy, i.e. reduce inspection and maintenance costs whilst preserving safety and reliability of operation at the desired levels.

Keywords: nondestructive inspection, probability of detection, POD, time-of-flight-diffraction, TOFD, pulse-echo, PE, guided waves, GW, magnetic flux leakage, MFL, human factor

1. Introduction

The maintenance of – often very complex – production installations in the chemical industry and the oil and gas sector is of paramount importance for these companies due to aspects of safety, production loss and reputation. Therefore such installations are inspected on a regular basis, carried out by skilled personnel using advanced nondestructive techniques. Timing of these inspections and locations is based on experience and also imposed by law, as degradation is often not visible and the locations are often difficult to reach.

Risk based inspection (RBI) strategies rely on detailed knowledge of the performance of inspection techniques, together with detailed knowledge and experience of the degradation of an installation, in order to quantitatively assess the risks associated with both detected and undetected defects. A widely used measure for inspection reliability, and thus more or less its effectiveness, is the probability of detection (POD), i.e. the probability a defect of a certain kind and size will be detected under certain circumstances.

It is well known that every inspection technique has limitations with respect to POD. Moreover, a POD is influenced by many factors. Apart from the technique itself, it depends on many and varied aspects such as the inspection procedure, the defect and object geometry and technique specific material conditions (and properties) like for example surface roughness and grain size for ultrasonic techniques. And last-but-not-least a POD depends on the inspectors applying a technique, i.e. the so-called human factor.

For several years now, a number of chemical plant and pipeline owners as well as inspection service companies in The Netherlands are participating in a joint industry project named the "POD generator" project. The objective of this project is to develop a numerical modeling approach allowing flexible and reliable assessment of the inspection effectiveness for a specific situation, in terms of POD, yet at a fraction of the costs necessary for empirical assessment.

Besides the models to simulate various degradation mechanisms, e.g. crack growth and corrosion, numerical models have been and are being developed and validated for accurately simulating the physics of various inspection techniques, currently ultrasonic inspection (TOFD, PE and GW) and magnetic flux leakage (MFL). Also the human factor is taken into account, either by translating human influences into physical parameters and chance factors, which are included in the models or by applying human interpretation to simulated inspection results. These numerical models are then used to generate quantitative POD curves for various techniques and circumstances.

This paper focuses on the generation of POD's for ultrasonic TOFD inspections with internal surface breaking cracks.

2. POD, a Modeling Approach

The POD generator consists of three main models: the degradation model, the inspection model and the integrity model (see Figure 1).

The degradation model simulates for each type of degradation the morphology of the object and damage. The degradation model is a statistical model; it simulates the degradation morphology for a number of realizations (e.g. of a pipe segment). For every realization the exact location and geometry of the defects are calculated over a certain period; e.g. 1 to 50 years. The inputs of the degradation model are the geometry, the environmental conditions and the process conditions of the object under simulation. The morphology of the simulated object, including all defects, is input for the inspection model.

The inspection model simulates the inspection on the degraded object simulated in the degradation model. Based on the type of inspection chosen for simulation, specific inspection parameters, e.g. the type of ultrasonic transducer and frequency, can be chosen. Besides the inspection technique, its parameters and other environmental conditions, also the inspection procedure is selected.

After human or automated interpretation of the simulated inspection results, the interpreted results together with the (known) simulated defects are used to calculate the simulated POD curve.

The integrity model calculates, based on simulated (or measured) POD curves and an integrity model of the object, the probability of failure (POF) of the object. Furthermore, the integrity is calculated as a function of time depending on inspection and maintenance strategy.

