ENHANCING WELLHEAD INSPECTION: STANDARDIZATION AND IMPROVEMENT WITH ALGORITHMIC ARTIFICIAL INTELLIGENCE

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INTRODUCTION

Wellhead inspections are critical to safe and efficient oil and gas workover operations. Traditionally, these inspections rely on operators manually interpreting electromagnetic (EMI) signal graphs[i]. However, outcomes are often inconsistent due to differences in training, experience, and subjective judgment.

The software studied introduces Algorithmic Artificial Intelligence to enhance reliability and standardize inspection results. By integrating advanced signal processing and automated classification techniques, the Algorithmic AI software approach aims to:

- Reduce variability in EMI graph interpretation
- Minimize human error
- Improve overall inspection reliability

This paper outlines the historical evolution of signal interpretation during wellhead inspection, the challenges of conventional inspection methods and outlines the algorithmic AI solutions developed and its benefits as a more consistent, accurate, and reliable framework for wellhead inspection.

HISTORICAL EVOLUTION OF SIGNAL INTERPRETATION IN WELLHEAD INSPECTION

Mechanical Recording (Paper and Ink Era): The earliest inspection systems displayed electromagnetic signals using mechanical recorders like seismographs[ii].

Signals were drawn in real time using ink on moving paper, producing a continuous graph of the inspection data.

Operators reviewed these printed traces and visually interpreted signal patterns to determine pipe conditions. The evaluation relied entirely on the operator’s experience and visual judgment.

Thermal Paper Chart Recorders: Later systems transitioned to thermal paper chart recorders, which improved reliability and reduced maintenance compared to ink-based systems.

Although the recording method changed, the process remained essentially the same:

- Signals were still represented as analog graphs on paper.

- Operators analyzed the curves and assigned defect values based on visual interpretation.

This stage continued to depend heavily on operator skill and subjective assessment.

Digital Acquisition and Laptop: With the advancement of electronics and computing, analog signals began to be digitized and displayed on computer screens.

Inspection data could now be viewed in real time on laptops or digital systems, allowing improved storage, visualization, and processing.

However, despite the technological improvement, the core interpretation process remained unchanged:

- A trained operator looked at the graph
- The operator assigned a value or classification based on visual interpretation.

Algorithm-Assisted Signal Interpretation “THE FUTURE”: New inspection technologies and powerful computing processors now allow the incorporation of advanced signal processing and algorithmic AI.

Instead of relying solely on visual interpretation, the system can:

- Analyze signals mathematically
- Detect patterns and anomalies
- Provide quantitative outputs that assist the operator

These tools do not replace the operator, but they augment decision-making, reducing subjectivity and improving repeatability in scan results.

WHAT IS ALGORITHMIC ARTIFICIAL INTELLIGENCE?[iii]

Algorithmic AI refers to systems driven by predefined, coded rules and mathematical instructions to process data, automate tasks, and make predictions. Algorithms act as a "recipe," using inputs to follow steps, learn patterns, and produce outputs.[iv]

OBJECTIVES OF ALGORITHMIC ARTIFICIAL INTELLIGENCE IN EMI TESTING

Wellhead inspections have encountered several obstacles and challenges over the years. These issues have led to inconsistent data interpretation with significant financial consequences, often resulting in unplanned reinterventions, production losses, and extra time spent on additional workovers.

To resolve these challenges, a systematic method was needed to minimize subjectivity and enhance data interpretation for more precise assessments. Algorithmic AI was applied to the interpretation of EMI outputs to produce the following objectives:

- Reduce dependency on subjective human interpretation during production pipe and rod scanning,
- To standardize inspection results and enhance reliability at the wellhead.
- Comply with API 5CT as close as possible and EMI regulatory requirements, adapting for field-specific challenges.
- Address operational variables such as uncontrolled pipe pulling speed and variable field conditions.

MAIN FUNCTIONALITIES OF THE ALGORITHMIC ARTIFICIAL INTELLIGENCE SOFTWARE

The AAI software studied is the first aftermarket software available that is compatible with standard Windows-based systems and existing EMI inspection platforms. It achieves its objectives by performing the following functions:

Real-Time Signal Processing and Filtering:

Advanced filtering algorithms eliminate environmental electromagnetic interference and operational noise, producing cleaner inspection data.

