IDEA

Innovations Deserving Exploratory Analysis Programs

NCHRP IDEA Program

TESTING OF IN-SERVICE BRIDGES USING AUTOMATED ULTRASONIC TESTING METHODS

Final Report for
NCHRP IDEA Project 191

Prepared by:
Shane Boone
Bridge Diagnostics, Inc.
Jeffrey Cohen
Bridge Diagnostics, Inc.
Phil Sauser
US Army Corps of Engineers

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IDEA Programs
Transportation Research Board
500 Fifth Street, NW
Washington, DC 20001

TESTING OF IN-SERVICE BRIDGES USING AUTOMATED ULTRASONIC TESTING METHODS

Stage 1 Final Report

NCHRP-IDEA Project 191

Prepared for the IDEA Program

Transportation Research Board

The National Academies

Shane D. Boone, Ph.D.

Bridge Diagnostics, Inc.

Jeffrey A. Cohen

Bridge Diagnostics, Inc.

Phil Sauser, P.E.

US Army Corps of Engineers

May 8, 2019

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EXECUTIVE SUMMARY

This goal of this project was to develop a prototype automated ultrasonic testing (AUT) system for detecting weld defects (flaws) in steel bridge members. Identifying the location, size, and extent of weld defects can be critical for ensuring bridge safety. Current bridge inspection practice relies primarily on visual inspection for detecting cracks but is not capable of detecting subsurface weld defects that may develop into crack under service loading. Other technologies such as conventional ultrasonic testing (UT) and radiographic testing (RT) can detect subsurface flaws, but are used primarily during the bridge fabrication process because the technologies are difficult to apply to in-service bridges. For RT, the geometry of in-service welds often preclude the proper alignment of the source and film, and required safety precautions for RT can limit practical application. For UT, the method requires a high level of expertise to implement and results can have uncertain resolution and accuracy because the method relies on an inspector's ability to effectively scan critical areas manually and interpret relevant indications.

The present study sought to investigate the effectiveness of AUT to improve the resolution, accuracy, and reliability of inspections. AUT systems are typically composed of an ultrasonic transducer coupled with some kind of electronically-driven positioning vehicle for moving the transducer in a controlled and trackable manner. In this way the position and orientation of the transducer is controlled, such that scanning critical areas is ensured and test repeatability is increased. AUT systems may employ conventional ultrasonic transducers or phased array transducers. Phased Array Ultrasonic Testing (PAUT) methods can produce better defined and quantified defect indications as compared with conventional UT because of its beam-steering capabilities. AUT is used as an established and proven technology in defense, nuclear, and pressure vessel applications, but has yet to be fully employed on steel bridges.

The primary objective of this project was to research and develop the mechanical and electrical equipment needed for an AUT system that could be applied for in-service bridge inspection. An industry scan of available scanning sensor architectures, data acquisition hardware, and analysis software was completed to inform the selection and design of the final inspection system. Based on this industry scan, a cost-effective prototype system based on a low-cost ($500) X-Y plotting printer system, with its inherent precision movement and programmable software, was developed. Figure 1 shows that AUT system developed through the research and illustrates the deployment of the technology for bench-top (lab) testing and for field testing. Preliminary testing was completed using the AUT prototype on a steel plate to make initial refinements to the coupling apparatus used to ensure contact between the UT probe and test surface.

Laboratory specimens consisting of steel weld mock-ups with manufactured defects were also fabricated. These specimens were fabricated to conform to the American Welding Society (AWS) terminology, joint

configuration, welding, and ultrasonic testing flaw classification. ASNT III inspectors were selected by an expert technical panel in partnership with the U.S. Army Corps of Engineers (USACE) to perform baseline manual UT inspections with traditional ultrasonic technologies and evaluate results produced by the prototype system. Specific procedures were developed and field tests were conducted on the selected bridge to test and demonstrate the prototype system. The field demonstration of the AUT system was completed under the supervision of an ASNT III inspector who confirmed the quality of the data being generated by the AUT prototype system were consistent with the results of the qualified inspector.

Based on the comparative results and procedures between the AUT system and qualified inspectors, the AUT system showed promise for effective deployment in providing initial survey results of a weld integrity on a bridge in lab or fabrication shop settings, allowing more informed and time-efficient selection of where expert inspectors should perform more detailed scans. In addition, the AUT system was found to be well-suited for use with PAUT probes as the need for a consistent linear probe path for successful testing is met by the fixed rails used by the AUT system. Field testing of the prototype AUT system demonstrated the feasibility of deploying the AUT technology in the field to collect data. It was found that the quality of data collected by the AUT technology was consistent with quality of data that would be gathered by an ASNT Level III UT inspector. Future systems will need to accommodate a greater variety of bridge configurations and allow for faster installation to be adopted for inspection of in-service bridges.

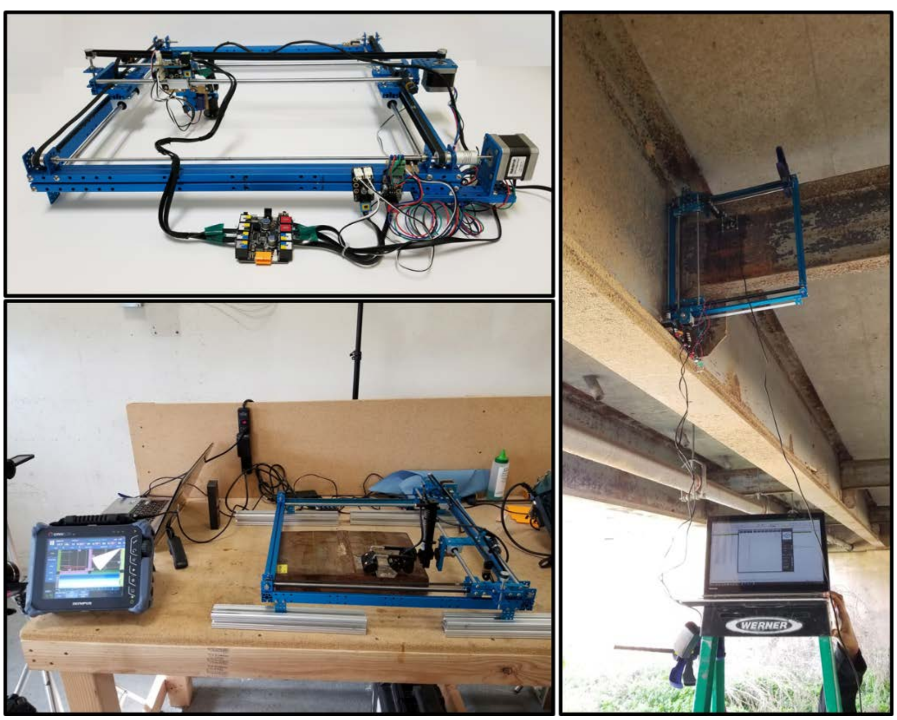


FIGURE 1 AUT System – Prototype (top-left), Lab Testing (bottom-left), Field Testing (right)

IDEA PRODUCT

This goal of this project was to develop a prototype automated ultrasonic testing (AUT) system for inspecting welds in steel bridges, and to and demonstrate the feasibility of such a system for producing results with quality consistent with an expert ultrasonic testing (UT) inspector. AUT systems are typically composed of an ultrasonic transducer and associated data acquisition unit that controls the sensor function and data collection, combined with some kind of electronically-driven positioning vehicle for moving the sensor probe in a controlled and trackable manner (*1*). The transducers used may be conventional UT angle probes, through-thickness probes, or phase-array probes for more advanced testing approaches. Through the electronic scanning control, automated test routines can be implemented to ensure repeatability while re-creating the same motion and pathing that an expert operator would use for a manual inspection. In this way, scans can be replicated and compared with previous scans, and the area interrogated using ultrasonic waves can be ensured. The performance goal of this project was to place into production a tool that efficiently produces consistent and accurate testing results. Engineers and managers can use the results produced to assess the portion of an agency's bridge inventory with susceptibly to cracking and fracture, namely welded steel bridges. The technology is applicable to both fabrication of new steel bridges and the evaluation of existing, in-service bridges.

Current bridge inspection practice is to use conventional testing methods like UT or radiographic testing (RT), or visually monitor a known defect through special inspections. Without knowing the true extent of a defect, conservative estimates must be made in analyzing the severity of a defect and the potential for crack initiation. These assumptions can lead to premature or unnecessary repairs or bridge replacements. Using innovative AUT methods defects can be more accurately characterized and quantified as compared with conventional UT using manual scanning procedures. Detection of cracking in steel bridge members is very sensitive to size and orientation of a defect, with planar cracks often being difficult to detect with RT despite its effectiveness for detecting volumetric defects such as porosity, slag inclusions, or lack of penetration defects. Though conventional UT can measure cracks of all types, the inspections require highly-trained operators and tend not to produce documented results suitable for future review and tests of repeatability (2). With AUT harnessing the ability to programmatically replicate the scan path of an expert operator in a repeatable fashion, an evaluation can be performed with a much higher degree of accuracy. This level of accuracy provides greater reliability of results and much less uncertainty in the potential that a defect will grow into a crack. Higher reliability leads to greater safety by differentiating those defects that may develop into cracks, thereby requiring monitoring or repair, from defects with low potential to initiate cracking. With this knowledge, engineers and managers can identify repair priorities and direct resources where they can be used most effectively (3).

CONCEPT AND INNOVATION

As the nation's bridge inventory deteriorates and structural performance conditions worsen, agencies must increasingly make difficult decisions on allocation of limited resources to maintain a safe and functioning inventory (*1*). This project aimed to assist these agencies in making more informed decisions regarding the repair and retrofit of steel bridges and to support the timely prioritization of needs. The efficient and reliable detection and characterization of weld defects and fatigue cracking is needed for agencies to effectively evaluate the impact of these defects on the performance of bridge members. The present study sought to address this need by applying AUT methods that can provide superior detection capabilities when compared to conventional testing methods. AUT approaches can produce results that have greater accuracy, precision, and repeatability for the locating, sizing, and characterizing defects to allow more refined and accurate structural analyses.

Current standards for conventional UT are workmanship standards intended to produce a certain quality level during the fabrication of steel bridges. In-service bridges may have defects that produce UT indications which do not meet the current fabrication standards, either due to as-built conditions or damage induced in service. Utilizing the current fabrication standards to analyze the severity of a defect in terms of structural integrity can lead to unnecessary and expensive repairs or retrofits, or premature replacements, because these standards were not developed with consideration of in-service performance. Therefore, existing structures may benefit from additional analysis that considers in-service performance qualities such as a Fitness-for-Service (FFS) analysis. A FFS analysis employs advanced analytical techniques including fracture mechanics to assess the effect of damage such as weld defects or cracking on the structural integrity of an in-service, damaged bridge member. To complete an FFS analysis, more accurate and detailed characterization of a defect is needed and therefore more advanced testing methods such as AUT are vital (*3*). The results from these analyses can enable agencies to make more informed decisions when managing their assets.

AUT methods have been successfully used in the nuclear, marine, pressure vessel, and piping industries. Multiple studies have been completed that indicate the greater reliability, repeatability, safety, and affordability of AUT over conventional UT and RT, including inspections completed by the US Navy and nuclear power plants(*4*). The piping and pressure vessel industries use AUT in lieu of RT and conventional ultrasonic testing (UT) to size discontinuities in weld joints and to determine whether repairs are required. The guidelines and methodology for such testing are outlined in the American Society of Mechanical Engineers (ASME) Code for Boilers & Pressure Vessels (*5*). The American Society for Testing and Materials maintains a similar standard for the use of AUT in evaluating girth welds on pipes (6,*7*). The international inspection community has also adopted guidelines for the deployment of AUT for the inspection of welded joints as a replacement for conventional UT (*8*,*9*,*10*). Finally, an earlier study by FHWA was completed in 2004 to evaluate the feasibility of an AUT using a conventional UT transducer, finding that the such a system out-performed conventional UT and worked as well as RT at a better cost efficiency and safety standard (*1*).

Building on that study, the present work took advantage of the relatively recent addition of new guidelines to the American Welding Society (AWS) Bridge Welding Code (AWS section D1.5) in order to explore the novel deployment of phased-array ultrasonic testing (PAUT) in an AUT system for the inspection of bridge members (*11*). PAUT is an advanced method of ultrasonic testing that uses a transducer comprised of multiple sensor elements. The sensor elements are pulsed in a sequential manner to produce an ultrasonic beam that can be steered or focused within test specimens to improve sensitivity, which can result in more accurate results and increased probability of detection as compared to more conventional methods. The ability to electronically steer the ultrasonic wave lends itself to the overall AUT approach by providing an additional degree of control of the beam angle. In comparison, conventional UT uses a single monolithic transducer with various different angle wedges (e.g., 45, 60 and 70 degree wedges) to produce similar results. For conventional UT, multiple redundant passes across the weld are required to provide coverage across the different angles, whereas PAUT only requires a single pass with the beam steered electronically through the different angles. Conventional UT also requires the expert operator to manually determine the appropriate pathing and orientation of the probe as the data is being gathered, while the electronic sweep of PAUT simplifies the pathing to single, straight scan lines that require no real-time oversight to be executed (*12*).

