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MODEL-ASSISTED PROBABILITY OF DETECTION FOR ULTRASONIC RAIL FLAW INSPECTION

SUMMARY

This report gives a roadmap for applying model-assisted probability of detection (MAPOD) to the ultrasonic detection of rail flaws. Researchers at ENSCO, Inc., selected this type of track inspection as the most suitable for the MAPOD approach (Bruzek, 2021).

MAPOD analysis involves identifying the factors that can affect the probability of detecting flaws using a defined technology. These factors are assessed either theoretically or experimentally. Experimental assessment involves physical tests with sample flaws. Analytical assessment involves computer modeling of flaw detection. MAPOD analysis combines the results from a relatively small number of physical tests with more extensive results from computer simulation. Two options exist for combining the theoretical and experimental results, both requiring analytical methods to be developed.

Ultrasonic rail flaw detection is suitable for MAPOD analysis because it can be modeled with commercially available software. The Federal Railroad Administration (FRA) has used this software to develop ultrasonic rail flaw detection models that could be used in this study.

Figure 1 shows a flow chart developed by the U.S. Department of Defense for applying MAPOD (U.S. Department of Defense, 2009). The roadmap for ultrasonic rail flaw detection follows this process.

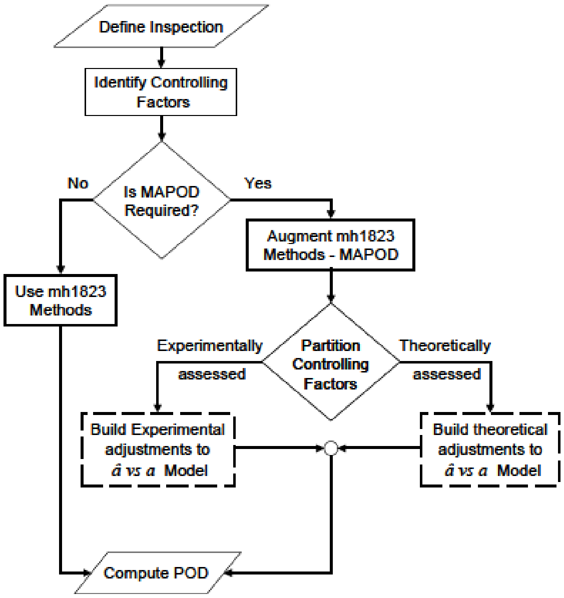

Figure 1 – Process Flow for MAPOD

The next step in this research is to demonstrate the technique using this roadmap and report on the results.

BACKGROUND

FRA is researching methods for evaluating the effectiveness of track inspection technologies (Bruzek, Maymand, Drape, Smart, & Tunna, 2020). These methods could be used to compare different technologies and determine if they are acceptable for the intended purpose.

MAPOD was one of the methods investigated, and researchers found it reduced the need for testing physical samples – making it more practical and affordable than conventional methods.

MAPOD requires a way to model the detection of flaws and physical tests on sample flaws. Previously, researchers investigated the availability of computer models and physical samples for six types of track inspection, and ultrasonic rail flaw inspection was identified as the most feasible for MAPOD analysis (Bruzek, 2021).

OBJECTIVES

ENSCO researchers sought to produce a roadmap that could be followed when applying the MAPOD approach. The roadmap needed to identify the steps in the process and any factors that could affect success.

RESULTS

The specific ultrasonic inspection equipment considered here was a handheld probe manipulated by an operator. This type of inspection is typically performed to verify indications from an automatic rail flaw inspection system. The inspection process involves:

1. Calibrating the equipment, including setting gains and scale factors
2. Sliding the probe along the rail while maintaining the correct alignment and lubrication
3. Monitoring A-scan and B-scan results for flaw indications
4. Re-scanning indicated flaws to determine dimensions
5. Documenting confirmed flaws for further action

Equipment details that must be specified include the number, shape, and size of transducer elements; probe angle; center and sampling frequencies; probe bandwidth; and the type of excitation.

The following controlling factors can affect the probability of the equipment detecting rail flaws. These factors need to be assessed either with theoretical models or by experiments:

Surface Condition

The surface condition of the rail affects the coupling between the ultrasonic probe and the rail. In addition, rust and grease (or other deposits) and surface defects, including rolling contact fatigue, also affect the coupling.

Flaw Type and Geometry

The development of this MAPOD roadmap focused on the detection of transverse flaws in the head of the rail, which include transverse fissures, compound fissures, and detail fractures (Nordco Rail Services, 2021). These types of flaws exhibit varying sizes, locations, orientations, and shapes all of which affect proper detection. A further complication is that the crack faces can be rough, polished, or patterned. Yet another complication is the flaws may break the surface of the rail or be completely internal.

Rail Type

Various rail cross-sections are possible and must be taken into account. For example, the railhead can be new or worn to different degrees – or have material flow on the gauge and field faces. The foot of the rail may be worn, which would affect calibration. Rail material properties are also important as the chemical composition and hardness can vary across the cross-section.

Track Features

Flaws near rail joints and welds may be difficult to detect. Rail joints introduce extra surfaces from which ultrasonic signals can reflect. And welds introduce variations in material properties.

Human Factors

When an ultrasonic probe is manually operated, human factors can have a strong influence on the probability of detecting flaws. The following types of errors are possible:

1. Insufficient lubrication of the probe-rail interface

2. Incorrect gain setting
3. Variation in vertical and horizontal alignment during operation
4. Missing A-scan and B-scan indications
5. Failing to re-scan indications
6. Incorrect flaw sizing
7. Incorrect reporting

Therefore, the operators' experience, training, fatigue, and stress need to be assessed. These conditions are difficult to model and would be assessed experimentally.

Many of the controlling factors described above can be modeled using commercially available software. These include surface condition, flaw geometry, rail type, and track features.

The model requires input data covering specific details of the controlling factors. The wide range of possible inputs leads to a large number of model simulations. The modeling software provides the functionality to combine these simulations and produce a probability of detection curve with confidence intervals.

Experiments are required to assess the effect of the human factors, including lubrication, calibration, alignment, and missed indications. These will be conducted in the field on the Rail Defect Test Facility at FRA's Transportation Technology Center in Colorado (Sheenan, 2018). Some, such as missed indications, will be assessed with laboratory simulations.

A complete experimental assessment will involve a cohort of operators with a range of skills. Testing will require operators to perform related tasks under a range of physical and mental conditions.

The final step in the MAPOD process will be to combine the theoretical results from the computer model with the experimental results from the physical tests. This is achieved through a Monte Carlo simulation or development of theoretical models from the experimental results for inclusion in the computer simulations.

FUTURE ACTION

The next phase of this research is to demonstrate the MAPOD analysis for handheld ultrasonic inspections using this roadmap and report on the results. This will be the first test of how well the MAPOD approach evaluates the effectiveness of a track inspection technology.

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