The system processes both Magnetic Flux Leakage (MFL) and Magnetic Flux Density (MFD) signals in real time during scanning operations. The algorithm incorporates built-in routines to regulate and filter these signals based on their interrelationship, ensuring that only consistent, valid data are evaluated.

Automated Classification:

Signals are automatically evaluated and classified according to established technical parameters and applicable inspection regulations. The system follows API and industry classification criteria, referencing baseline readings from a reference standard run at nominal values. Signals are rebalanced using known calibration factors or factors derived from acquired data to ensure consistent, standards-compliant results.

Enhanced Signal Amplitude Resolution:

The software allows for more accurate classification of tubulars and improves the detection of defects, even in areas that are typically challenging, such as near couplings. Once the system detects the standard signal associated with a coupling, it continuously evaluates incoming data and classifies signals up to the point where the coupling begins. When the coupling passes through the sensors, the software initiates a new classification process for the next joint, ensuring precise and reliable identification throughout the entire inspection sequence.

Generic graph showing the coupling pattern and point of reference identify by AI to start and end data evaluation.

Intelligent Defect Interpretation:

The system integrates advanced detailed presentations to assist operators in interpreting inspection signals. These algorithms reduce the likelihood of human error and help to standardize the classification of defects across inspections. By employing traditional signal presentation methods, the software ensures familiarity and ease of use for operators. In addition, it provides a secondary, detailed view that displays enhanced signal information. This detailed view includes rebalanced signals alongside interpretation results, equipping operators with valuable insights and supporting more informed decision-making during the inspection process.

<u>FIELD TEST</u>

The AAI studied was installed on three separate EMI Units from August 2025 through March 2026. Different operators with various levels of training and experience used the software on different units.

During the time frame studied the software was applied to the inspection of approximately 50,000 tubing joints, ranging in size from 2 3/8" to 4 1/2", under real wellhead operating conditions.