INVESTIGATION

INDUSTRY SCAN

An industry scan of available sensor architectures, data acquisition hardware, and analysis software was completed to inform the selection and design of the final inspection system. Given the availability of commercial data acquisition systems and sensors for AUT in other industries, the initial test system considered would couple off-the-shelf equipment with a custom assembly for holding and positioning the sensors to meet the unique needs of the bridge inspection industry. An expert technical panel was assembled in partnership with the U.S. Army Corps of Engineers (USACE) to identify team members to perform the baseline manual inspections with traditional ultrasonic technologies as well as evaluate the feasibility of the selected AUT technologies. Several of the considered AUT technologies are presented in Figure 2, which shows a linear dual-probe scanner (left) and a single-probe track (right).

Based on a review of the industry, the high cost of commercially available scanner systems coupled with the necessity to still customize these systems to accommodate steel bridge members were identified as major challenges to using off-the-shelf or professional-grade systems for the present stage of work. The need for customization to these already robust scanner systems arises from their designed purposes in the inspection of steel pipelines and pressure vessels, rendering their motion and attachment mechanisms ineffective for use on the kinds of steel weld configurations observed on bridges. “Rover-style” scanners were also considered by the project team as an alternative to the “fixed-rail” scanners presented in Figure 2 as they would provide greater flexibility in terms of movement along a bridge as well as portability, but the expert technical panel advised that the magnetic encoders typically available for such scanners are unreliable.

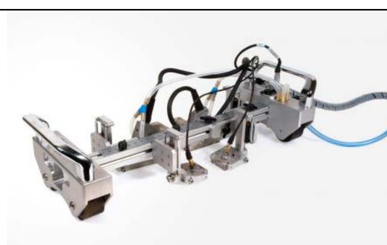
Olympus HSMT-Compact Scanner	**AUT Solutions Accutrak**
	

FIGURE 2 Examples of the AUT Scanners identified during the industry scan for potential use in this project

AUT PROTOTYPE CONSTRUCTION

Feedback from the expert technical panel led the project team to construct a prototype scanner system using an X-Y plotting printer system (Figure 3). With the cost of such technology having dropped significantly over the last decade, 3-D printing instrumentation meets the need for a device that emphasizes the precise and controlled movement of a sensor along a custom-programmed pathway. By replacing the printer head of such a system with the ultrasonic sensor of choice, the same programming interface and modalities can be used to automate the motion of that sensor in the course of scanning along its fixed rail system in two dimensions.

The Makeblock XY Plotter Robot Kit was selected for its extensible hardware and software capabilities. Figure 3 shows the prototype AUT scanner. The prototype system developed in this stage was maintained at its default 1’x1’ working area, however, the exterior frame and probe rails can be extended to varying sizes with relative ease to accommodate different inspection configurations. As identified in Figure 4, the plotter uses two steppers motors (one for each axis) in conjunction with a pulley and rail system to move a mounting platform within the working area of the prototype frame, allowing for a movement speed of up to 50mm/s. In addition, the system makes use of Makeblock’s Orion microcontroller board, which itself is based on the Arduino UNO microcontroller board. Such boards offer extensive yet technically accessible options for customization of system logic and control, particularly as they are open-source and thus do not have proprietary limitations to their documentation. This extensivity opens up the possibilities for introducing different motor and programming configurations when addressing different steel weld configurations.

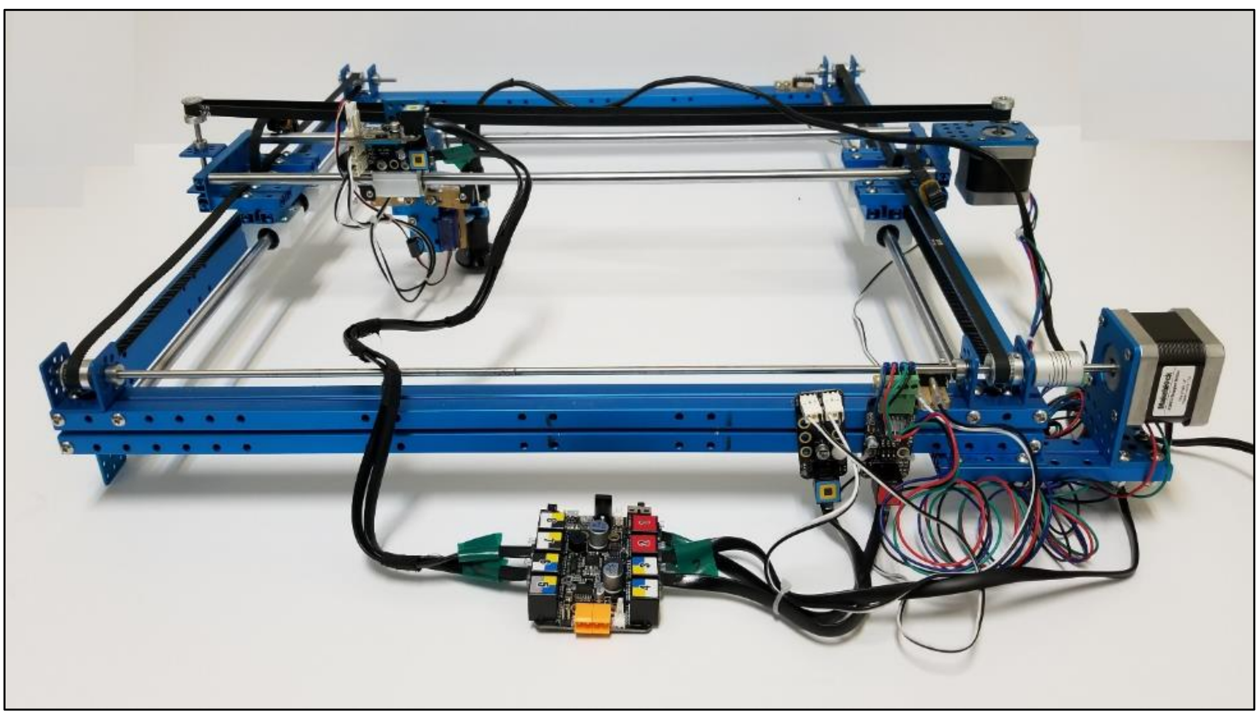


FIGURE 3 Selected prototype AUT System (based on Makeblock XY Plotter Robot Kit)

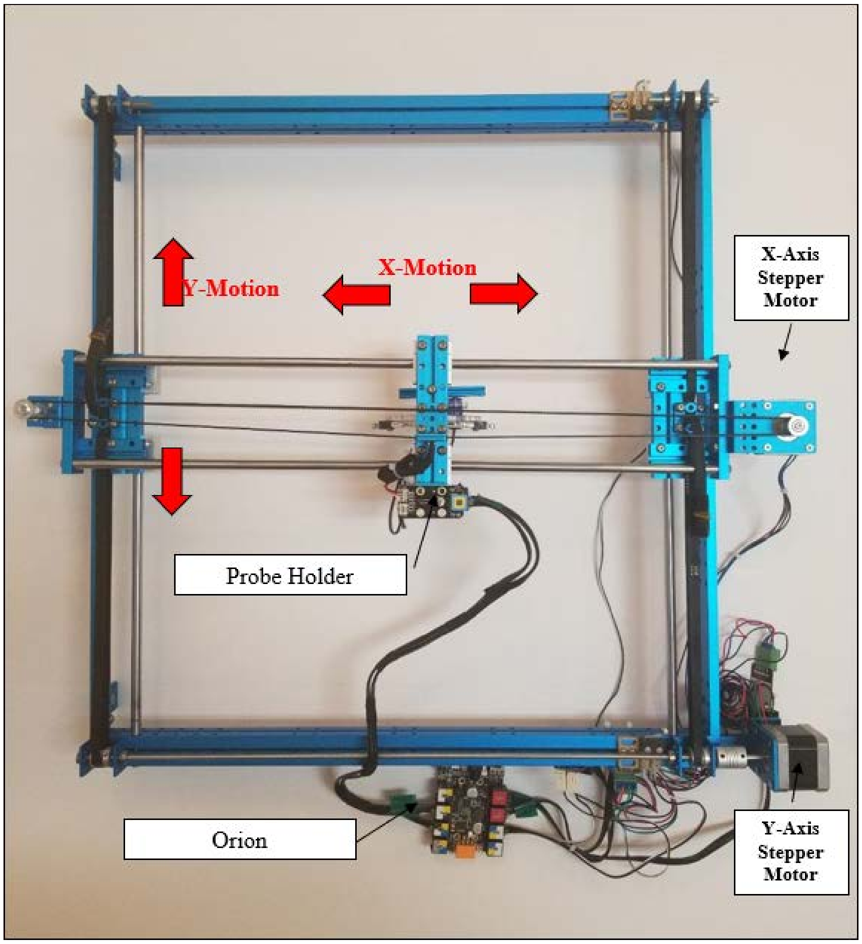
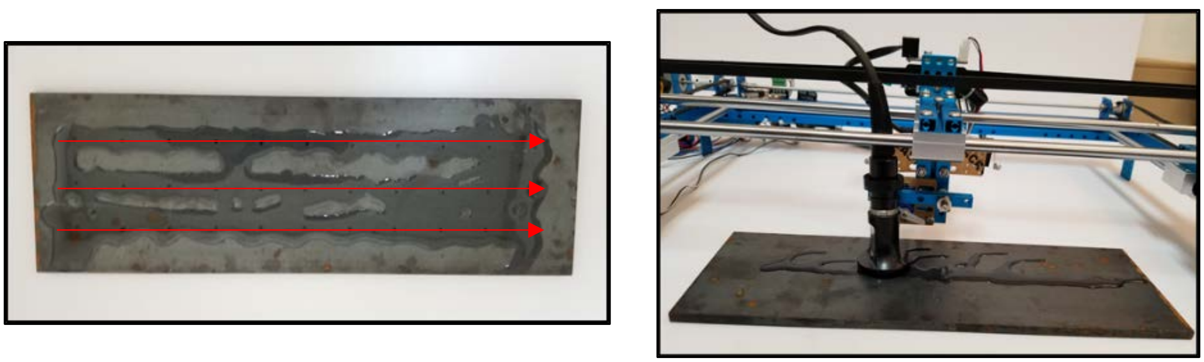


FIGURE 4 Diagram of prototype system components

On the software side, the Python-based mDraw program by Makeblock was identified to be a strong starting point for the project team's testing of the prototype system. The provided graphical user interface (GUI) allows for remote positioning of the probe within the allowable movement area of the prototype frame using the program's point-and-click functionality. In addition, exact coordinates can be entered individually or through scripting to move the probe with a precision 0.1mm. Finally, since the prototype system is based on an XY plotter, the software and instrumentation are able to take image files with predrawn path outlines on them and trace the probe along that outline, opening up the possibility for a UT inspector to draw out a custom path for their testing within the working area of the prototype.

To provide a baseline for the base system's functionality, preliminary testing with a conventional ultrasonic thickness gauge (Olympus Panametrics-NDT MG2-XT system using an Olympus Panametrics-NDT D790-SM 5MHz probe) was completed on a 12”x4” steel plate of 0.250” thickness. A grid of test points was laid out on the plate at 1” spacing in both directions with 1” offset from the plate edges for a total of three [3] scan lines with eleven [11] points each (Figure 5a). Glycerol-based ultrasonic couplant was applied to the plate at each test point prior to testing. Manual inspection of the plate's thickness at each point was completed by an operator to compare to the results of the prototype system, yielding a measured average plate thickness of 0.251” ± 0.001”. The plate was then placed into the working area of the prototype system to complete a remote controlled inspection of the plate (Figure 5b), yielding a measured average plate thickness of 0.278” ± 0.002”.



(a) (b)

FIGURE 5 Ultrasonic thickness testing of 0.25” thick steel plate (a) Steel plate with grid points and scan lines indicated (b) Probe on prototype system moving on steel plate with couplant

The poor agreement of the thickness measured using the prototype system with the known and manually-measured thickness suggested a need to re-evaluate the method by which the probe was held and kept in contact with a given test surface. This first attempt at deploying the prototype used a stiff connection with the mounting platform in conjunction with the weight of the probe itself to provide the kind of contact pressure produced by a manual operator pressing the transducer in contact with the surface. Based on the increased thickness measurements obtained, this approach was insufficient in replicating the coupling pressure of an operator. The increased thickness measurements obtained using the AUT prototype indicated that the coupling layer between the transducer and the surface of the steel plate was increased as a result of inadequate contact pressure. The resulting signal delay manifested as an increased thickness measurement. Therefore, it was necessary to increase the coupling pressure between the transducer and the plate in order to simulate the pressure produced by a manual operator.

Fortunately, the customizable nature of the prototype system's hardware allows for flexibility in the probe holder design and its mechanics using more static components for improved stability, springs for better pressure, or the introduction of additional motors controlled by the microcontroller board. This preliminary test emphasized the reality expressed by the expert technical panel that even though universal probe holders are available, it might still be necessary to have different jigs and adapters available for ensuring probes are maintaining consistent contact with a given surface. This recommendation came from similar observations made about the "rover-style" AUT scanners where mismatches of pipeline geometry with a given scanner could produce irregular or inaccurate results.

