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Comparison of Aerial Robotic Vs. Manual Ultrasonic Testing on Elevated Carbon Steel Plates

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Jamie L. Branch, P.E. Corrosion Engineer

INTRODUCTION

This study evaluates wall thickness readings obtained using ultrasonic testing (UT) with an aerial robot and compares them with readings performed manually by a human hand. The testing surface consists of elevated carbon steel plates, constructed to approximate an above-ground storage tank. Working at heights taking UT readings can require scaffolding, cranes, or ropes. These methods create risk for the inspector collecting the readings. Using aerial robotic platforms can remove humans from harm's way—what OSHA describes as "engineering the risk out and away." This removes the risk of people falling by keeping them safe on the ground and the aerial platform with the UT measurement device in the air.

Testing was performed on an elevated 15-foot diameter facsimile of an aboveground storage tank (AST), constructed of A36 carbon steel welded plates with a nominal thickness of 1/8 inches. Half of the tank was coated with fast-cure epoxy base coat and a hi-solids polyurethane top coat. The other half was left uncoated and exposed to the natural environment. A dual-element 5MHz contact transducer was used on the corroded, uncoated side, and a single-element 5MHz contact transducer with multiple echo technology was used on the coated side. Testing was performed in the southern coastal region of the United States.

The aerial robotic system used to perform measurements is a hardened custom drone equipped with an array of sensor systems, a full computer, and custom software to allow automatic flight to contact wall structures for measurements. The aircraft also has a robotic arm with an end effector (hand), which is the component that physically contacts the material being tested. The end effector contains the UT measurement probe and an integrated couplant dispenser. Lastly, the aircraft was powered by two 6-cell lithium polymer rechargeable batteries. While the aircraft is able to operate on ground-based "shore power," that option was not utilized for this study.

Figure 1: Apellix NDT Aerial Robot

BACKGROUND

Ultrasonic testing (UT) is a form of nondestructive testing (NDT) used to determine various material properties. UT thickness gauges are specifically used for measuring the thickness of materials by measuring the time required for a sound pulse to travel through a material and reflect back from the opposite wall. The sound waves are transmitted perpendicular to the material surface in longitudinal (compression) waves. The transducer receives the reflections of the sound wave, or "echo," from the opposite wall and converts the sound energy back into electrical energy. The measured round-trip transit time is converted to a thickness value by multiplying the transit time by the velocity of sound in the material being measured.

To obtain measurements, the inspector must manually touch the probe to the material being measured. Due to surface profile irregularities, a couplant (typically gel, glycerin, propylene glycol, water, or oil) is applied to eliminate air gaps and facilitate pulse transmission into the material.

Current handheld electronic UT equipment is lightweight and portable and requires the inspector to physically access test sites, which are frequently located at dangerous heights. Scaffolding, scissor lifts, fall protection, and other access equipment are required to reach most elevated test sites, which are expensive and present fall hazards to personnel accessing them.

Performing UT and other NDT measurements using aerial robotic systems seeks to improve occupational safety and reduce injuries and deaths attributed to falls by allowing measurements to be taken with the worker safely on the ground and the aerial platform in the air. It is important to note that the UT device and probe capturing the readings is the same technology currently being used by the industry. The UT technology integrated on the aircraft is not novel, only the method of delivering the probe tip to the surface is.

Using drones to perform NDT is a novel approach that is just beginning to be integrated into standard operations at industrial facilities.

MATERIALS

The materials used to conduct testing in this study are listed below:

Type	**Description**
Test Plate (2)	A36 Carbon Steel, 1/8 in. nominal thickness
UT Device	DeFelsko Positector 6000 Advanced Body
UT Probe (uncoated side)	DeFelsko UTG C (corrosion) with dual element 5 MHz contact transducer
UT Probe (coated side)	DeFelsko UTG M (multiple echo) with single element 5 MHz contact transducer
UT Couplant	Sonotech ULTRAGEL II. Part No. 25-901; Batch No. 18H016
Calibration Block	Olympus part number 2214E 5-step precision thickness block (NIST certified). 1018 Carbon Steel. English Unit 0.100in., .200in, .300in, 0.400in., and 0.500 in.
Anemometer	Digital, HoldPeak 866B
Thermometer	Digital Infrared, Toll House Model No. 770343S
Aerial Robotic System, FAA Tail #: FA3FAHE439	● (4) Propellers ● Onboard computer ● Onboard sensors ● Custom computer circuit cards ● Proprietary software ● Articulating robotic arm ● End effector containing UT device probe tip ● Flight controller with GPS ● Handheld aircraft remote controller ● Brushless motors with ESC (electronic speed controller) ● (2) Rechargeable 6-cell lithium polymer batteries

