GROUNDWORK FOR RAIL FLAW DETECTION USING ULTRASONIC PHASED ARRAY INSPECTION

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ABSTRACT. An apparent increase in the detectability of certain flaws results when the ultrasonic inspection beam was oriented off the longitudinal axis of railroad rail. Here, artificial reflectors were used to better define the extent of material “seen” by inspection beams, and determine how surface curvature might affect the inspection. Presumably, such information could be useful for suggesting optimum positioning of linear array probes in testing, and help determine the validity of simulation models of this inspection for various cases.

INTRODUCTION

In previous work, railroad rails having internal transverse defects in the head region were scanned via ultrasonic C-scan inspection to reveal the extent of high-amplitude regions that conceivably corresponded to good flaw detection [1-3]. Although such scans were admittedly not practical for service inspection, it was felt that they could provide an indication of the likelihood of a flaw being detected during the linear sweep of inspection probes along the rail. Presumably, the higher this likelihood, the greater would be the probability of detection for that flaw.

An apparent increase in the detectability of these defects was noted when the refracted 70° angle beam typically used to find such flaws was aligned off of the longitudinal axis of test rails. This appeared to be the case for standard immersion transducers, a linear phased array transducer, and a roller search unit (RSU) used in service inspection. These results were quite interesting, furthering the suggestion that there could be an enhancement possible for rail inspection if non-traditional beam alignments were to be used.

The questions exist of how much of the rail head is viewed by this alternative inspection protocol (or any inspection), and how different surface profiles will affect beam behavior. Natural flaws are not suitable for clearly discerning the answers to these questions; it’s currently not possible to predict the precise signature of an inadequately-defined flaw under varying profiles. However, repeatable calibration reflectors could conceivably provide such information. In the past, such reflectors have been notoriously difficult to produce, or yield signal reflection information confounded by non-relevant phenomena. In this study, a simple new reflector was used on our test rails with seeming success.

Finally, one goal of this ongoing laboratory work, testing rails in immersion, is to provide benchmark information that will ideally assist in validating ultrasonic simulation
models. To that end, modeling a simple ultrasonic probe would be easier than modeling the interface between a fluid-filled wheel’s membrane and the rail surface, along with the rest of the fluid-filled wheel probe used in service. A series of tests was therefore run to confirm if the use of a single, undamped transducer from an RSU would see the same enhanced flaw signatures using “off-axis” alignment. Such tests would also provide some information on the nature of signal change from using the fluid-filled wheel membrane going to full immersion.

TEST PROCEDURE

Four rail samples were studied: three worn rail sections with internal defects and a new rail having an as-made profile. Each of these rails had three top-drilled holes machined into them, at both sides of the rail head, “just in” from the vertical edge of the head as well as over the center of the web. The holes were 0.25” (6.35 mm) wide and 0.5” (12.7 mm) deep, angled 20° off of the vertical transverse plane. These were therefore small, cylindrical holes tilted back to the anticipated configuration of transverse defects, and should provide their strongest reflection when an incident 70° ultrasonic beam was used for inspection. A photo of a rail sample with a steel rod stuck into one of these calibration holes is shown in Figure 1.

The profiles of the 3 worn rails are shown in Figure 2. As may be seen, the surfaces of these samples represent varying degrees of head loss and gage face curvature. The unused rail looks symmetric, roughly approximating the field side appearance of Rail 1 on both of its sides.

FIGURE 1. A photograph of a test rail with three calibration holes drilled into the top surface. A steel rod is inserted into one of these holes to indicate the angle of the hole, tilted back longitudinally from the transverse plane. Such reflectors were found to provide clear signals during inspection, avoiding some of the pitfalls associated with other reflectors attempted in calibration rails.
As with previous work [1-3], automated ultrasonic scans of the test rails were made using a Sonix system. Conventional immersion transducers, the transducer from a fluid-filled wheel assembly, the entire fluid-filled wheel, and a linear element phased array transducer were scanned along the rail aligned either parallel to the longitudinal axis or rotated toward the field side of the rail.

In all instances, the signal from the top-drilled reflector centered over the web of the rail was used to adjust gain on the pulser/receiver. The peak signal from this reflector was set to about 100% FSH (full screen height) during a preliminary scan.

RESULTS

A myriad of scans were performed during the course of this work, and a range of conclusions can be made from them. In the cause of expediency for this document, just a few, select observations will be discussed.

Phased Array Scans of Rails with Machined Reflectors

Figure 3 shows the scans of the four test rails, each having the three top-drilled and angled reflectors. The rails were scanned using a 16-element linear array transducer, with no delay laws implemented for steering or focusing. The data was gained by using two time gates, the first one being 12.5 μ-seconds just subsurface (following the reflection of the sample surface) and the second gate representing signals that occurred in the next 22.5 μ-seconds of time/depth. This allowed the signals generated from the back sides of the actual holes to be distinguished from the through-metal reflection of the cylindrical sides of the drilled reflectors. While it is debatable how ultimately useful this scheme was, in this instance it afforded us the ability to distinguish between internal reflections and surface waves that were seen to creep into the picture from surface-breaking phenomenon such as the drilled holes.

It can be seen that of the three artificial reflectors on these rails, the indications are clearly pronounced and symmetric on the new rail. To varying degrees, their signals degrade when curvature of the entry surface is included in the consideration. It is not clear why there is not a “perfect symmetry” from the three reflectors in the new rail; it was expected that such would be the case. It is evident, however, that when pronounced curvature is encountered, such as on the gage face of Rail 3, that the anticipated “rectangular” signature of a drilled hole distorts. Of possibly a greater concern is that the anticipated signature of the reflector, as seen through less dramatic curvature as seen.
FIGURE 3. Ultrasonic C-scans of new (far left) and used rails having three top-drilled cylindrical holes in them, scanned by a linear phased array transducer utilizing no beam steering. The upper row of scan data is from a time gate 12.5 μ-second below the running surface of the rail; the second row is 22.5 μ-second later/deeper. The data here shows us how various rail curvatures affect the signal from a simple drilled hole. It is not clear just what is going on in all instances of beam/sample orientation.