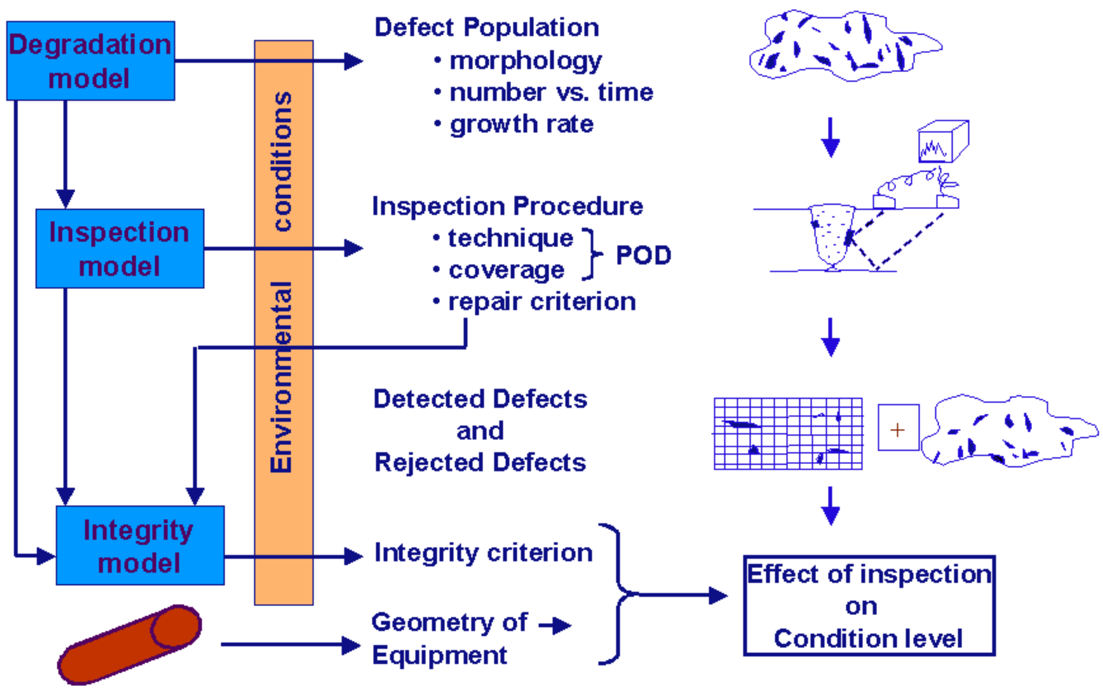

Figure 1 Probability of detection, a modeling approach.

3. Modeling realistic TOFD Inspections

Many factors influence the result of a time-of-flight-diffraction (TOFD) inspection. These factors can be roughly divided in two main categories. The first category consists of factors, or more appropriate parameters, associated with the inspection procedure, i.e. parameters which can be chosen more-or-less freely like for example:

- probe frequency, transducer angle and crystal diameter;
- probe separation distance;
- probe pair step size during scanning.

The second category of influencing factors is those factors one cannot choose but has to cope with like for example:

- object geometry and usually most important the wall thickness;
- surface roughness and presence and condition of coatings;
- grain scattering.

In order to generate realistic POD curves, the output of the inspection model, B-scans in the case of TOFD inspections, must also be realistic. In order to obtain a sufficient level of realism of the B-scans, the factors listed in Table 1 are included in the simulation of the TOFD inspection. To validate the realism of the output of the inspection model, the output is compared to experimentally obtained B-scans.

Table 1, Overview of the implemented influencing factors:

Factor	Effect	Implementation	Parameters
Surface roughness	Wave front breaks up on interface. This causes noise on the B-scan.	Small height variations on the surface of the pipe wall	Ra Profile
Grain scattering	Due to grains small material properties variations exist in weld. This causes scattering of wave fronts.	In weld the shear and longitudinal wave speed has small variations around the mean wave speed.	Δc_p Δc_s Size of grains
Probe position variations	While scanning the distance between the probes varies or the probes are slightly tilted.	The position of the source and receiver are given a slightly different position at every scan step.	Variation amplitude Variation profile

4. Validation of Modeling Ultrasonic TOFD Inspection

The modeling of the ultrasonic TOFD inspection was validated on a test piece with known defects. The test piece was a 25 mm thick steel plate and contained three defects; a root crack, a slag and porosity. To perform the validation thoroughly the test piece was inspected with different TOFD setups. The varied parameters were the distance between the probes, frequency and crystal diameter. The geometry of the test piece was also imported into the inspection model to simulate the inspection. The simulations were carried out with the same parameters as the measurements. The results of the simulations and measurements were compared on A-scan and B-scan level.

Figure 2 shows the measured and simulated A-scan result for one setup (see caption for the settings). In the figure the three relevant echoes (head wave echo, back wall echo and mode converted echo) are clearly visible. The measured and simulated A-scan match very well in terms of travel time, amplitude and signal shape. Also the noise generated by grain scattering and surface roughness corresponds. Small differences still exist because the measured signal was clipped and the because of reduced bandwidth of the simulations.