METHODS

The author of this study utilized standard qualitative research methodologies and documented as many variables as possible. To minimize variation across the plate, only a 3 foot by 3 foot area was used for gathering data on each side of the tank. While a larger sample size is optimal, the author opted to use 50 reading attempts on each the coated and uncoated side when measuring with the aircraft. An aircraft reading attempt is classified as an aircraft approach and contact with the wall surface of the tank. Not all aircraft attempts produced a reading, which explains why N=45 (uncoated side) and N=42 (coated side) instead of N=50 for both. Analyzing the success rate of the number of approaches to the number of successful readings is an important aspect of investigation in this study. The study was initially designed to solely analyze the corroded, uncoated side of the tank. The author selected N=50 for handheld measurements to compare to the aircraft measurements on the uncoated side. This resulted in approximately one inspection reading per 25in^2 of the 3ft by 3ft measurement area. After testing the uncoated side, it was decided at a later date to also test the coated side. For the coated side, the number of handheld/manual measurements was increased from N=50 to N=200 to better account for variability in the material thickness by taking a reading approximately every 6.5in^2 instead of every 25in^2 as previously done for the uncoated side.

FAA Compliance

The aircraft used in this study was legally registered with the Federal Aviation Administration (FAA), and airspace authorization was received to conduct flight at the testing location, which is under the jurisdiction of Naval Air Station Jacksonville Air Traffic Control.

Figure 2: Coated and Uncoated Elevated Carbon Steel Test Plates

Personnel

An FAA part 107 licensed pilot conducted all test flights on the coated and uncoated plates. An experienced NDT corrosion engineer calibrated the device, performed calibration verifications, and performed manual testing on both the coated and uncoated test plates. Aircraft testing results were not reviewed until after all handheld measurements were collected.

Test Material Construction

Two carbon steel plates were elevated to mimic a storage tank (see Figure 2). One plate was left uncoated and exposed to the natural environment. The second plate was surface prepped with a wire brush and simple green solvent and then coated with Sherwin Williams MACROPOXY 646-100 fast-cure epoxy base coat, and Sherwin Williams Hi-Solids Polyurethane top coat. The finished coating system had a dry film thickness (DFT) of 7-10 mils. To limit the inspection test area, the corners of a 3ft-by-3ft square were lightly marked on each plate as the allowable measurement area. The measurement area started at 12 feet and ended at 15 feet from ground level. Only measurements obtained in these squares were included in this study.

Environmental Data

Environmental data was collected immediately prior to gathering UT measurement data. An anemometer was used to determine wind speed and ambient temperature. An infrared digital thermometer was used to measure the temperature of the carbon steel plate test surface. Cloud coverage was recorded based on weather station reporting.

Safety

Prior to takeoff, a safety briefing was held with involved personnel and a Job Safety Analysis (JSA) was performed.

Calibration

Calibration was performed pursuant to ASME Section V and with reference to the original device manufacturer's calibration manual. Zero calibration was performed to adjust the device for any transducer delays or other factors affecting pulse transmit time. A two-point material sound velocity calibration was performed using a 5-step calibration block of the same acoustic velocity and attenuation as the test plate material. The steps closest to the maximum and minimum anticipated thickness range of the material being measured were used. Temperature adjustments were not required, as the calibration block temperature was within ±10°F of the test plate surface temperature.

Initial calibration was performed immediately prior to conducting testing. Measurements were taken first by the aircraft and immediately followed with manual measurements to keep environmental factors as consistent as possible. A calibration verification of accuracy was performed during the one battery change required for each aircraft testing period. Additional verification was performed upon completion of flight testing and at the beginning of manual testing.

At the completion of taking handheld readings, a final verification of accuracy was performed.

TESTING

The initial UT readings from the uncoated surface of the elevated carbon steel plates were collected on July 6th, 2018 at the test location in Jacksonville, Florida USA. The UT readings from the coated area were collected at the same location on October 23rd, 2018. On both dates, the aircraft readings were collected by the same pilot, and the handheld readings were collected by the same NDT engineer.