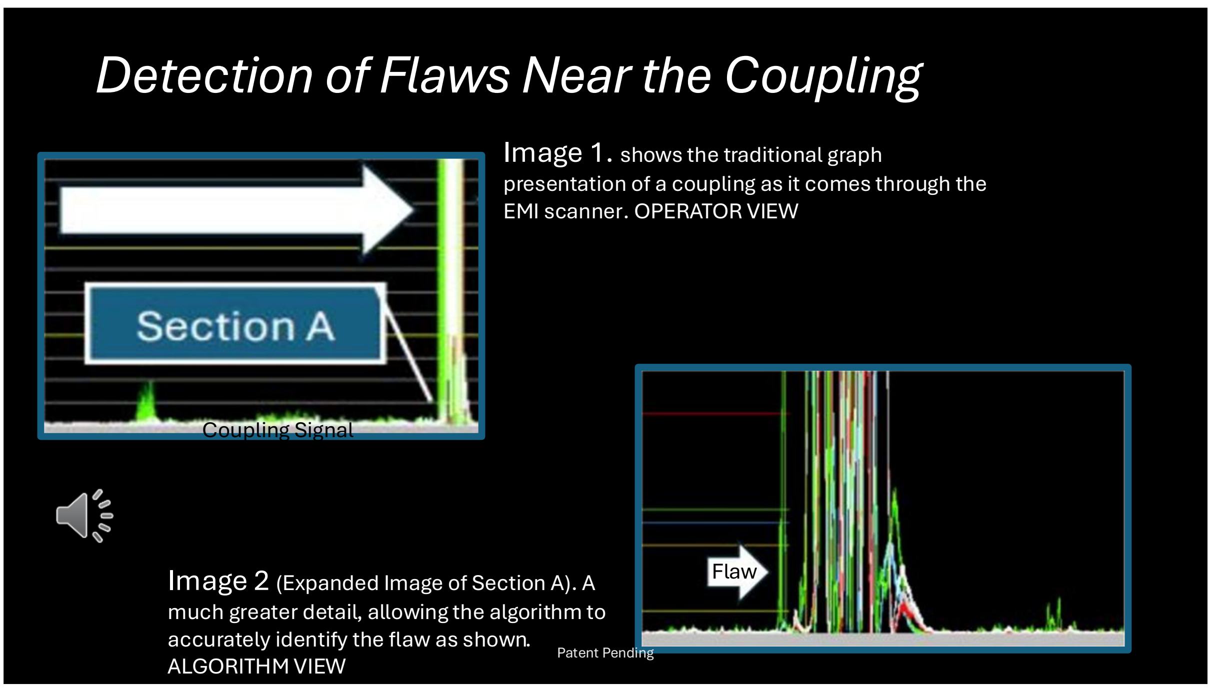
Field Test Results

The system processed inspection data from thousands of joints during routine workover operations, no errors attributable to the algorithm were detected during the testing period. Inspection outcomes showed strong consistency across operators with different levels of training and experience. Positive feedback from operators and service companies has resulted in increasing demand and broader industry interest.

<u>NOTABLE CASE STUDIES DURING TESTING</u>

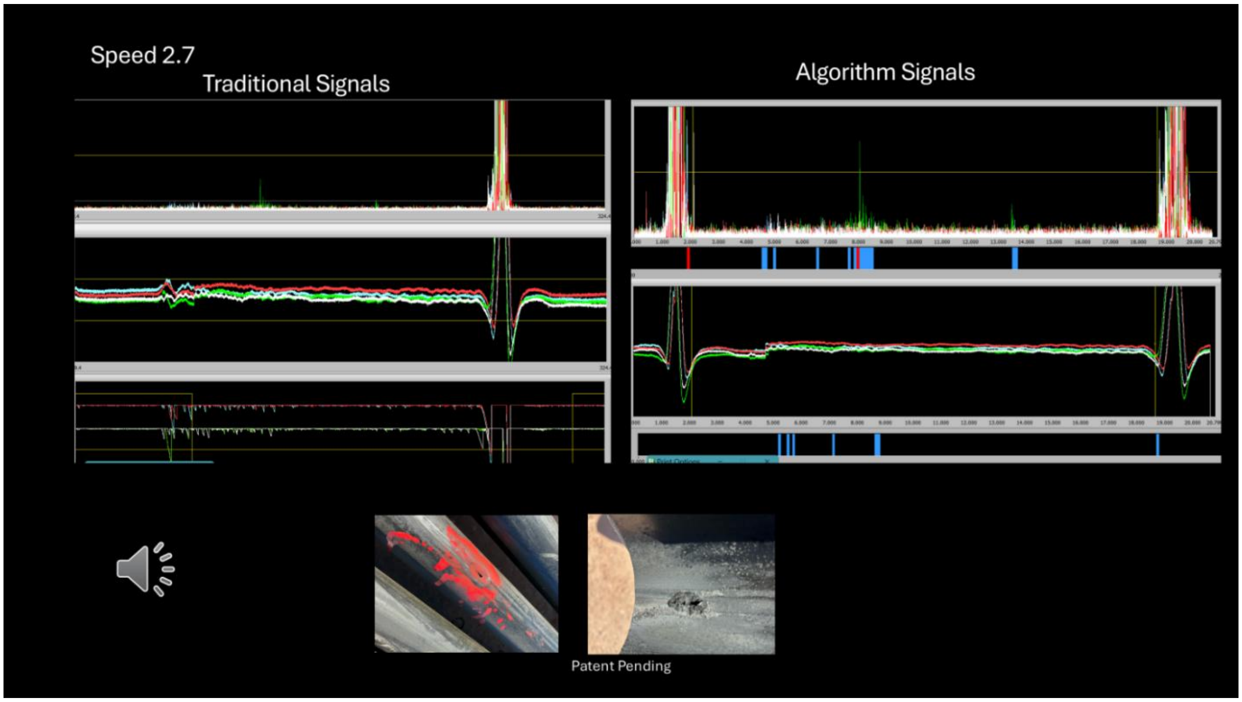
Case 1:

Traditionally while running the EMI Unit an operator would see the first graph as the pipe coupling moved through the EMI machine. Without the AAI the operator would not be able to distinguish the flaw from the coupling signals. In this case the algorithm was able to identify the flaw unable to be seen by the operator.