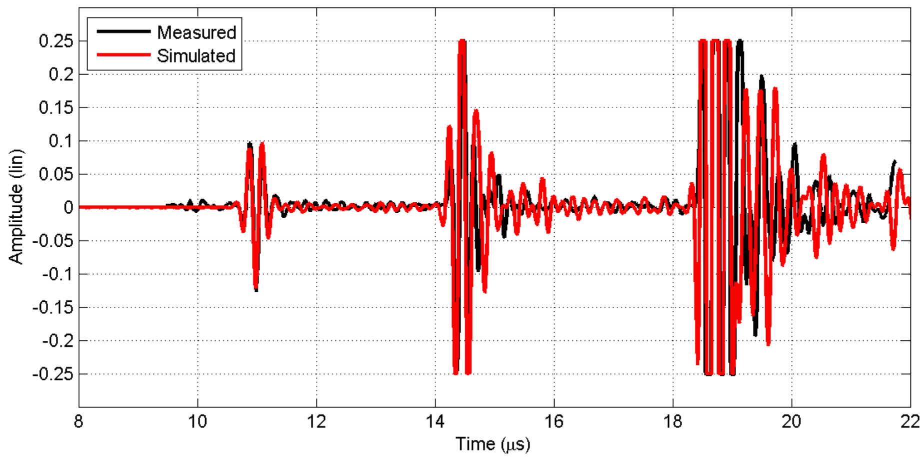

Figure 2 Validation of modeling ultrasonic TOFD inspection comparing measured and simulated A-scans. Measurement setup: probe distance 50 mm, probe angle 60º, frequency 5 MHz and crystal diameter 3 mm.

The simulations and measurements are also compared on B-scan level. The simulated B-scans are obtained by performing a 2D finite difference simulation at every scan position along the test piece. Due to the finite difference algorithm all wave phenomena such as wave conversion and diffraction are automatically taken into account. At every scan position the signal on the transducer is recorded and combined to a B-scan.

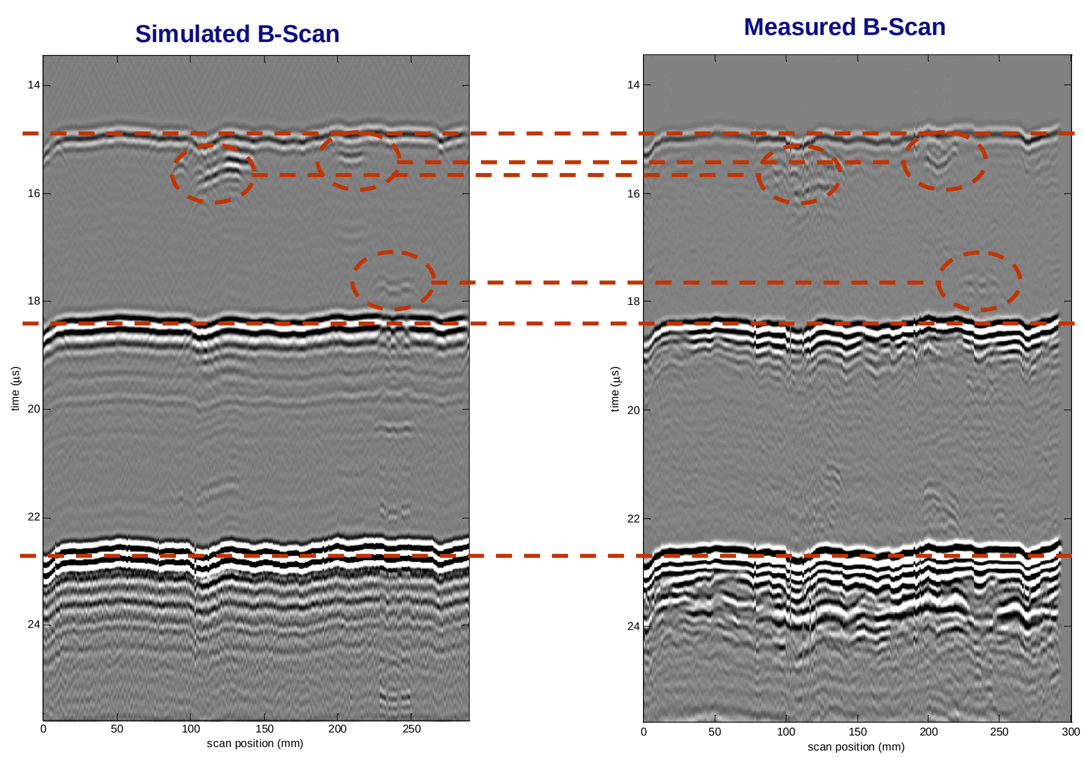

Figure 3 Validation of modeling ultrasonic TOFD inspection by comparing measured and simulated B-scans. From left to right three defects can be discerned: around scan position 125 several gas inclusions, at position 220 a slag inclusion, and a root crack around position 240.