Two promising outcomes of this test came from the success of the precise movement of the instrumentation as well as the relative consistency of the measurements with the prototype. An operating method was developed during testing whereby the relative positioning of the system was set to use the grid origin as the system origin. In this way the offsets to each grid point could be easily entered with the system and this proved effective at precisely and quickly moving the probe to each point. Meanwhile, though the accuracy of the UT in measuring the plate thickness required adjustment to the probe holding mechanism, the relatively high precision and consistency of these measurements demonstrated viability of the overall approach as the data suggests (as presented in Figure 6) a need to resolve only the systematic source of error from the probe holder.

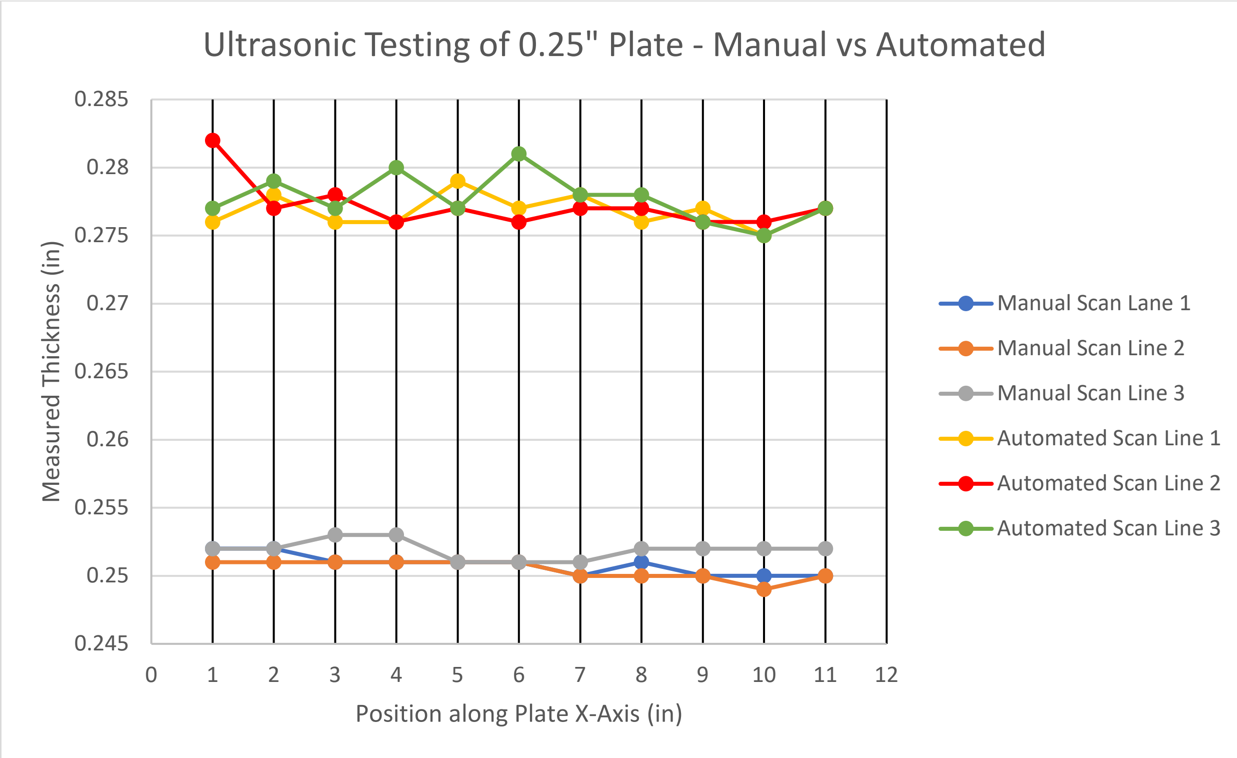


FIGURE 6 Results of ultrasonic thickness testing using manual inspection vs automated inspection

From these lessons, a compression spring was added to the probe holder assembly to maintain more consistent pressure between the probe and test surface. The modified assembly allows for the entire mounting frame to be lowered such that the spring is placed into compression when the probe is pressed into the test surface, then the frame is locked into position to maintain the spring force on the probe. This new assembly is presented in Figure 7 below.

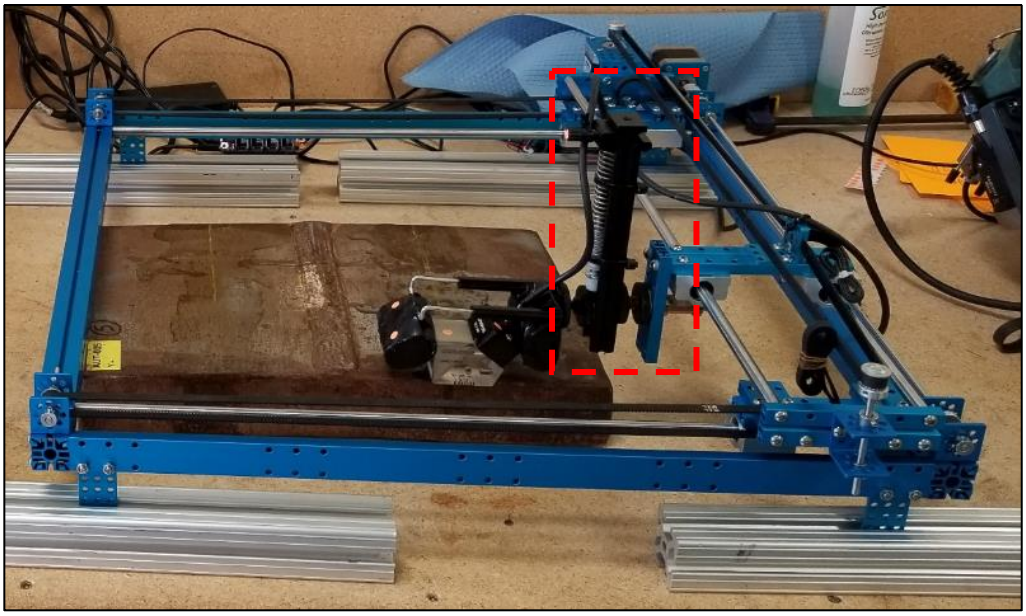


FIGURE 7 Improved prototype with spring-loaded probe holder (indicated in red)

The baseline test on the 0.250” plate was completed again using the modified prototype system with the spring-loaded probe holder. Automated inspection of the plate’s thickness with this new holder produced a measured average plate thickness of 0.252” ± 0.002” which placed it within the uncertainty bounds of the manual inspection measurement, indicating that the new holder resolved the pressure issue with the ultrasonic thickness gauge. For ease of viewing, the individual line scans for the three sets of tests (Manual, Automated with No Spring, and Automated with Spring) were averaged and plotted for visualization of the measurement consistency obtained as the probe moved over the plate, as presented in Figure 8.

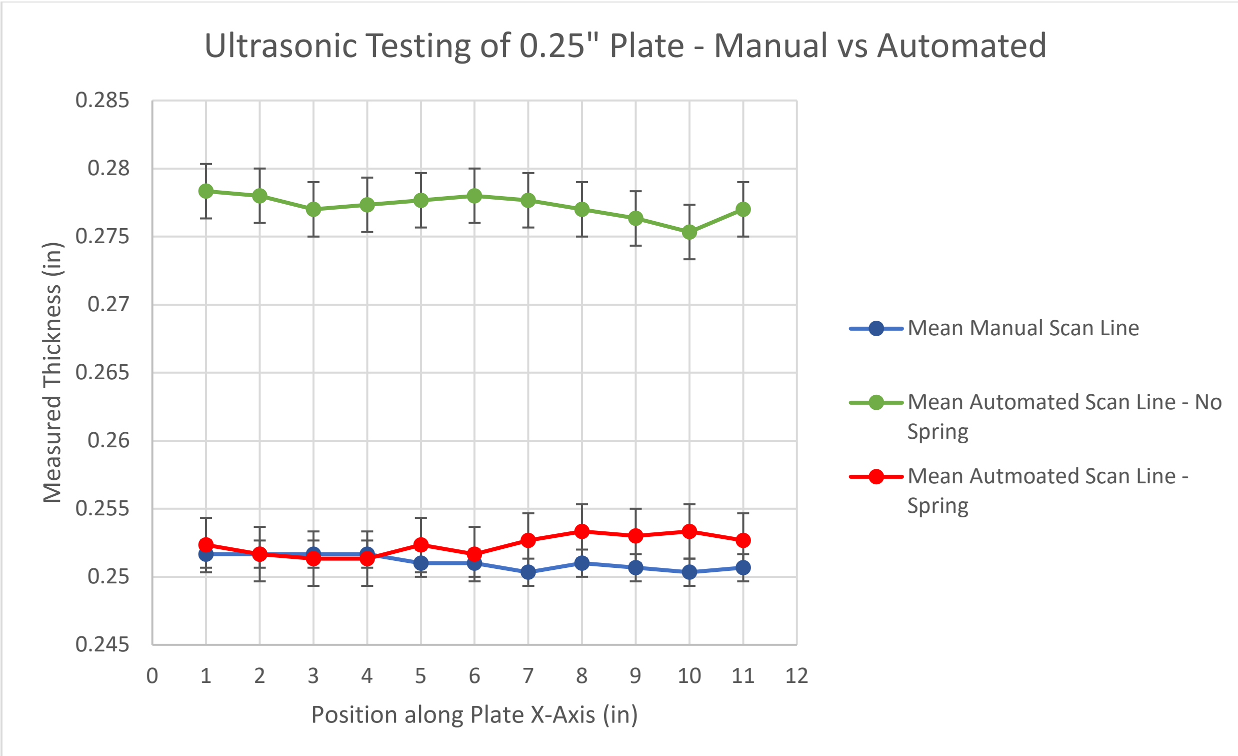


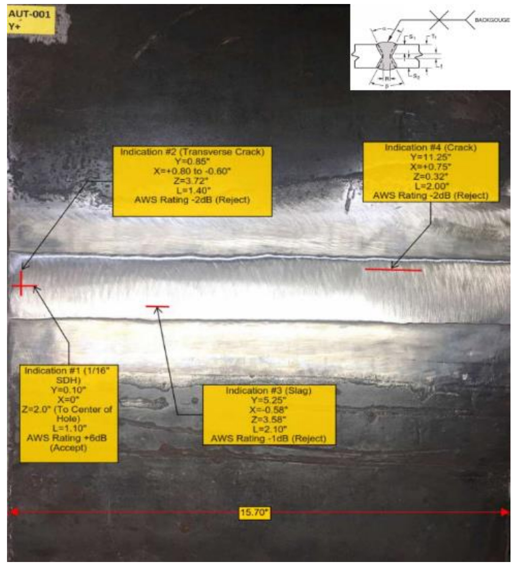
FIGURE 8 Results of ultrasonic thickness testing using manual inspection vs. automated inspection with and without the spring-loaded probe holder. Error bars were added to reflect the uncertainty in the averaged measurements across multiple scan lines.

Specimen Construction

Laboratory mock-ups were fabricated to conform to the American Welding Society (AWS) terminology, joint configuration, welding, and ultrasonic testing flaw classification. These mock-ups were produced with known void locations to simulate weld defects. The specimens were tested in order to help develop the encoder and scanning procedures needed to accurately identify, characterize, and quantify weld defects both in the laboratory and in the field. The specimen and their manufactured defects were categorized by the expert technical panel as being Easy, Moderate, or Difficult depending on how challenging the panel considered the specimen in terms of the weld configuration, number of flaws, and flaw location. Table 1 summarizes the metadata associated with each of the six [6] specimen constructed for this stage of testing, while Figures 9-14 present the configuration of each test specimen with their manufactured flaws indicated.