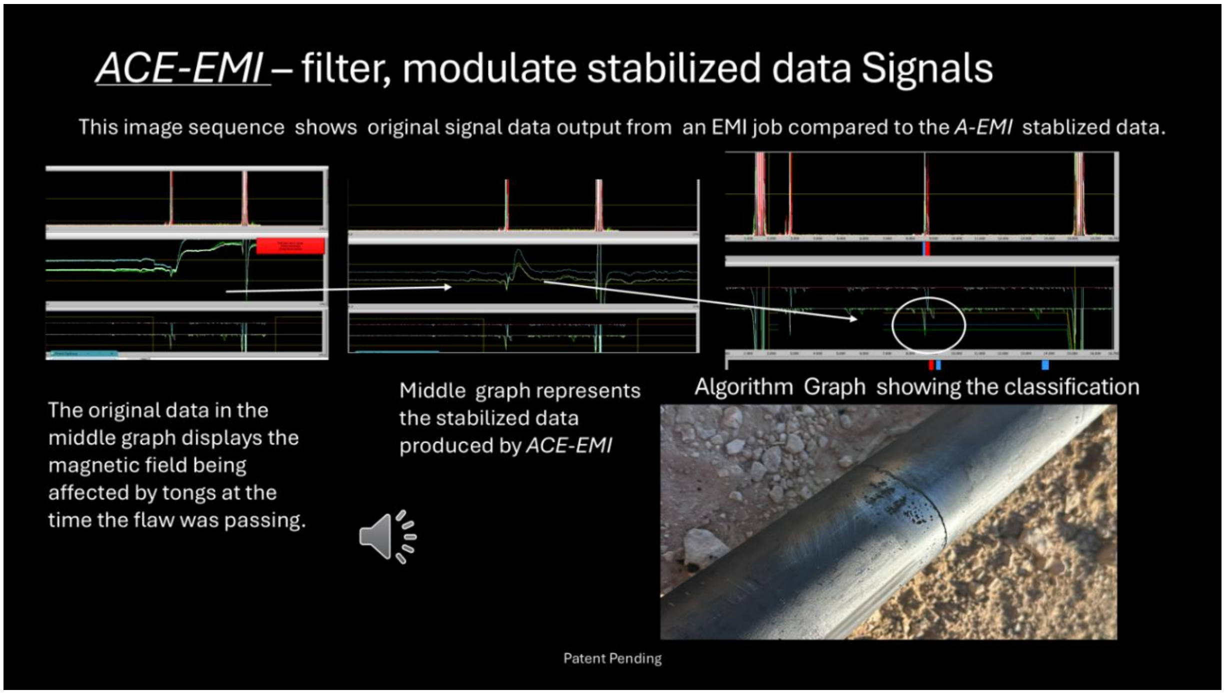
Case 2:

In this case, an operator was scanning a length of pipe through the EMI machine with external pitting which would not be visible on traditional operating software. However, due to enhanced signal amplitude resolution the AAI was able to catch the flaw that the operator would have missed.



Case 3:

In this case there was tong interference happening at the same time flaw was passing thru the unit. Using real time signal processing and filtering the software was able to identify the flaw and filter the interference.



CONCLUSION

Wellhead inspections have long faced challenges including signal noise, environmental interference, and variability in operator expertise. These factors often lead to inconsistent data interpretation and reduced reliability in defect detection.

Historically, these limitations have carried significant operational and economic consequences, including unplanned reinterventions, production losses, and additional time required for repeated workover operations.

Addressing these challenges requires a systematic approach that minimizes subjectivity and improves the quality and consistency of inspection data.

The AAI Software introduces a more efficient and reliable method for EMI scanning by integrating intelligent signal analysis and automated processing. The system assists operators by:

- Automatically balancing scanner sensitivity to adapt to changing field conditions
- Reducing dependency on extensive operator training
- Improving detection accuracy, including defects located near couplings
- Standardizing signal interpretation through mathematical analysis

By enhancing inspection consistency while maintaining operator oversight, this innovation significantly improves operational efficiency and reduces the risk of costly inspection errors.

As more operators and service companies recognize the value of intelligent inspection tools, broader adoption is expected across workover operations.

"The future of wellhead inspection is not replacing the operator but empowering the operator with intelligent tools that deliver consistent, reliable, and data-driven decisions."

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[i] https://share.google/WMseiq8fNwbzqrYlF
[ii] https://patents.google.com/patent/US20090243604A1/en

[iv] https://www.tableau.com/data-insights/ai/algorithms