Towards the sides of Rail 1, seems to clearly diminish the response from these reflectors. The reason for this is currently not known.

A simple observation might be that any curvature, for this angle of incident beam for 70° refraction, badly distorts the reflections from internal targets. The implications of this for real-life inspection are unclear.

Figure 4 shows the same rails, now scanned utilizing a number of delay laws in sequence to generate ultrasonic beams steered at 5°, 10°, 12.5°, 15°, 17.5° and 20° off of the rails' longitudinal axes, aiming toward the field side of the rail, in addition to the "normal" shot along the length of the rail. The previously noted trend of loss of reflector signal in certain areas of curvature was again seen, suggesting that the effect of curvature noted in other scans was real, if not fully explained. Some of the reflections from the drilled reflectors are seen to be "smeared" in the scan data, indicating that the same holes were seen from various positions. However, this is likely a good thing: a flaw at a given point would be seen from different angles and points in the scan, increasing the likelihood that it would trigger a detection gate.

Comparison of Response from Single Transducer to Response from Full RSU

An RSU used for service inspection of rail was attached to the Sonix scanning hardware and a C-scan was made of the three reflectors drilled in the new rail. During this scan, any one of the three refracted 70° inspection elements could be selected. Typically,
FIGURE 4. Ultrasonic C-scans of new (far left) and used rails as seen in Figure 3, scanned by a linear phased array transducer with the beam steered toward the field side of the rail at various angles up to 20°. The upper row of scan data is from a time gate 12.5 µ-second below the running surface of the rail; the second row is 22.5 µ-second later/deeper, as before. Apparent smearing of the reflector signatures suggests that they are being detected with high amplitude signal from a greater number of positions than for non-steered ultrasonic beams.

they were found to behave quite similarly; their lateral positioning, of course, needed to be accounted for. The results of scanning with a channel in such a fluid-filled wheel were compared to the same samples scanned using a single, undamped rectangular transducer element from another RSU. Both transducers were nominally rated as 2.25 MHz transducers, of the same size and shape, but they were from different manufacturers.

The results of this comparison are shown in Figures 5 and 6, which show the scans of the test rails using the full fluid-filled wheel normally used in service inspection and scans with just a single transducer from such a wheel, respectively. The scans indicate an overall similarity, but with some important distinguishing features. A general trend toward higher amplitudes in the near surface region is seen with the undamped transducer in immersion scans the membrane of the fluid-filled wheel. Yet, disconcertingly, the drilled reflectors in the center of the worn rails are not clearly visible. This is not the case when the same rails were scanned using the fluid-filled wheel.

It is not currently clear as to why these differences exist. Whether a basic distinction exists between the transducers, a subtle alignment difference is present, or the presence of the membrane affords a significantly altered inspection result may affect the results. Irrespective, modeling of rail inspection, if to be practical, must eventually account for such differences.
FIGURE 5. Ultrasonic C-scans of new (far left) and used rails, scanned using a Sperry Rail Service fluid-filled wheel. Note the way in which the drilled reflectors in heavily worn Rail 3 are obscured.

FIGURE 6. Ultrasonic C-scans of new (far left) and used rails, scanned using a transducer from a fluid-filled wheel. While similar overall, scans made with the full wheel (Figure 5) seem to afford a clearer rendition of internal details in rails than scanning with a transducer in immersion mode.
DISCUSSION

A continuing aspect of inspection suggested by this work is that rotation of the refracted ultrasonic beam off from the longitudinal axis of the rail appears to improve the detectability of internal flaws. This was shown by results in scans where a series of off-axis steered-beam configurations, via phased array inspection, were added to a conventional beam aligned with the rail. The rotation of an inspection probe may accomplish this, but the use of appropriate delay laws to allow a phased array element to send a series of signals at varying angles makes this much simpler.

The use of phased arrays in rail inspection, however, still is not without specific challenges. To create the scans that have served well to visualize internal reflectors, the phased array transducer and its supporting computer were connected to conventional scanning hardware. The result was an acceptable image of the scan, but often meant a trade-off between scan image quality and scan speed. In addition, if the necessary comparisons to current inspection are to be made directly, a move away from C-scans toward B-scan data will be required. The logistics of making this happen with current capabilities have not been resolved.

Promising results of one aspect of this work effort was the apparent usefulness of top-drilled and angled holes as artificial reflectors in the sample rails. In railroad related work, flat-bottomed holes are sometimes drilled into the ends of rail to act as calibration targets. Our previous work suggested that this could create unacceptable surface wave reflections from the ends of the rails, obscuring the information desired from the holes themselves. While some doubt exists as to how badly such reflectors could obfuscate data of interest under various means of inspection, the use of top-drilled holes certainly alleviates this concern. Additionally, these holes appear to indicate the detrimental effect that rail head curvature could have on inspection. This was seen by looking at the scans in question: when the rail surface was flatter, a typically better indication of the holes could be had than were the rail head to be severely worn and curved.

Finally, if ultrasonic modeling of rail inspection is to be fully realized, the effect of the membrane of fluid-filled wheels needs to be understood and incorporated into models. Initial tests suggest that inspection with this membrane in place can have unpredicted effects.

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REFERENCES