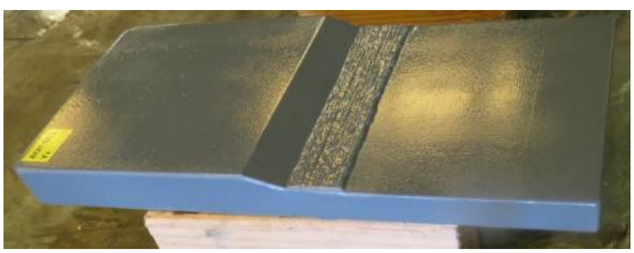
TABLE 1 Summary of Fabricated Steel Weld Mock-Ups

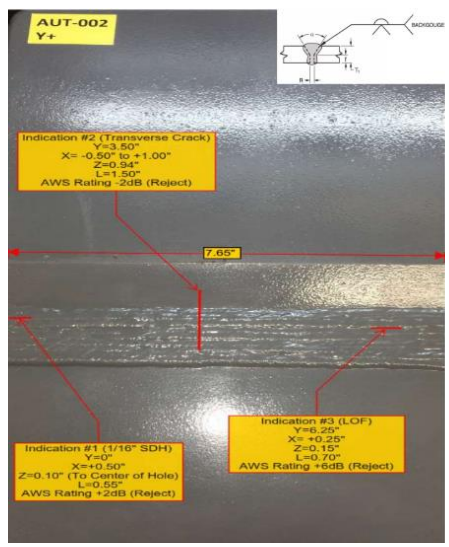
Sample	Steel Type	Thickness	Joint Type	Weld Length	Number of Flaws	Difficulty
AUT-001	A709-50	4.00"	Double V-Groove Weld	15.70"	4	Difficult
AUT-002	A709-50	1.00"/1.50"	Single V-Groove Weld	7.65"	3	Moderate
AUT-003	A709-50	1.50"	Double V-Groove Weld	7.50"	0	Easy
AUT-004	A709-50	0.62"	Single V-Groove Weld	14.00"	2	Easy
AUT-005	A709-50	2.00"	Double Bevel Groove Weld	9.00"	3	Difficult
AUT-006	A709-50	0.5"	Single V-Groove Weld	5.75"	2	Moderate



(a) Specimen Image **(b) Flaw Indications**

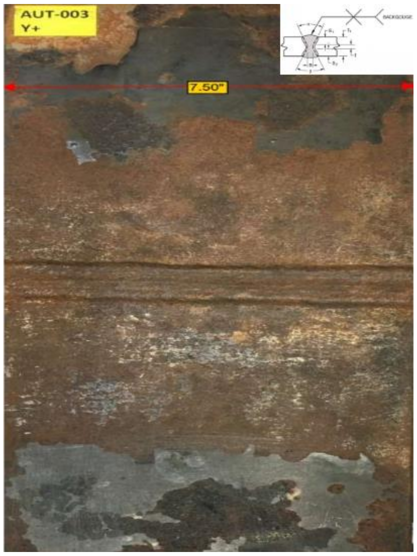
FIGURE 9 Specimen AUT-001 – (a) Image of the manufactured weld sample and (b) flaw overview





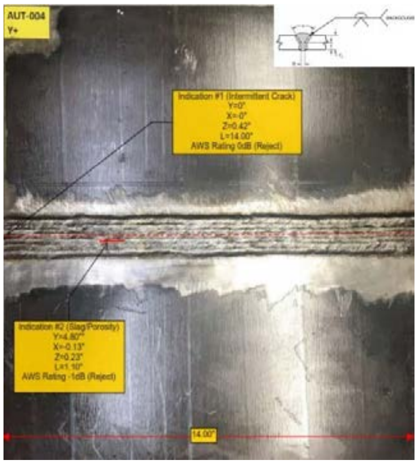
(a) Specimen Image **(b) Flaw Indications**

FIGURE 10 Specimen AUT-002 – (a) Image of the manufactured weld sample and (b) flaw overview



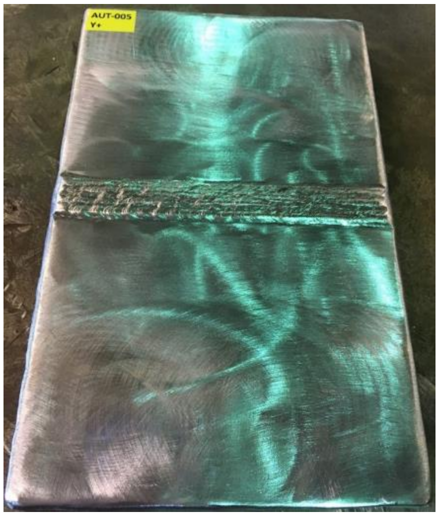
(a) Specimen Image (b) Flaw Indications

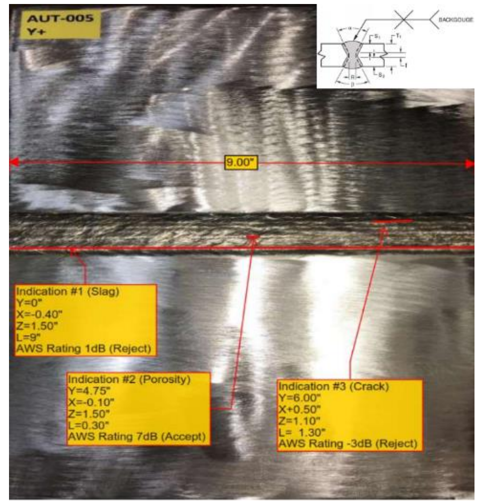
FIGURE 11 Specimen AUT-003 – (a) Image of the manufactured weld sample and (b) flaw overview



(a) Specimen Image (b) Flaw Indications

FIGURE 12 Specimen AUT-004 – (a) Image of the manufactured weld sample and (b) flaw overview





(a) Specimen Image **(b) Flaw Indications**

FIGURE 13 Specimen AUT-005 – (a) Image of the manufactured weld sample and (b) flaw overview

(a) Specimen Image **(b) Flaw Indications**

FIGURE 14 Specimen AUT-006 – (a) Image of the manufactured weld sample and (b) flaw overview

Specimen Testing – Inspection Overview

The expert technical panel put together a team of four [4] ASNT Level III UT technicians to complete testing on each of the six [6] fabricated weld specimens. Beyond following AWS and ASME standards in their data collection and analysis, the inspectors were instructed to use their own methodology and approaches to evaluating each of the weld specimens. The results reported by the inspectors were anonymized because the purpose of the present study was to capture data on several different approaches to determine which could be replicated by the AUT system, not to determine which inspector had the best approach. All of the inspectors used PAUT probes for their primary evaluation of the specimens, but conventional UT probes were used in some cases to gather comparison data with respect to the scanning path of the probe. Table 2 summarizes the different technologies and approaches used by each inspector.

TABLE 2 Summary of Inspector Technical Information

Inspector ID	ASNT Level	Probe Frequency	Probe Elements	Acquisition System	Encoder System
A	3	5MHz	64	Advanced OEM Solutions – FMC/TFM System	Wheel
B	3	2.25MHz	16	Olympus Omniscan MX2	String
C	3	5MHz	64	Olympus Omniscan MX2	String
D	3	2.25MHz	16	Olympus Omniscan SX	Wheel

During the inspection, the pathing, orientation, and approach of each inspector's probe was captured by cameras with time-stamps used to synchronize the video data during post-processing. Overhead cameras were used to capture lateral motion and rotation of the UT probes, side profile cameras were used to confirm such motion, and cameras fixed on the data acquisition systems were used to ensure motion capture was occurring in line with data collection. Figure 15 presents the overall test set-up where two data collection stations were prepared to allow two inspectors to complete their work in parallel, while Figure 16 presents an example of an inspector's work being captured by the three static camera angles used during the data collection.

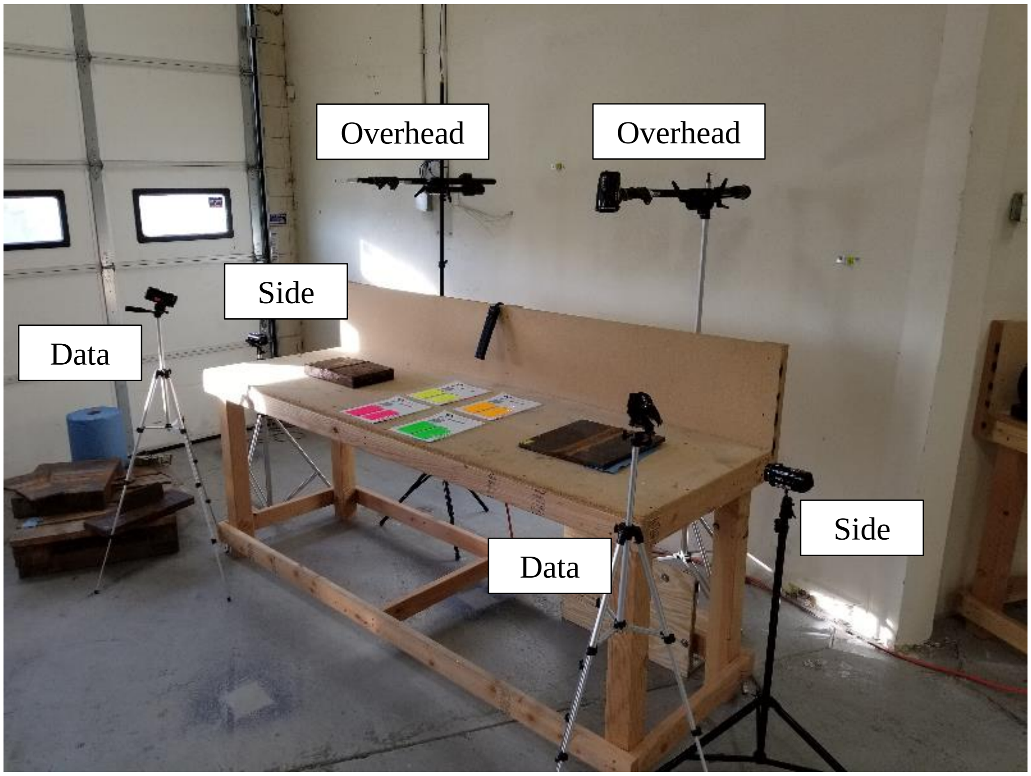


FIGURE 15 Set-Up for Specimen Testing – Overhead, Side, and Data cameras indicated

(a) **(b)** **(c)**

FIGURE 16 Example of video capture during inspection from the three camera angles (a) Overhead (b) Side Profile (c) Data Acquisition

Use of such recording devices served two key purposes in the AUT system development. The first purpose was informing the creation of a proper test protocols for calibrating and setting up the AUT system on a given test specimen. In addition to capturing video of the inspectors performing their scans on the specimens, the process of setting up the encoder and data acquisition systems was also collected from all three angles. This provided a unique perspective on some of the considerations needed to make the AUT system functional in the field. The steps of setting up reference points for the encoder wheel and entering field measurements could be added to the software developed for the AUT system to expand its usability.

The second purpose for motion capture data was to support automation of the analytical functions of the inspection. Specifically, these data can be used for the purpose of building a machine-learning algorithm into the UT data acquisition system that could provide a decision-making logic for moving the probe to best capture detected features in the data. This algorithm can be developed by relating the time-stamped positioning of an inspector's probe with the observed features on their data acquisition system with the goal of making the AUT scanner achieve similar decisions to the inspector when feature data is inputted.

To facilitate the analysis of the motion capture data, colored dots were added to the tops and sides of the UT probes in such a way as to not affect the data collection. The coloring on the dots allows for easy identification of the probe location by its pixels in the video data, allowing for the position to be extracted from each frame of the video data collected.

Specimen Testing – Data Collection

Data collection on the six [6] weld specimens was carried out on October 23rd-25th, 2018 in a round-robin manner at BDI Headquarters in Louisville, CO. Each inspector had a unique approach to setting up their encoder systems, adjusting their data acquisition system settings, applying their ultrasonic couplant, etc., providing a variety of possible approaches for use by the AUT system. Inspectors were given standardized notes packages for recording their findings to maintain comparability between their findings, but they were not provided any information on the number or types of flaws they would find in each sample.

One challenge identified by all inspectors at the beginning of testing was the presence of significant reinforcement on all of the welds, where reinforcement is any amount of welded material in excess of what is needed to fill a given joint. The inspectors indicated that the ideal condition for inspection was to work on welds that have been ground flush with the adjacent steel plate. The reinforcement added significant noise to their data collection, but the choice to leave this reinforcement was intentional. Given the high-level of expertise present in the inspection team, the expert technical panel wanted to simulate the worse possible conditions for weld inspection. The presence of weld reinforcement was identified as a relatively common confounding factor in testing due to the irrelevant indications (noise) commonly produced from irregular surface of the reinforcement. The objective was to identify how each inspector addressed the added noise.

In observing the inspectors develop and execute their scan plans, all of them followed a process of taking an initial survey scan across the entire weld length after completing their calibration procedure, evaluating the collected data in their data analysis software of choice, and returning to the specimen to more closely inspect any anomalies they identified in the analysis process. This approach of taking a relatively fast, low-precision survey scan ahead of taking slower, high-precision scans of select weld areas appeared to be the best balance of time management and fine-tuned measurement of the flaw dimensions.

