Development of an Improved Rail Flaw Detection System

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(2193 words)

ABSTRACT

Herzog Services Inc. is currently running prototype trucks of our new Rail Flaw Detection System, Herzog 2020. The novel system integrates real time 3D rail profiling with live 3D ultrasonic data. The system is also the first railroad application of phased array ultrasound. Phased array allows the system to compensate for known rail testing issues such as rail wear. Phased array together with the real 3D rail view allows for faster and more complete characterization of flaw indications while in motion on the truck. Previously, this characterization required a manual hand test outside the truck. Overall, the new system presents advancements in efficiency, accuracy, ease of operation, and safety in ultrasonic rail testing. The integrated profiling system also allows for concurrent inspection services such as rail wear and gauge measurement. The presentation and paper will detail the system and benefits, and update the progress and results of the prototype trucks.

BODY

Introduction:

If left unmonitored, rail defects can lead to rail fractures and possibly derailment of rail cars. Ultrasonic Rail Flaw Detection Systems are widely employed by railroads as a means to identify and contain rail defects. Typically, ultrasonic testing systems are implemented on a hy-rail vehicle platform that is dedicated specifically to the ultrasonic inspection service. Current day ultrasonic rail testing platforms are capable of identifying greater than 90% of common rail defects. Peak testing speed can exceed 20 miles per hour, but start-stop-“hand verify” operation often limits average test speeds around 7~8 miles per hour. Ultrasonic testing offers significant benefit and value to the railroad as is, but there is certainly room for improvement. Ideally, next generation systems should aim for improvements of both defect detection rates and efficiency on rail.

Herzog Services newest inspection platform, Herzog 2020 (patent pending), is designed to improve defect detection rates, average inspection speed, ease of operation, and safety. The 2020 system integrates phased array ultrasound and rail profiling sensors. The multiple benefits of phased array ultrasound and integrated rail profiling are presented below.
Impact of Rail Wear on Ultrasound Inspection:

Current rail testing systems are built around conventional ultrasonic transducers. The transducers are typically contained in a Roller Search Unit, or RSU. The RSU is a fluid filled tire that conforms to the rail head (See Figure 2).

The contour of the rail surface directly affects the refracted angle of the ultrasound beam. An issue with current conventional technology is there is not a means to correct for the surface contour. The conventional transducers are in a fixed position based on the RSU axle, not the rail surface. The result on ultrasound beam propagation is illustrated below in Figure 3. New rail is compared to worn rail; the misguided ultrasound beams on the worn rail result in a less than ideal inspection. The effect is greatest on extremities of the rail such as the gauge corner. Mechanical adjustment of conventional transducers could be a solution. However, given the limited speed of physical adjustments and the mechanical complexity of such a system, it is desirable to find a more elegant solution.
Herzog 2020 is built around *phased array* ultrasound transducers. *Phased array* technology allows ultrasonic beams to be steered, thus 2020 can actively correct for rail wear. Beam steering is accomplished by sub-dividing a transducer into several transducer elements. Each element is pulsed and sampled independently. Through varying the delay of pulsing and sampling of each elements – a specific beam angle can be selected. No mechanical adjustment is necessary; the beam steering is completed electronically. See Figure 4 below for an illustration demonstrating phased array steering:

![Figure 4](image1)

*Figure 4 – Illustration of wave front formed by independent delayed firing of phased array elements (illustration courtesy of Olympus NDT website)*

Herzog 2020 utilizes phased array beam steering principles, but to accomplish somewhat of the opposite effect. 2020 controls phased array elements in order to keep the beam straight while the rail head varies. The result is essentially an RSU that is perfectly matched for every rail cross section. There is not a compromise of coverage on worn rail with the 2020 system. See Figure 5 below for a comparison of the passive conventional ultrasound beams versus the actively steered phased array ultrasound beams.

![Figure 5](image2)

*Figure 5 – Comparison of conventional ultrasound (left) misguided wave compared to proper wave steering possible from phased array (right).*
In addition to correcting for rail contour, the 2020 phased array technology can also adjust beam targets depending on rail cross-section. Consider a sound beam meant to cross the rail head and reflect off the opposite corner of the rail. The entry angle of that beam would be specific to the depth and width of the rail head. Figure 6 below shows such a scenario with two distinct rail wear patterns. A non-adjusted beam, as with conventional transducers, would not reach the reflection target. This is illustrated in figure 7. The non-return is ambiguous as to whether rail wear or a defect caused the non-return. Herzog 2020’s phased array probes can adjust per rail cross section to target the proper reflection surface.

![Figure 6 – Beam Targeting based on rail head width and height](image1)

![Figure 7 – An uncorrected cross head beam compared to a phased array corrected cross head beam](image2)

Converting from conventional transducers to phased array transducers dictates a jump from dozens of ultrasonic pulser-receivers to hundreds of ultrasonic pulser-receivers. The 2020 system has a proprietary hardware solution in order to drive hundreds of phased array elements at full rail testing speed.