The B-scan results of the measured and simulated ultrasonic TOFD inspection on the test piece are shown in Figure 3. The simulation results show good correlation with the measured signals. The timing of the head wave echo, the back wall echo and the mode converted echo corresponds with the measured signal. The probe positioning variations are incorporated in the simulation of the TOFD inspection by reading out the actual probe variation from the measured B-scans.

Furthermore, the signals due to the three defects in the test piece, the root crack, the slag inclusion and the porosity are very similar in the measured and the simulated B-scan. Small differences still exist in the response from the defects, but this is caused by the unknown three dimensional geometry of the defects.

5. Generating realistic POD curves for TOFD inspection

In this section the concept of the POD generator tool is illustrated for circumferential welds suffering internal surface breaking cracks inspected with TOFD. The degradation of the circumferential welds is modeled using the degradation model for fatigue cracks. The output of the degradation model is a pipe morphology including welds and defects. A typical result is shown in figure 4. Next, the morphology of the pipe is imported in the inspection model to simulate the TOFD inspection.

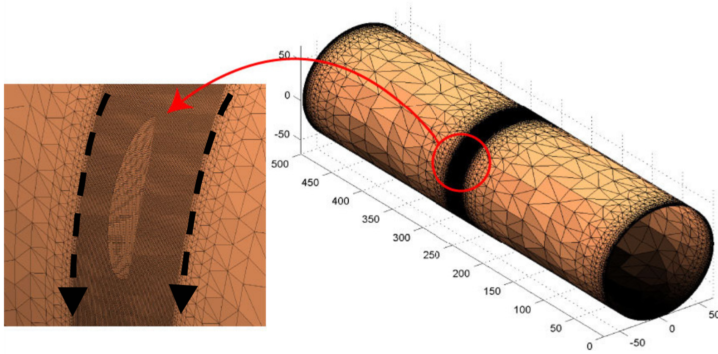

Figure 4 Mesh describing the inner surface of a simulated pipe with a fatigue crack near the root of a circumferential weld. The dashed arrows indicate the TOFD scanning direction.

The ultrasonic TOFD inspection is simulated the same way as during the validation of the simulations. At every scan position the signal on the transducer is recorded and combined to form a B-scan. The inspection parameters are the same at every scan position. The influencing factors from the environment are randomly determined at every scan position.

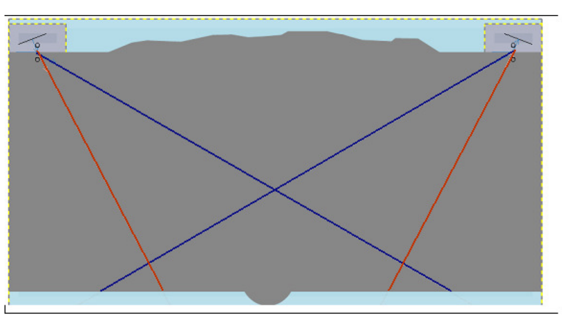

Figure 5 Simulation set-up of the TOFD modeling

Figure 6 shows a sample B-scan obtained with the finite difference modeling of the ultrasonic TOFD inspection on the simulated circumferential weld suffering internal surface breaking cracks. The three, for TOFD inspection, relevant echoes are clearly visible. The noise is caused by the grain scattering and the surface roughness. The echoes from the tip of the root cracks in this weld arrive between the surface and the bottom echo. Note that only defects from a certain length can be discerned from the bottom echo.

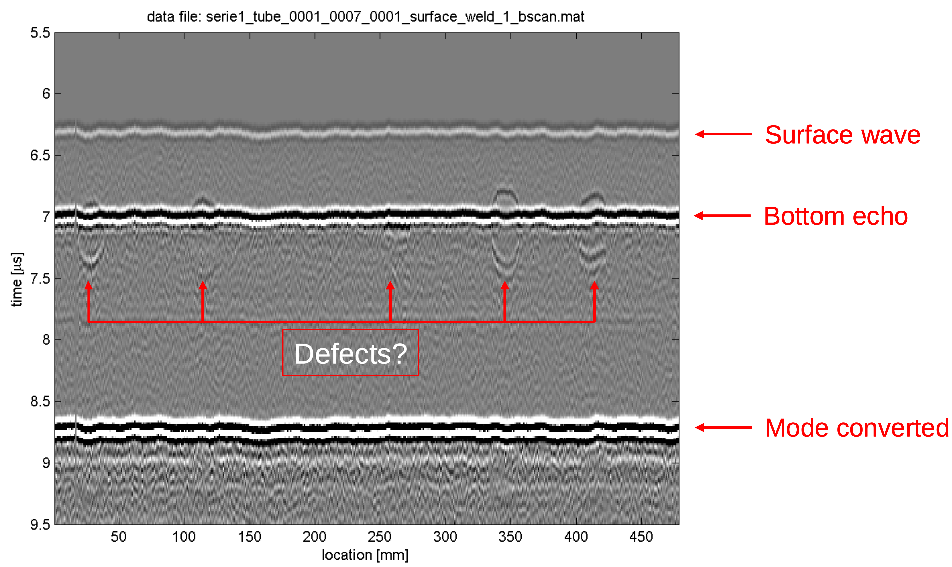

Figure 6 Simulated TOFD B-scan image for a number of defects, i.e. weld root fatigue cracks.