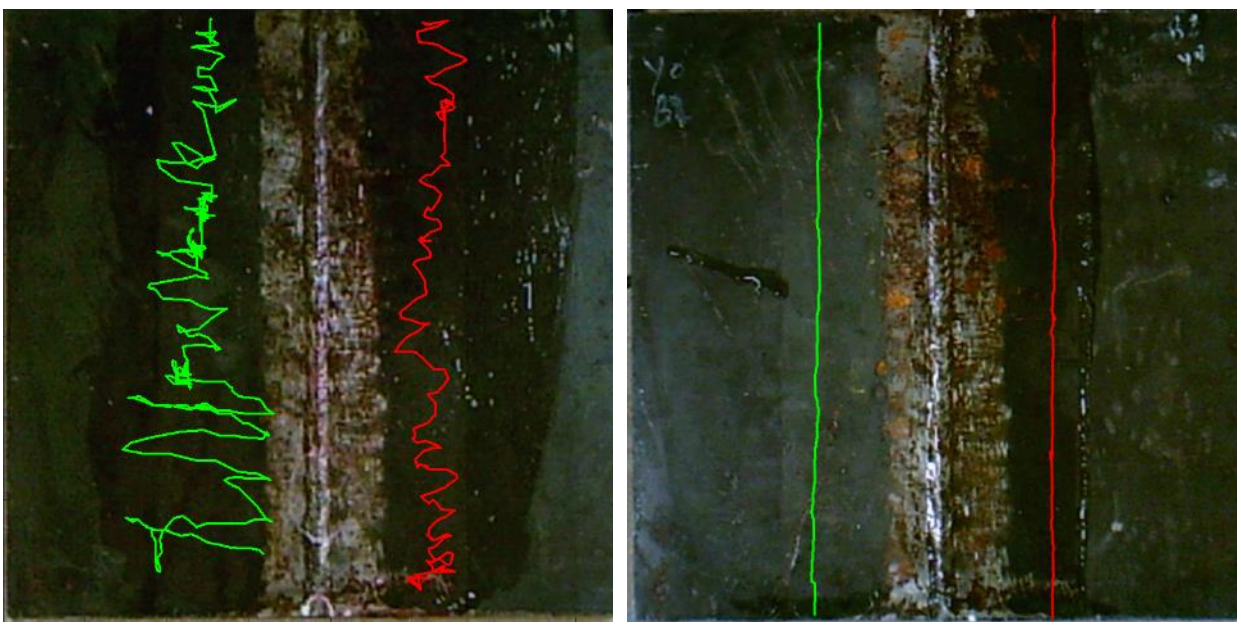
While all of the inspectors primarily used PAUT probes for their inspection, conventional UT probes were used on several samples to capture the motion data for comparison purposes between the two technologies. One unexpected observation made during the data collection with the PAUT probes came from the purely linear path of the scan plans. The strong beam control associated with PAUT was anticipated to minimize the need for rotating or rastering the probe to get good signal capture, but there was no need for any such motion. In fact, the only observed drawback was the significant set-up needed to ensure no deviation from the linear path as such deviations could result in poor signal capture. Meanwhile, the conventional UT probes required the considerable rotation and rastering process to generate results with full coverage of the weld.

In the case of sample AUT-001, the inspection team determined that the 4” thick plate was actually two 2” thick plates welded together, creating a discontinuity between the top-side and back-side of the full plate. It was noted by all of the inspectors that this kind of situation would be identified instantly by use of a conventional UT probe such that these probes should be used as initial survey instruments even where PAUT is deployed.

Although the majority of available time with the inspection team was spent on collecting as much motion capture data as possible while they completed their inspections, the prototype AUT system was deployed on AUT-004 and AUT-005 to compare the scan data it gathered while holding a PAUT probe against the scan data gathered by the inspectors. Positioning the AUT system to align the probe with the appropriate relative start position on the weld represented the only source of manual interference with the execution of a pre-programmed scan plan on the sample, which was otherwise completed without manual interference. The irregular geometry of the PAUT probes and wedges proved challenging in terms of maintaining consistent pressure on the specimens, even with the spring applying a strong compressive force. Several modifications were made to accommodate the probe geometry, with notes being gathered on how refine the adaptability of the probe holder looking forward.

Specimen Testing – Data Analysis

The inspection teams provided their initial findings on-site at the BDI headquarters. Following the on-site testing, the data collected was more fully analyzed by the research team. This included processing and evaluation of the video data captured during the testing. A combination of the time-stamps and observed similarities between the camera angles was used to synchronize all of the video data with edits being made to reduce the videos down to the most interesting features. Although some degree of motion capture was completed on the video data, particularly with respect to the convention UT probes, the strictly linear nature of the PAUT scan plans made such post-processing unnecessary with respect to application for the AUT system. For comparison of the two different scan plans, Figure 17 presents the captured scan path of a conventional UT probe moving on either side of a weld for a given specimen against the path of a PAUT probe from an overhead perspective.



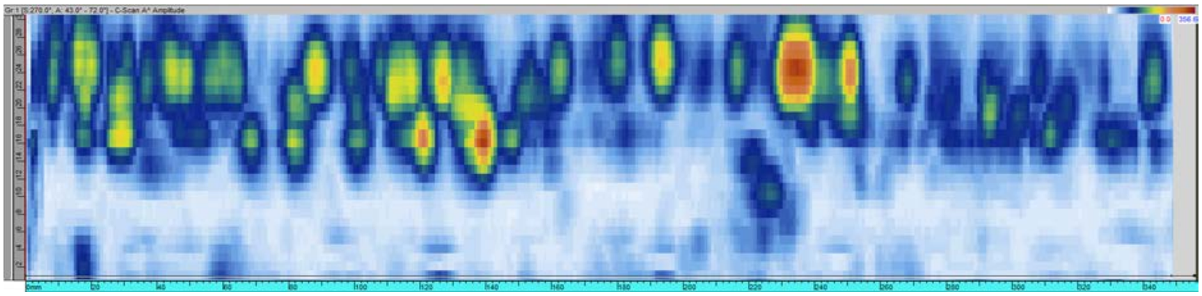
(a) (b)

FIGURE 17 Comparison of (a) conventional UT and (b) PAUT probe paths – scans from the left side are in green and scans from the right are in red.

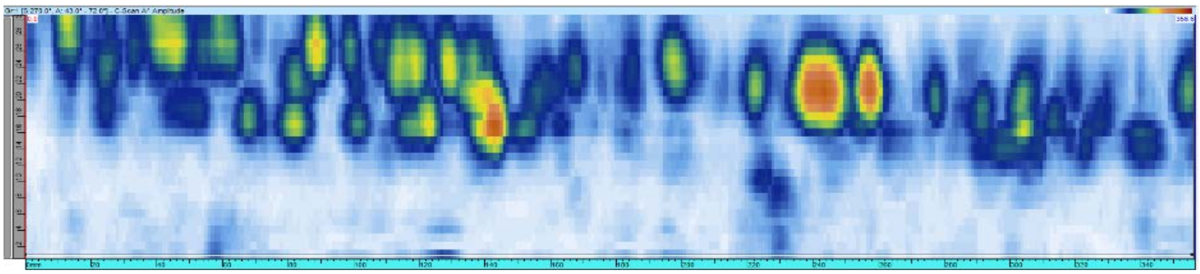
Specimen Testing – Results

The main purpose of the present study was to capture the scan plans and technique of the inspection team as well as demonstrate the feasibility of replicating their approaches using the AUT system. In the course of the team performing their investigation of the weld specimens, full specimen scans were captured such that the weld flaws could be mapped in post-processing. As noted during the data collection, significant noise was introduced by the weld reinforcement such the results were more likely to be prone to erroneous results.

The projection profiles gathered on specimens AUT-004 and AUT-005 using the AUT system were extracted for comparison with scans taken by an inspector using the same test set-up. These results are presented below in Figures 18-19. The results presented in Figure 18-19 demonstrate the significant similarity of measurements gathered by the inspector and AUT system with many of the same features being captured by both approaches. In Figure 18, the test sample under inspection (AUT-004) did not have a level test surface so where the operator was able to correct for this non-linearity, the AUT system's pathing went off-line and produced a more angled image. Meanwhile, the operator was able to perform filtering adjustments in real-time to minimize noise in their testing of the sample presented in Figure 19 (AUT-005), while the AUT system did not have the benefit of such adjustments.

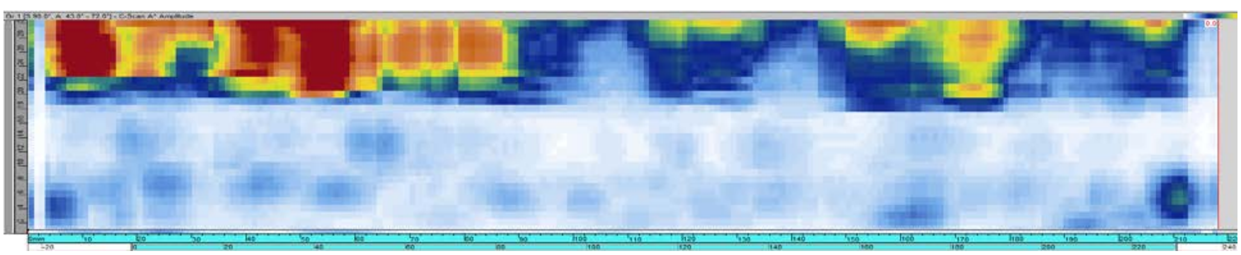


(a)

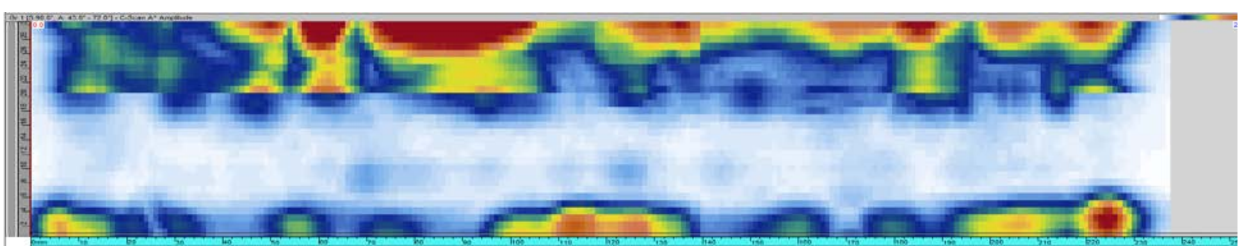


(b)

Figure 18. Raw Projection Results of AUT-004 Inspection by (a) Inspector (b) AUT System



(a)



(b)

Figure 19. Raw Projection Results of AUT-005 Inspection by (a) Inspector (b) AUT System

Field Testing – Demonstration

A field demonstration was completed to evaluate the system's ability to accommodate the geometry of a in-service welded bridge member. Given that the lab testing was completed on welds where the prototype system was oriented in its intended horizontal position, the decision was made to select welds on the bridge in vertical or overhead orientations to challenge the limitations of the instrument. A weld of each type was selected on the bridge. The vertically-oriented fillet weld connected a channel diaphragm to a bolted angle connection plate, as shown in Figure 20 (left). The weld in the overhead orientation connected a tapered cover plate to the bottom flange of a primary member, as shown in Figure 20 (right).

(a) **(b)**

Figure 20. Selected weld locations for field testing of AUT system (a) Selected Vertical Weld (b) Selected Overhead Weld

For this demonstration, an ASNT III UT inspector was on-site to operate the data acquisition system and PAUT probe. The inspector completed a manual inspection of each weld to provide a baseline for testing, with no defects being identified at either site. The inspector also developed a scan plan the AUT platform could replicate after the inspector completed their manual inspection. In the case of the vertical weld, the scanning was completed from the opposite side of the channel diaphragm to avoid interference from angle at the fillet weld. Multiple passes were needed to scan the welds in the overhead orientation due to the tapered geometry of the cover plate.

After the inspector completed their work, the AUT system was attached to each girder using temporary clamps with each weld being placed in the center of the system's rail perimeter. The height of the probe holder was adjusted to press the probe firmly against the steel, using the spring mechanism to maintain the pressure after the height was set. The top of the girder provided a convenient straight edge for aligning the probe holder with the vertically oriented weld. For the weld connecting the tapered cover plate, there was not a similar reference line, so careful adjustments were necessary in the attachment of the system to ensure proper alignment between the probe and the weld. In addition, the angled scans that the inspector was able to perform were not possible as there were no secure anchor points to properly clamp down the system to achieve ideal alignment. Overall, the attachment process took 5-10 minutes to ensure good stability of the system. Figure 21 presents pictures of the AUT system attached to the weld locations for testing.

(a) **(b)**

Figure 21. AUT system mounted in two configurations to accommodate different weld locations (a) Selected Vertical Weld (b) Selected Overhead Weld

During the AUT scanning of the vertically oriented weld, the scan was initiated with the probe at the top of the weld. The scan proceeded down the plate, enabled gravity to assist the AUT motors in moving the probe. It was found that the AUT motors had inadequate capacity to initiate a scan near the bottom of the weld and proceed upward. Regardless, the data collected during the scan was evaluated by the ASNT III inspector and it was found that the results were consistent with the results gathered during their manual scan.

Discussion

It was found during the round-robin testing that there was significant commonality in the approach taken by each of the inspectors in performing initial line scans using the PAUT probes. This common approach highlights a clear role for the AUT system in making inspection process more efficient and standardized, because the AUT system provides a more repeatable, mechanized line scan within a rigid frame that is inherently more consistent than manual scanning or establishing individual encoder paths. Therefore, the AUT system could fulfill an important role in standardizing these initial scans which are completed before more specific scan plans were applied to analyze indications detected (if any) during the initial scans. Considering the video data that confirmed the uniform application of straight-line scanning of the probe during these initial scans, the rail-based AUT system is well-suited to completing such initial scans with minimal user interaction.

Additionally, deploying the AUT system to perform initial straight-line scans would reduce the work-load of inspectors, since the line scans could be performed autonomously. In this way, the inspector could review the initial scan results and only become engaged on those joints where indications are found from the initial scans performed using the AUT system. In addition, already in-place AUT rails could be used for subsequent scans needed to analyze specific indications, eliminating the set-up of the encoder systems typically used by the inspectors. The inspector could manually move the probe using the system's rails as a guide, or they could also use the remote functionality of the robotic control program to move the probe into the proper positions.

It was also found during the round-robin testing that the weld reinforcement presented a significant challenge for reliably detecting and locating defect indications. While some features were successfully identified, certain manufactured defects were not located accurately as a result of the significant amount of noise introduced by the weld reinforcement. AUT-004 provided one of the greater challenges with a flaw going the entire length of the weld. The inspectors were able to identify parts of the flaw, but it's likely that the full-length flaw may have been conflated with the full-length weld reinforcement noise such that these two features were indistinguishable. Consequently, it was found that the weld reinforcement should be removed to ensure good UT performance.