Correcting for rail wear, rail contour, and rail dimensions results in a consistent inspection on all rail samples. The Herzog 2020 system is designed to improve inspection results on worn rail, especially on defects located in the gauge corner of the rail where wear can be extreme.
Further Benefits of Phased Array – Sweeping and Configurable Beams:

The 2020 system can pick a target in the rail head and adjust the sound beam per the rail contour. Given that these adjustments are made in software, the phased array steering can also accomplish other beneficial tasks.

The system has the ability to iteratively sweep a sound beam across the rail head by changing the beam target. Present technology requires the rail test operators to exit the vehicle in pursuit of characterizing suspicious indications. Current procedure is for the operator to manipulate a hand probe at different angles and positions on the rail head in order to gather more information. Confirmation of the defect, defect size, and defect location are determined via the manual hand test. With the Herzog 2020 system, it is possible to characterize defect information automatically from the truck. The phased array wheel probe can manipulate the sound beam in the same fashion as the operator in order to characterize ultrasonic indications. This can be accomplished in seconds and from the safety of the operator’s seat, versus present day procedures taking a minute or more outside of the vehicle. Saving trips out of the vehicle reduces chances for slips, trips, dangers from adjacent tracks, dangers from road crossings, and danger from bridges. Enabling decisions in seconds versus minutes greatly reduces idle time of the truck, which can have a significant impact on average test speed.

Live Profiling – Novel Application for Phased Array Rail Testing:

Phased Array ultrasonic testing offers clear benefits when compared to conventional ultrasound technology. However, despite vast adoption of phased array in other testing industries, the rail testing industry struggled to solve application hurdles. First is the increase in hardware complexity. Rather than try to adapt a conventional UT system, Herzog 2020 overcame the hardware issue by building the system from the ground up. The new generation hardware is specifically designed to handle phased array at high speed inspection rates. The second challenge is that practically, the rail shape is unknown until the moment of inspection. As discussed, phased array can overcome surface contour issues, but in order to do so the system must know the surface contour. Herzog 2020 solves this issue by integrating rail profiling sensors.

A significant part of the 2020 invention is a solution for generating phased array steering parameters on the fly. Capturing live profile data and generating phased array steering parameters in real time is a novel solution to bring the benefits of phased array ultrasound to rail testing. The entire data process must happen in fractions of a second. Several specialized algorithms and significant computer processing resources are necessary to perform the live profile phased array calculations.

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Profiling Integrated with UT Data for 3D Review:

With the addition of a laser profiling unit, Herzog 2020 can reapply the rail profile data to create an immersive 3D representation of the rail. The system compounds the 3D benefit by integrating the ultrasonic data with the live rail scan. The result is a true 3D scan of the subject rail. The benefits of the 3D scan include:

- Definitive indications - i.e. known proximity of indications relative to bolt holes, welds, bond pins, and rail surface
- Reduced re-runs and out of truck visual inspection of rail – leading to an increase in average test speed

A screen shot from the 2020 system is shown below in figure 8. Ultrasonic reflections are indicated by the colored disc. Notice the distinction of expected indications on the rail base and around bolt holes versus the defect indication in the rail head.

*Figure 8 – 2020 3D Scan screen shot – 5% detail fracture defect shown*
Concurrent Services:

As discussed in the introduction, rail testing trucks offer a specific dedicated service, rail defect detection. Utilizing the profiling data, Herzog 2020 can offer several additional track inspection services. Examples of potential additional services include:

- Rail Wear
- Rail Inventory
- Fastener Inspection
- Fastener Inventory
- Joint Bar Inspection
- Surface Condition Inspection
- Gauge Measurement

Addition of optional camera equipment further augments 2020’s potential inspection range. Customer specific data storage, trend reports, and data hosting will be made available as add-ons to 2020 rail inspection. Multiple inspection services on an ultrasonic vehicle inspection schedule would benefit the railroad in several ways:

- More efficient use of track time
- Better value for the inspection dollar
- Higher frequency inspection for trending inspections such as rail wear
- Less latency on detection of critical track flaws such as rail gauge or broken joint bars

The following figures (9-15) demonstrate the potential of the Herzog 2020 profiling system. Resolution of certain features is dependent upon vehicle speed. Thus an ultrasonic inspection vehicle can see fastener details at a level not possible from rail bound high speed profiling systems:
Figure 10 – Rail Joint and Joint Bar

Figure 11 – Tie Plates, Rail Lettering, Ballast Void

Figure 12 – CF&I Rail, Manufactured July of 1954
Figure 13 – Tie Plate with one spike

Figure 14 – Tape stuck to Rail. Demonstrates benefits of 3D imaging over camera exclusive technology – immunity to color and stains

Figure 15 – Field Weld
Progress of Development, Schedule for Service:

As of June 2012, the Herzog 2020 system is operating as a prototype. It is scheduled for full release October of 2012. Continued development is expected throughout the first year of operation – including tailoring of add-on concurrent services per railroad. With extended service, metrics on defect detection improvements and efficiency improvements will be tracked. Efforts will continue to provide papers to AREMA detailing results and statistics from revenue service.