Testing Procedures

1. Perform aircraft safety checks.
2. Calibrate UT device onboard the aircraft.
3. New memory batch started on UT device to record readings.
4. Pilot navigates aircraft to approach the surface of the plate within the 3ft-by-3ft area. Once the transducer is in contact, the pilot holds contact for 3 seconds before navigating the aircraft away.
5. The process is repeated until 50 approaches are completed. Calibration is performed at all battery changes.
6. Once 50 approaches are complete, the memory batch is closed and the UT device and probe are removed from the aircraft, to be immediately used for handheld measurements.
7. A calibration check is performed at the completion of aircraft testing and at the beginning of manual testing.
8. New memory batch started on the UT device to record manual readings.
9. Inspector manually measures the same 3ft-by-3ft measurement area used by the aerial robotic system. Fifty measurements were performed on the uncoated side, and 200 measurements were performed on the coated side.
10. Once manual measurements are completed, the memory batch is closed and a final calibration check is performed.
11. Aircraft and manual memory batches are loaded into Microsoft Excel spreadsheet for analysis.

Figure 3: Pilot taking measurements on coated side

RESULTS

The results shown below include the environmental data from the days the UT readings were collected, as well as information on the calibration of both the UT handheld electronic device used by the NDT engineer and the one utilized by the aerial robotic system. The UT data for the thickness of the steel plates is also shown. Total flight time for measuring the uncoated and coated side was approximately 15 minutes each, including battery changes. Figure 3 captures the pilot taking a measurement on the coated side.

Environmental Data

Table 1: Environmental Data on Testing Day

	Uncoated	Coated
Date/Time Started	7/6/2018, 11:15 AM	10/23/2018, 12:10 PM
Ambient Temperature	82ºF	74ºF
Cloud Coverage	15%	Scattered
Wind	2-3.5mph sustained, gusts to 4.5mph	2mph sustained, gusts to 6mph

Calibration Documentation

Table 2: Calibration Data

	Uncoated	Coated
Cal. Block Temperature	104º F	80º F
Testing Plate Temperature	112º F	79º F
Initial Cal. (Aircraft)	11:15 AM	12:20 PM
Cal. Check (Aircraft)	11:25 AM	12:31 PM
Final Check (Aircraft), Initial Check (Manual)	11:31 AM	12:48 PM
Final Check (Manual)	11:48 AM	1:22 PM

Thickness Readings

Table 3: Comparison of aircraft vs. manual handheld UT thickness readings

	Uncoated		Coated	
	Manual	**Aircraft**	**Manual**	**Aircraft**
N	50	45	200	42
$\bar{X}$ (in)	0.13050	0.12980	0.12758	0.12757
s_x (in)	0.00157	0.00290	0.00060	0.00055

Approach Success Ratio

Table 4: Successful aircraft approaches that resulted in a valid UT measurement

	Uncoated	Coated
Successful Approaches	45 out of 50	42 out of 50
Success Rate	90%	84%

DISCUSSION AND FINDINGS

The aerial robotic device successfully achieved contact to obtain ultrasonic thickness readings of the elevated carbon steel plates. The ability of an aircraft to take accurate readings is especially important, as it establishes that valid UT readings can be collected by an aerial robotic system. As the feasibility of taking UT readings utilizing an aerial robotic system is firmly established, the author would like to see further developments to enhance the functional ability of the aerial robotic system.

A statistical analysis of the UT thickness readings shows there is no statistically significant difference between the readings obtained by the person on a ladder holding the UT device probe tip to the test surface, and the readings obtained by the aerial robotic system holding the UT device probe tip to the test surface.

The success ratios of the uncoated and coated side (90% and 84%, respectively) indicate satisfactory efficiency of the aircraft in obtaining readings. However, testing was performed in ideal wind conditions, and it is expected that the success ratios would decrease with an increase in wind velocity. Anecdotally, approaches that failed to produce a reading appeared to be due to the probe sliding on the plate surface, which did not allow enough stability to gather a reading. Successful attempts had stable contacts with minimal sliding of the probe on the plate surface. Further developments of the end effector design will assist in mitigating the probe tip sliding on the test surface after it makes contact.

CONCLUSION

Using handheld digital testing devices to take UT nondestructive testing measurements at height can be dangerous, expensive, and time-consuming. When possible, working at heights should be eliminated as part the hierarchy of fall protection stipulated by both OSHA and ANSI. This study provides evidence of the efficacy of a UAS performing UT measurements at height, proving that there is no statistical difference between the data gathered by a UT device in a human hand and a UT device mounted on an aerial robotic system. Companies should give consideration to a changing paradigm wherein they utilize robotic systems instead of humans for UT measurements at height.