The comparative results of the C-Scan gathered by the inspector and AUT system for AUT-004 and AUT-005 showed promise for the viability of the system to replicate human scan processes. In the case of AUT-004, many of the same indications appear to be aligned with one another, although it did appear that there was some skew between the AUT scan and the manual scan that may have resulted in somewhat weaker signal amplitudes. The misalignment of the scan lines demonstrates the need to develop appropriate procedures for aligning and securing the AUT system to ensure proper orientation of the probe.

For both the manual and AUT systems, the variation in amplitude may also be a function of the coupling pressure, because the irregular shape of the PAUT probe may have resulted in less-than-ideal contact with the test surface. This source may also have caused additional noise observed in the C-Scan for AUT-005 that is not present in the inspector C-Scan. The pressure issue was more significant for AUT-005 because the specimen was also warped in such way that the scans had to be completed at angle that the AUT system couldn't easily accommodate. These results indicated that further refinement of the probe holder may be needed to provide uniform and consistent coupling pressure.

In evaluating the use of the AUT system on an in-service bridge, some limitations of the prototype were identified to provide an important roadmap for future development. Control motors that move the UT probe must be sufficiently strong to allow for a variety of probe sizes and weights to be implemented. The motors must also support vertical scanning where gravity is acting against the driving force provided by the motor. In addition, the probe holder must have the ability to rotate and change elevation in order to move around corners or perform non-linear scan plans, such as may be needed for tapered cover plates.

Weld Inspection Results

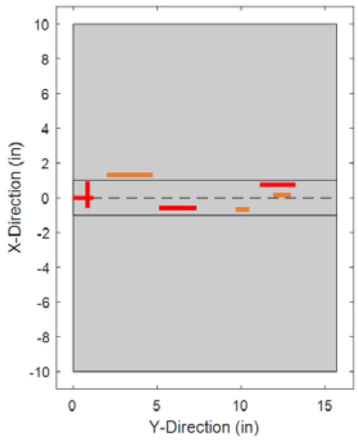
Indications identified by the inspection team in each of the test specimens are presented in Figures A1-A6. These mappings are provided as a reference for the work completed by the inspection team in evaluating the weld specimens using PAUT where weld reinforcement has not been removed, introducing significant noise into the measurement of results. Performing measurements on welds in such condition was completed for the purpose of determining the effectiveness of PAUT in non-ideal conditions with the presented results indicating that the reinforcement produces too much noise for effective PAUT deployment.

Table A1 provides a legend for the different colors being used to classify indications. During the de-briefing on the final day of testing, significant discussion focused on the the presence of unintended flaws in the weld specimens in addition to the known flaws introduced intentionally during the specimen fabrication. For this reason, it is important to distinguish between the different possible classifications for the results, using the following definitions:

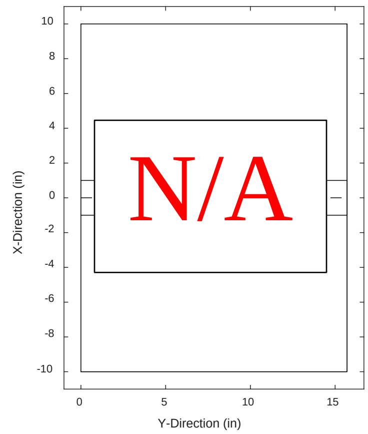
- True Positive – A weld flaw identified by an inspector correlates well with a weld flaw identified in the validation data
- True Negative – The absence of a weld flaw identified by an inspector correlates well with the absence of a weld flaw identified in the validation data
- False Positive – A weld flaw identified by an inspector does not correlate with a weld flaw identified in the validation data
- False Negative – The absence of a weld flaw identified by an inspector does not correlate with a weld flaw identified in the validation data

TABLE A1. Color code for indication classifications

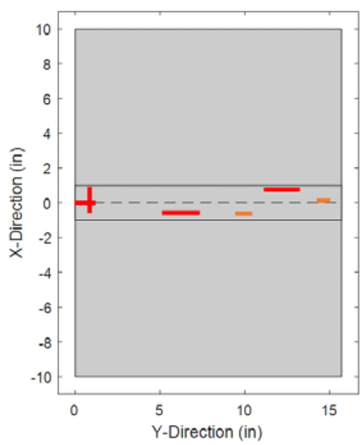
True Positive		**False Positive**	
True Negative		**False Negative**	



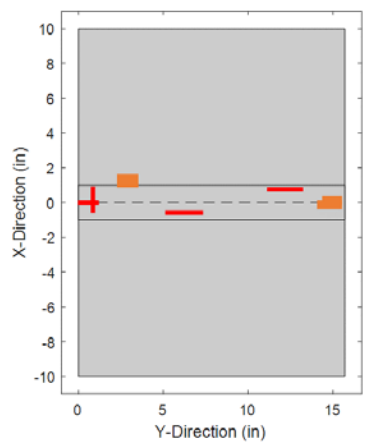
Inspector A



Inspector B

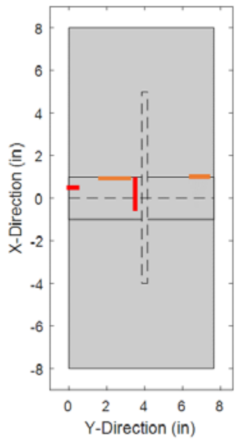


Inspector C

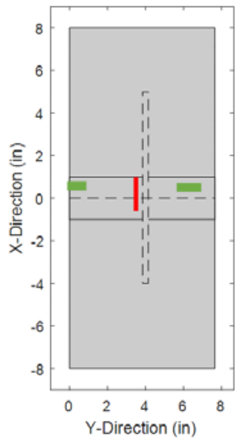


Inspector D

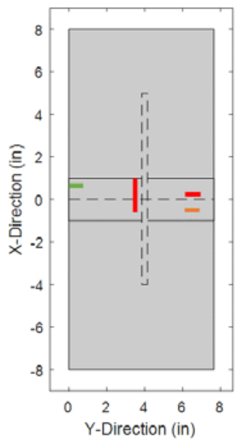
FIGURE A1. Results of AUT-001 Inspection



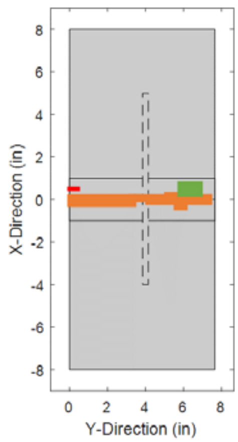
Inspector A



Inspector B

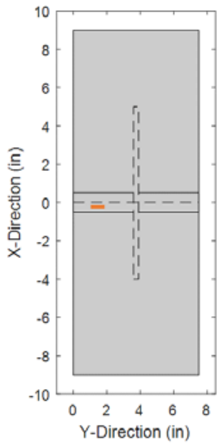


Inspector C

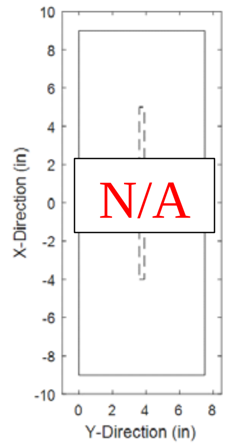


Inspector D

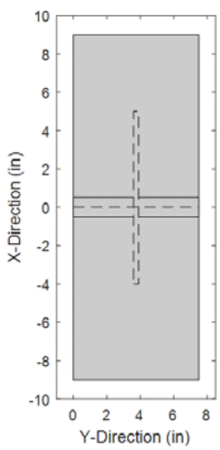
FIGURE A2. Results of AUT-002 Inspection



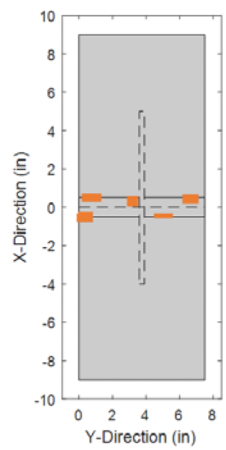
Inspector A



Inspector B

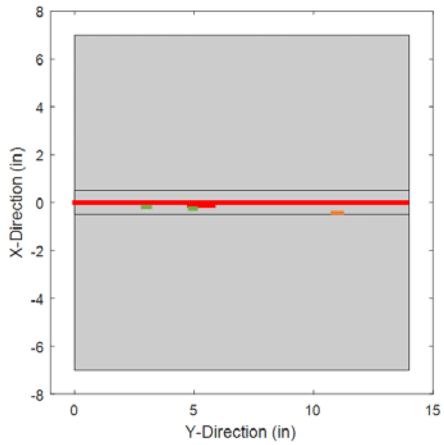


Inspector C

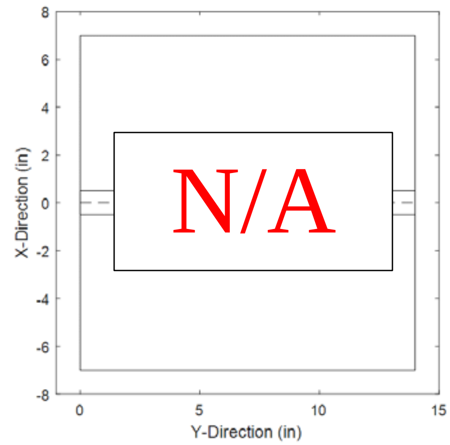


Inspector D

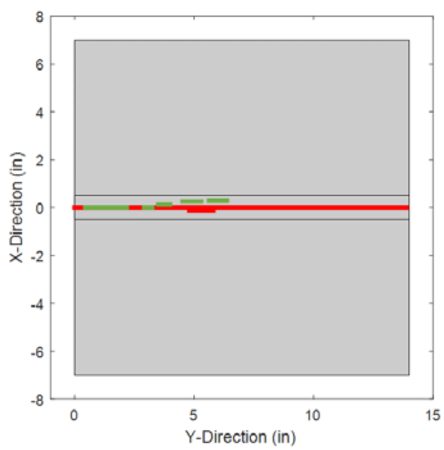
FIGURE A3. Results of AUT-003 Inspection



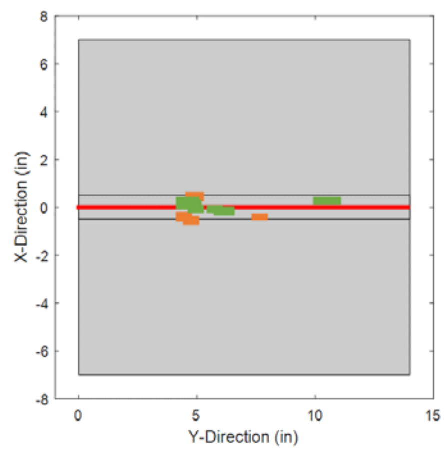
Inspector A



Inspector B

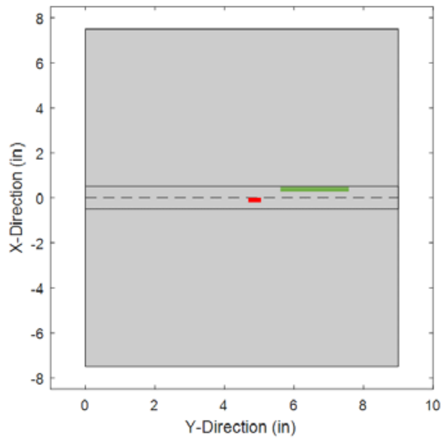


Inspector C

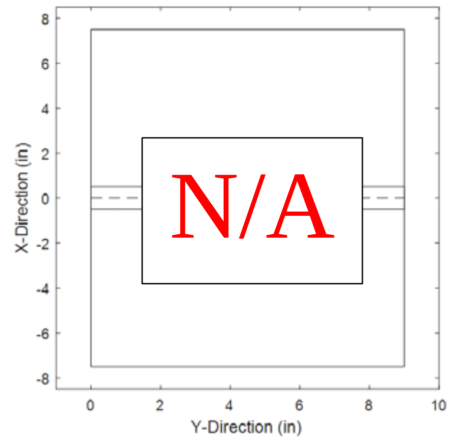


Inspector D

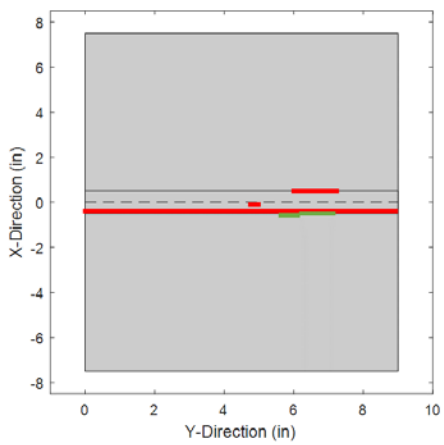
FIGURE A4. Results of AUT-004 Inspection