Conclusion:

There are several advantages to phased array ultrasound when compared to conventional ultrasound as applied to rail testing. With an integrated live profiling system, the test vehicle can take full advantage of phased array’s capabilities. Profile data can also be re-applied for concurrent inspection services. Together, such a platform offers greater benefit and track utilization. Better rates of defect detection, faster average inspection speed, and improved safety can be achieved from Herzog’s next generation rail inspection platform.

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Development of Improved Rail Inspection System

AREMA 2012

Presented By: Jeff Wigh
Industry Requests

• Test Faster
• Do more with the track time
• Multiple inspection services
  – Improve accuracy
• ... Basically, offer more value!
Herzog 2020

• Herzog’s Direction
  – Launching a new platform, Herzog 2020
  – System aims to improve
    • Inspection accuracy
    • Efficiency
      – Average Speed of inspection
      – Additional inspection services
What is 2020

• 2020 is an integration of rail profiling and ultrasonic flaw detection
• It is a step in ultrasonic technology from “conventional” ultrasound to “phased array” ultrasound
First…
Ultrasound Testing Systems Today

• Typical Setup
  – Two or more probe wheels per rail
  – Discrete beam count per rail
Rail BScan

• Operator monitors a “BScan”
Verify Procedure

• Hand Test to Classify Indications
  – Operator traverses rail surface with probes
  – Determines size, position, confirms defect
Limitations of Conventional UT

- Discrete Beams
  - Can not steer towards targets
  - At the mercy of rail contour
Contour?

- One wheel – but there are many rails
  - Contour issue – sounds “refracts”
Targeting?

• Ideal beam direction – dependent on head shape
  – Especially for beams that must bounce
Drawbacks of Hand Verification

• Safety – vehicle exits
• Procedure takes time... track time
  – Consider actual run below
  • High Defect Area (~5 defects / mile)
  • 42 vehicle stops for hand verification
  • 4:40:27 total track time
  • 2:49:37 time stopped for hand tests
    ~4 minutes per hand test
  • >60% of track time is idle time!
What can be done?

• Overcoming Rail Contour
  – A sound beam can be steered!
• Phased array Ultrasound
Conventional Beam

• 1 “Element” = Fixed Direction
Basics of Phased Array

• Divide into several “Elements”
• Delay firing **Electronically**
Applied to Rail

- Contour Correction

- Beam Targeting
Sweeping = Hand Test

- Arbitrary Beam Steering... Leads to Beam Sweeping
Beam Sweep

- Can be equivalent to hand verification
  - Yet can be done from the truck
  - Can be done in seconds
  - Software configurable
Where has Phased Array Been?

• Rail Testing is unique
  – Test subject is unknown shape
  – High speed inspection compared to other NDT industries

• Roadblocks to Phased Array adoption
  – Focal Law Calculation
    • Depends on Rail Shape
    • Processing Power
  – Increase in Ultrasonic hardware
2020 started with development of Custom UT hardware
  – Drives many channels
  – Many thousand times per second
Speed, Hardware, Rail Shape...

• Focal Law Calculation
  – Proprietary Software
  – Optimized for Rail testing
  – ... but still must know Rail Shape?
Integrated Rail Profiler

- Laser Profiler on lead of truck resolves Rail Shape
Profile → UT Settings

- Fraction of a second to process profile
- Result is Phased Array “Focal Laws”
  - The laws serve to correct for rail wear and to steer beams to proper targets
Rail shape, re-applied

- Phased Array benefits from profiler, but so can the operator...
- Re-use the profile information to construct 3D scan
3D Scan

• Indications mapped to true position in rail
Advantages of 3D Scan

• Definitive indications
  – Depth in material
  – Orientation
  – Proximity to surface features
    • Welds
    • Spalling
  – Not just defects, but confidence in negative indications:
    • Bond Pins
    • Bolt Holes
Recap of 2020 Improvements

• Beam Correction and Targeting

• Beam Sweeping for on board characterization
Recap of 2020 Improvements

• 3D Scan
“Do More with Track Time”

- With a 3D profiler, concurrent services are possible
  - Thousands of profiles per second
  - ~0.1 mm accuracy on X-Y shape
  - Travel (z dimension) resolution depends on inspection speed, but different levels of profilers available to achieve < 1mm slices
Rail Wear Inspection

• Data available with frequency of UT Testing
  – Trend and forecast
    • GPS Data
    • Mileage
    • Track ID
Rail Inventory

- Possible to see beyond cross-section...
  Read the brand directly
Joint Bars

- Counts and Inspection
  - Run on Run data by GPS
Fasteners

- Identification
- Inventory
- Inspection (High, Missing)
Frog and Switch

• 3D rendering yields superior image and ability to measure critical dimensions
More...

- Gauge Measurement
- Surface Conditions
- Crushed Head Detection
- Rail Cant / Rail Seat Abrasion
Herzog 2020

- Application of Phased Array UT
- Integrated Profiling
- Accuracy, Safety, Efficiency
- Concurrent Services
- Starting Service 2012
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