In order to generate sufficient data to construct a POD curve, a series of B-scans has been simulated for TOFD inspection on a several realizations of circumferential welds suffering internal surface breaking cracks.

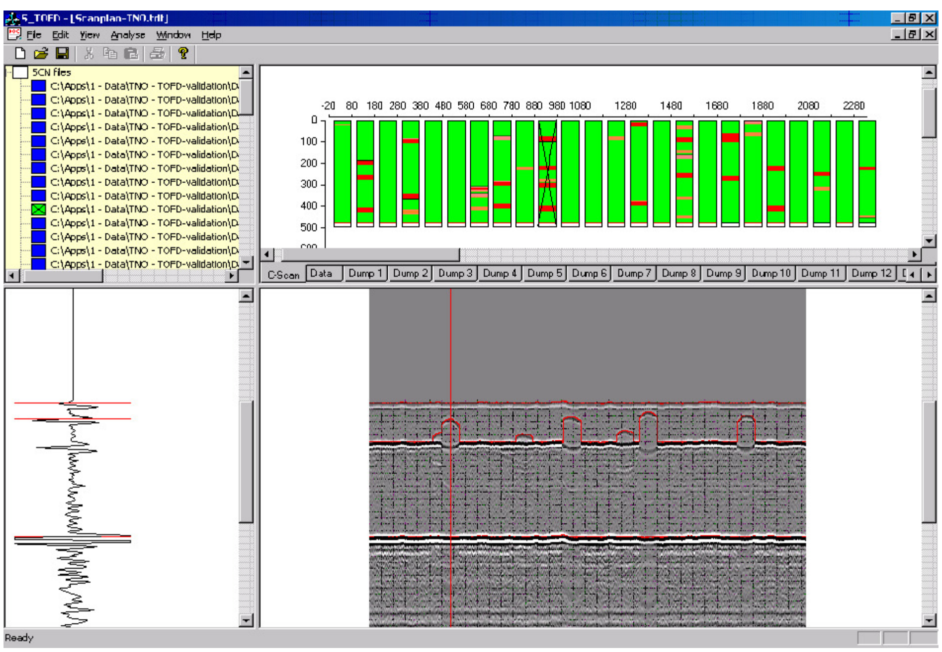

Figure 7 Simulated TOFD B-scan image imported into TOFD analysis software for interpretation..

The simulated B-scans are interpreted identically as experimentally obtained B-scans using standard TOFD analysis software (Figure 7).

The output of the interpretation is a list of found and sized defects. The list after interpretation is compared with the list of defects from the degradation model. Based on this comparison a POD curve is calculated. More results and the corresponding POD curves will presented in the conference presentation.

6. Discussion and Conclusions

In this paper the modeling approach of the POD generator tool is discussed. This approach enables a flexible and reliable quantitative assessment of inspection techniques at acceptable costs. The simulation of POD curves for ultrasonic TOFD inspection with internal surface breaking cracks is discussed and the results shown.

The important factors that influence the result of a time-of-flight-diffraction (TOFD) inspection have been addressed and incorporated into the model. The realism of the B-scans is validated, by comparing the simulated results with experimentally obtained results.

All simulated B-scans can be interpreted identically as experimentally obtained B-scans using standard TOFD analysis software. As a result, the human factor due to interpretation issues, can be included in the simulated POD curve

As indicated many times in this paper, the POD depends on many factors. In that respect it is suitable to introduce a multi dimensional POD, where every specific case is a section of this higher dimensional POD curvature. The parameters of the axis that span up the multidimensional POD are all the factors that influence the POD. For the special case of TOFD inspection on circumferential welds suffering internal surface breaking waves, the influencing factors on the POD are exemplified and discussed.

The POD generator tool will help to determine the inspection effectiveness for every specific technique and situation. Furthermore, the POD generator will help asset owners to rationalize their inspection and maintenance strategy, i.e. reduce inspection and maintenance costs while preserving safety and reliability of operation at the desired levels.

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