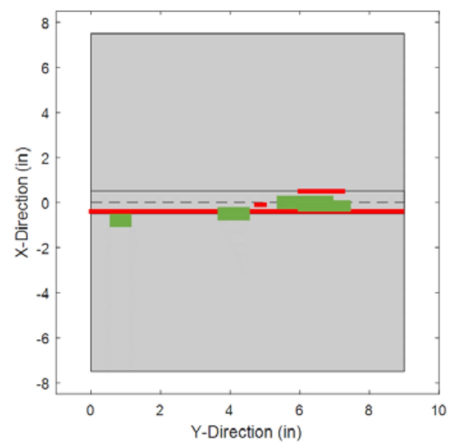
Inspector A



Inspector B

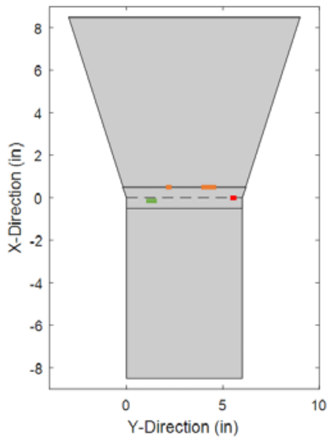


Inspector C

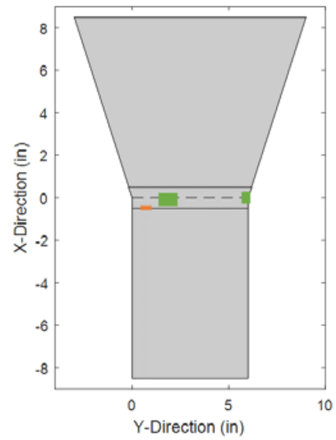


Inspector D

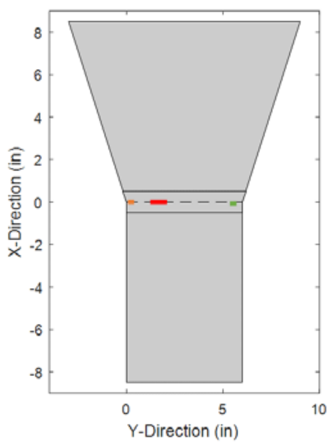
FIGURE A5. Results of AUT-005 Inspection



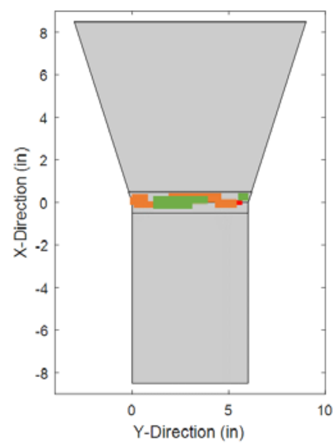
Inspector A



Inspector B



Inspector C



Inspector D

FIGURE A6. Results of AUT-006 Inspection

PLANS FOR IMPLEMENTATION

The prototype AUT instrument showed promise for producing results consistent with the output produced by expert operators performing a manual inspection in both the lab and field testing. Improvements to the prototype mounting hardware, frame geometry, and installation procedures are needed to support broader implementations in the field and future adoption by bridge owners. The mechanical parts and frame of the MakeBlock XY Plotter were selected on the basis of their modularity and ease of custom construction, which lend themselves better to adaptability for unique or variable conditions than currently available commercial scanners that are typically designed for specific testing geometry. In addition, where commercial systems were found to cost up to $50,000 during the industry scan, the prototype system for this project was built for a cost of $500 including supplemental components for field modification. Along this line, the AUT system evaluated in this project presents bridge owners with a tool that trades the robust and rugged design of single-geometry scanners for a more cost-effective adaptable platform.

Another challenge to field implementation relates to this project's particular use of PAUT as the primary inspection method. The computationally intensive nature of PAUT and its electronic scanning requires a data acquisition system, encoder, and probe set-up that have all been designed together and thoroughly tested to ensure quality of data. Where it might be possible to build a custom data acquisition system around conventional UT such that integration of the AUT system would be relatively trivial, integration of the AUT system with the more complex PAUT algorithms presents additional challenges. A partnership with one of the industry vendors identified in the industry review would likely be necessary to realize a commercially viable solution. This issue motivates the present high price point for AUT systems in the pressure vessel and piping industries, where connection geometries are typically less complex than those in bridges. It is likely that a system which could accommodate the varying connection geometries typical of in-service bridges would be even more cost prohibitive. However, the low-cost, modular approach of the prototype system in the present study could keep such overhead low on the instrumentation side, even if the integration between instrumentation and data acquisition would require more investment.

Despite the unlikelihood of adoption of AUT systems in the in-service bridge inspection industry, the prototype benchtop system would be appropriate for fabrication shop applications where the standardization of the welds would reduce the need for customization. Furthermore, while full automation of a PAUT system would still likely require engagement of a third-party manufacturer, the need for manual interaction could be minimized relative to in-service bridge inspection as a detailed procedure could be developed for operators to follow that would be much harder to do for in-service bridges in trying to address all possible weld configurations. Expert inspectors performing manual inspections would still be necessary to validate any flaws and confirm data produced by the AUT system, but as discovered during lab testing of the prototype, the inspectors spend the majority of their time carefully laying out their scan plans even on weld of ordinary geometries. Use of the AUT system could reduce or even eliminate this time by providing an already built framework, or even a motorized assist, for encoding the position of their probe as they scan the welds. Future work will be to pursue additional testing of the AUT system in cooperation with bridge owners to find the best roles and uses of the systems in their work as well as to identify how to use the present system's cost-effective components to make AUT financially viable and appealing to weld inspectors and bridge owners alike.

CONCLUSIONS

Based on the results presented in this report, the following conclusions can be made:

- Field testing of the prototype AUT system demonstrated the feasibility of deploying this technology for the in-service inspection of steel bridges. It was found that scanning in-service welds with the AUT prototype resulted in data of similar quality to data gathered by an ASNT III UT inspector. Future AUT technologies will need to be more flexible and mobile in their design to accommodate a greater variety of bridge configurations and allow for faster installation.
- Initial results from application of the AUT system in evaluating the weld specimens show promise for the system's deployment for initial survey scans that allow more informed and time-efficient selection of where expert inspectors should perform more detailed scans. More complicated scan plans that involve rastering and rotating the PAUT probe using the AUT system may not be presently viable given the probe coupling pressure limitations, which are still being resolved.
- The AUT system is well-suited for use with PAUT probes as the need for a consistent linear probe path for successful testing is met by the fixed rails used by the instrumentation platform.
- The significant amount of noise introduced by weld reinforcement may require that grinding of the weld flush with the steel be part of the protocol for an ideal weld inspection using ultrasonic testing.

INVESTIGATORS' PROFILES

Shane D. Boone, Ph.D., Vice President of NDE at BDI, has spent over 17 years in the government, academic, and private sectors of specialized infrastructure inspection and monitoring. He specializes in the research, development and application of nondestructive testing & evaluation technologies and monitoring for civil infrastructure. Previously, Dr. Boone worked for the Federal Highway Administration for whom he managed the Agency's NDE Program and performed research on the inspection of bridges, pavements, culverts, tunnels, and other transportation infrastructure, and the fusion of multiple NDT/NDE techniques. He managed three individual studies on the development of PAUT protocols for inclusion in AWS D1.1 and D1.5 standards. Additionally, he assisted in the development of the Long Term Bridge Performance Program's Structural Health Monitoring committee, of which he is a member.

Phil Sauser, P.E., has been an employee of the USACE since 1989 and serves as the USACE Technical Expert in Bridge Safety, conducting bridge inspections, evaluations, and repair designs. In addition, he is charged with developing USACE Bridge Safety Program policy, guidance, and standards and implementing bridge inspection training. He is the primary developer and manager of the Corps of Engineers Bridge Inventory System (CEBIS), the USACE web-based Bridge Safety Program database, and consults on interpretation and implementation of USACE and National policy and guidelines on Bridge Safety for other Districts and State, Local, Federal, and DOD agencies and other countries. He has also led investigations & overseen the implementation of automated testing procedures (AUT) with a particular focus on efforts to update and develop USACE guidance for the design, fabrication, evaluation, and inspection of Hydraulic Steel Structures (HSS).

Bill Hardy is an AWS Certified Welding Inspector & ASNT Level III- (UT & MT) with over 20 years of experience in structural steel welding, fabrication, NDT, quality control and quality assurance for bridges (Fracture Critical and Non-Fracture Critical) and hydraulic structures for the US Army Corp of Engineers. Bill is a graduate of Moorefield High School and attended South Branch Valley Vocational Center with a graduate certificate in Combination Welding and the US Navy Builder "A" School in Gulfport, MS.

Curtis Schroeder, Ph.D. is skilled in advanced inspection techniques for the fabrication of new welded steel structures and the evaluation of existing steel structures using fitness for service (FFS) assessments. He completed his Ph.D. with research on the use of phased array ultrasonic testing (PAUT) of steel bridge welds at Purdue University. Prior to his work as a research assistant, Dr. Schroeder worked for five years at Fish & Associates, Inc. (now Fickett Structural Solutions), where his responsibilities were centered on nondestructive testing research using PAUT and writing engineering guidance documents for improved fatigue and fracture design of steel structures and FFS evaluation of members with existing flaws. Dr. Schroeder also has aided in the development, revision, and instruction of training courses in welding and bridge inspection. Dr. Schroeder joined WJE in March 2019.

Alan Caulder has been working in the NDT industry for over 17 years, in both the technical and business arenas. He has experience in the areas of quality, personnel and executive management as well as that of Corporate Level III. He currently holds an ASNT Level III certification in Ultrasonic Testing and Magnetic Particle Testing. As the VP of Sales for Advanced OEM Solutions, his primary focus is business development and sales in North America.

Jim Leeser has been performing NDT for nearly 40 years with 25 years focused on the ultrasonic testing. Mr. Leeser currently works for High Steel Structures, LLC in Lancaster, PA and has been employed there since 1999. He has been certified as an ASNT Level III in the MT, RT and UT methods.

Jeff Cohen has been in the NDT industry for 7 years, working for BDI during the last 3 years while having gained experience at every role in the execution of NDE services for a variety of infrastructure, having planned, performed, and reported on successful investigations on bridges, dams, telecom towers, and other civil structures. He has deployed and provides instruction on a multitude of acoustic, electromagnetic, and electrochemical NDE technologies and techniques. Furthermore, he drives the development of software, hardware, and methodology to support the company’s use of various NDE methods, helping to maintain the company’s high standard for quality data collection, data analysis, and reporting. Outside of the NDE industry, Mr. Cohen has worked for a large data warehousing company, specializing in the development of machine learning applications in Big Data for commercial clients as well as the automation of company processes.

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APPENDIX: RESEARCH RESULTS

Sidebar Info

Program Steering Committee: NCHRP IDEA Program Committee

Month and Year: June, 2019

Title: Testing of In-Service Bridges Using Automated Ultrasonic Testing Methods

Project Number: 191
Start Date: March 3, 2017
Completion Date: June 3, 2019

Product Category: New or improved tool or equipment

Principal Investigators:

Shane Boone, Ph.D., Vice President – NDE
E-Mail: shaneb@bditest.com
Phone: 919.999.3779 x108

TITLE:

Automated Ultrasonic Testing of In-Service Steel Bridges

SUBHEAD:

Development of an automated ultrasonic testing platform for better inspections of critical steel bridge weld inspections and the improvement of effective, efficient, and safety-focused engineering judgments

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WHAT WAS THE NEED?

As the nation's bridge inventory deteriorates and structural performance conditions worsen, agencies must increasingly make difficult decisions on allocation of limited resources to maintain a safe and functioning inventory. Defects in bridge members can lead to crack formation and these cracks can lead to premature repairs and even catastrophic failures. Identifying the location, size, and extent of defects in the welds of steel bridge members is critical in determining the bridge's continued safety. Current bridge inspection practice is to use conventional testing methods like ultrasonic (UT) and radiographic (RT) test methods, but unfortunately UT and RT are limited in their image resolution. Without knowing the true extent of a defect, conservative estimates are assumed. These assumptions can lead to premature or unnecessary repairs or bridge replacements. To increase this image resolution and at the same time improve the accuracy and reliability of the measurements the present study sought to investigate the effectiveness of automated ultrasonic testing (AUT).

The AUT equipment collects and analyzes weld integrity information using Phased Array Ultrasonic Testing (PAUT) methods to produce better defined and quantified defects in combination with a programmable encoder system that allows for automation and standardization of testing. AUT is used as an established and proven technology in defense, nuclear, and pressure vessel applications, but has yet to be fully employed on steel bridges. This level of accuracy provides greater reliability of results and much less uncertainty in the potential that a defect will grow into a crack. Higher reliability and repeatability lead to greater safety, either in knowing a defect has a low potential for cracking or in identifying those defects that need attention on a long-term basis, either by monitoring or repairing. With this knowledge, engineers and managers can identify repair priorities and direct resources where they can be used more efficiently and effectively.

WHAT WAS OUR GOAL?

This goal of this project was to develop a prototype automated ultrasonic testing (AUT) system for inspecting the welds of bridge members and demonstrate the feasibility of such a system producing results with quality up to the standards of an expert ultrasonic testing (UT) inspector. The performance goal of this project was to place into production a tool that can be universally used by engineers and managers to assess a specific portion of an agency's bridge inventory that will efficiently produce consistent and accurate testing results and is applicable to both new steel bridge fabrications and the evaluation of existing conditions.

WHAT DID WE DO?

- In aiming to develop a highly adaptable and cost-effective prototype, the project team constructed its system using an low-cost ($500) X-Y plotting printer system as its basis. Such platforms are already designed for precision movement and the ability to move in a programmable way, allowing automation.

- Preliminary testing with a conventional UT steel thickness gauge was completed with some success, using the probe to move along a pre-programmed path on a steel plate at a consistent speed, leading to a modification of the probe holder to maintain consistent pressure between the probe and steel plate.

- Laboratory mock-ups of steel welds with manufactured defects were fabricated to conform to the American Welding Society (AWS) terminology, joint configuration, welding, and ultrasonic testing flaw classification. ASNT inspectors were selected by an expert technical panel in partnership with the

U.S. Army Corps of Engineers (USACE) to perform the baseline manual inspections with traditional ultrasonic technologies as well as evaluate the results produced by the prototype system.

- A field demonstration of the AUT system was completed under the supervision of an ASNT III inspector who confirmed the quality of the data being generated by the system as it scanned welds on a selected bridge, producing results in line with the results of the qualified inspector in their survey.

WHAT WAS THE OUTCOME?

- While more complicated scan plans that involve rastering and rotating the ultrasonic probes may not be presently viable given the probe pressure issues still not being fully resolved, the initial results from application of the AUT system in evaluating the weld specimens show promise for the system's short-term deployment in providing initial survey results to allow more informed and time-efficient selection of where expert inspectors should perform more detailed scans.
- The significant amount of noise introduced by weld reinforcement may require that grinding of the weld flush with the steel be part of the protocol for an ideal weld inspection using ultrasonic testing.
- Field testing of the prototype AUT system demonstrated the feasibility of deploying such an instrument in the field to collect data consistent with the kind of data that would be gathered by an ASNT III UT inspector, though future systems will need to be more flexible and mobile in their design to accommodate a greater variety of bridge configurations and allow for faster installation.

WHAT WAS THE BENEFIT?

The prototype AUT instrument showed promise for producing results consistent with the output produced by expert operators performing a manual inspection in both the lab and field testing. Improvements to the prototype mounting hardware, frame geometry, and installation procedures are needed to support broader implementations in the field and future adoption by bridge owners. In addition, where commercial systems were found to cost up to $50,000 during the industry scan, the prototype system for this project was built for a cost of $500 including supplemental components for field modification. Along this line, the AUT system evaluated in this project presents bridge owners with a tool that trades the robust and rugged design of single-geometry scanners for a more cost-effective adaptable platform.

Despite the unlikelihood of adoption of AUT systems in the in-service bridge inspection industry, the prototype benchtop system would be appropriate for fabrication shop applications where the standardization of the welds would reduce the need for customization. Furthermore, while full automation of a PAUT system would still likely require engagement of a third-party manufacturer, the need for manual interaction could be minimized relative to in-service bridge inspection as a detailed procedure could be developed for operators to follow that would be much harder to do for in-service bridges in trying to address all possible weld configurations. Expert inspectors performing manual inspections would still be necessary to validate any flaws and confirm data produced by the AUT system, but as discovered during lab testing of the prototype, the inspectors spend the majority of their time carefully laying out their scan plans even on weld of ordinary geometries. Use of the AUT system could reduce or even eliminate this time by providing an already built framework, or even a motorized assist, for encoding the position of their probe as they scan the welds. Future work will be to pursue additional testing of the AUT system in cooperation with bridge owners to find the best roles and uses of the systems in their work as well as to identify how to use the present system's cost-effective components to make AUT financially viable and appealing to weld inspectors and bridge owners alike.

LEARN MORE

IMAGES

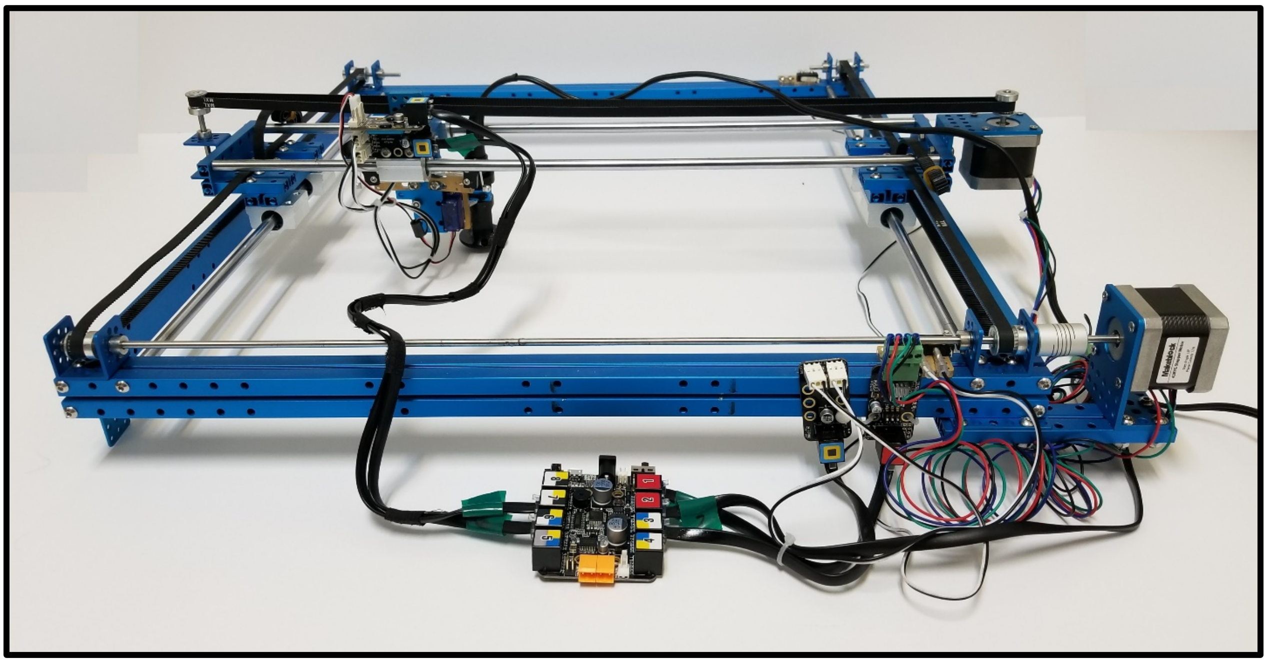

FIGURE 1 Prototype Automated Ultrasonic Testing (AUT) system

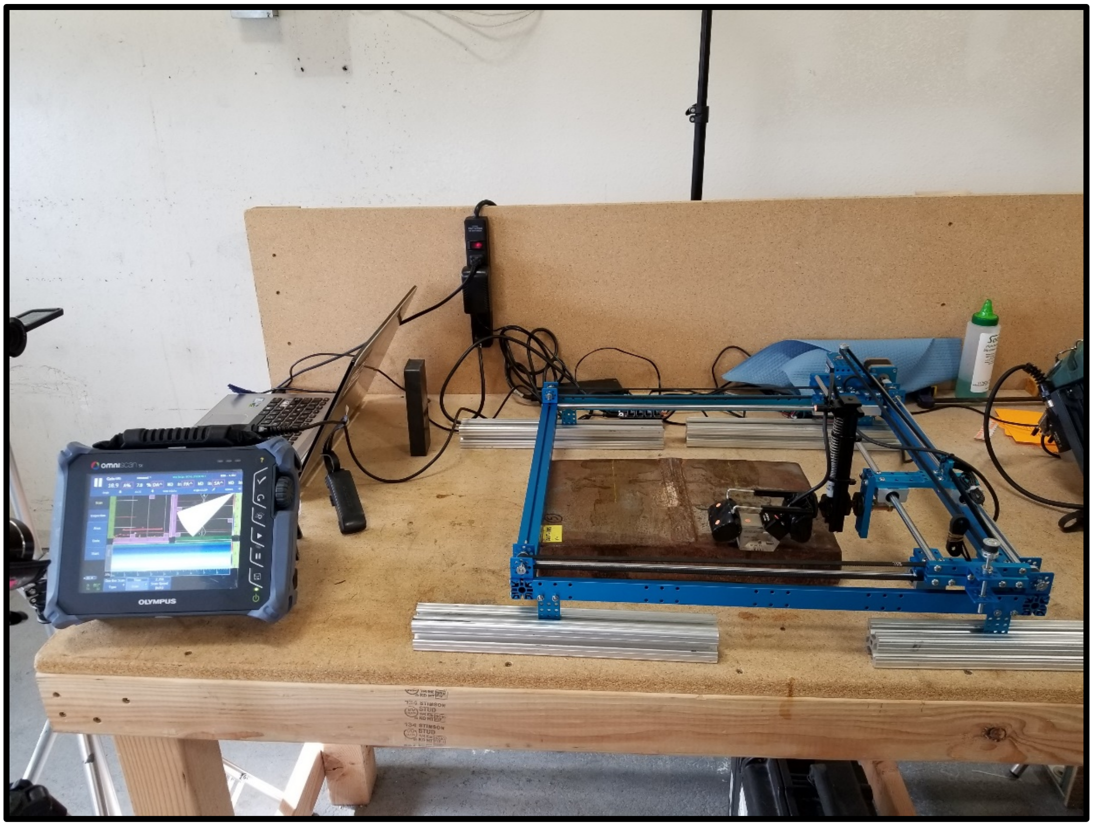

FIGURE 2 Lab testing of AUT system on steel weld specimen

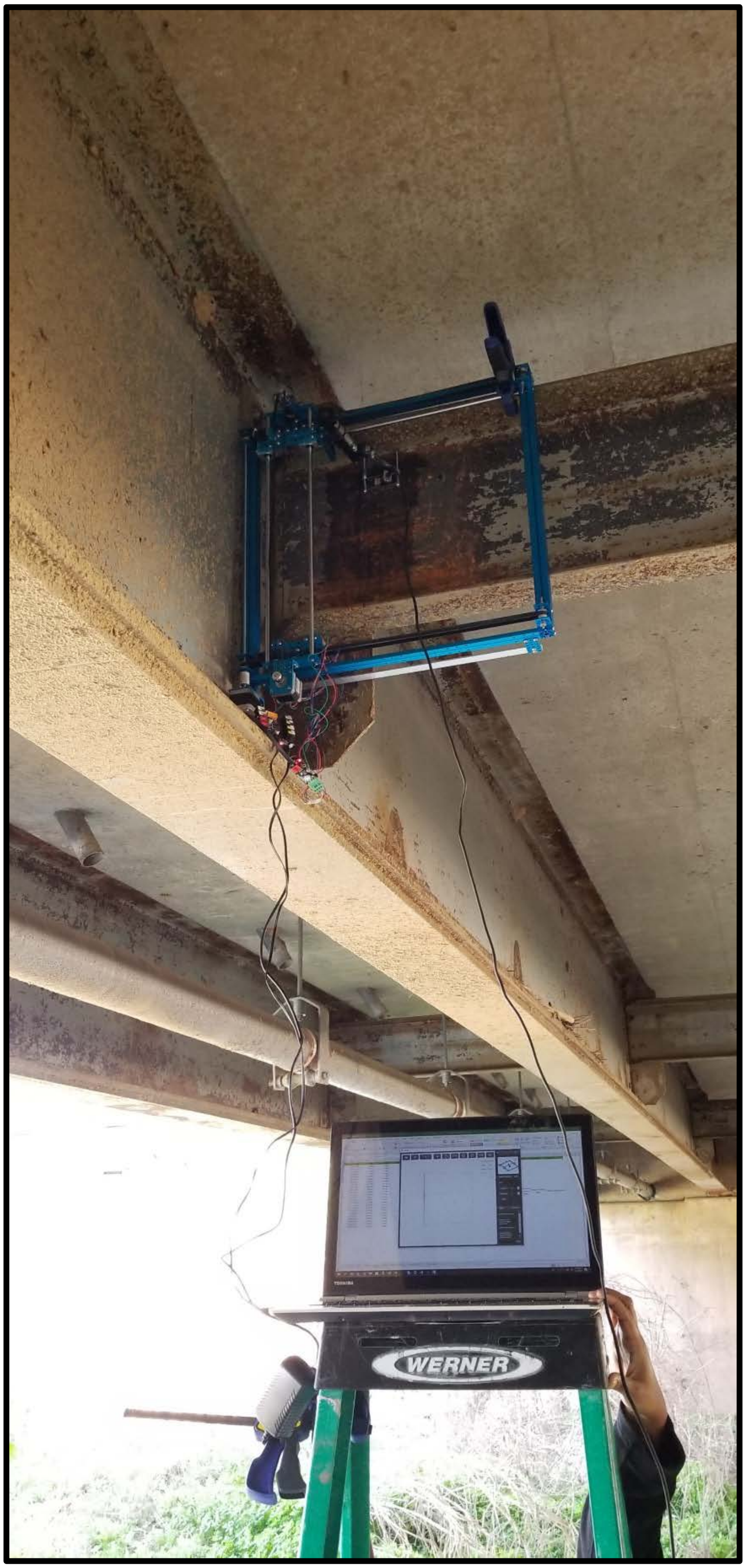

FIGURE 3 Field testing of AUT system on in-service steel bridge