The Feasibility of Ultrasonic (UT) Material Thickness Readings of an Aboveground Storage Tank Using an Aerial Robotic System (Drone)

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INTRODUCTION

This case study evaluates the feasibility and limitations of obtaining ultrasonic thickness (UT) readings on an above ground storage tank utilizing an aerial robotic system (drone).

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 a 45-foot diameter above ground storage tank, constructed of ASTM 283 Grade C carbon steel riveted plates. The original design thickness was 0.250 inches. The tank was coated, with bare metal exposed on approximately 20% of the surface area. An original coating specification could not be located. The tank stored utility service water prior to being decommissioned over forty years prior. The tank was located at a refinery tank farm in the United States Gulf Coast Region.

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, 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.

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 test sites, which are expensive and present fall hazards to personnel accessing them. The Bureau of Labor Statistics reports that 849 workers lost their lives in 2016 from falling while on the job across all industries[1].

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 used by industry; the aerial robotic system just places the probe tip against the wall surface instead of a person.

Using drones to measure NDT is a novel approach that has yet to be integrated into standard operations at industrial facilities.

METHODS

Safety

Prior to conducting work onsite, a safety meeting was held with involved personnel and a Job Safety Analysis (JSA) was performed. A Safe Work Permit specific to the facility was issued by the operations crew of the facility and discussed with personnel involved.

Calibration

The aerial robotic platform was equipped with a factory calibrated DeFelsko UTG M single element 5 MHz contact transducer. The device was set to multiple echo to echo mode to achieve readings that ignored the coating thickness. 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 by an experienced NDT professional using a 5 step (0.100 inch to 0.500 inch) standardized calibration block of the same acoustic velocity and attenuation as the tank material. Temperature adjustments were not required, as the calibration block temperature was within ±10°F of the contact surface of the material being tested. At the completion of taking readings, a final verification of accuracy was performed using the same calibration block. Calibration was performed pursuant to ASME Section V and with reference to the original device manufacturer's recommendations.

Figure 1: Aerial Robotic System Preforming UT Reading on Tank Wall

Flight

Measurements were performed in the afternoon, with passing clouds, 32% relative humidity, and temperature of 66°F. A hand held digital anemometer was used to measure a wind velocity of 6 miles per hour at the pilot's location, approximately 20 feet from the tank. Wind velocity near the tank surface was measured to be 8 miles per hour. The increase in wind velocity at the tank surface is attributed to venturi effect.

The aerial robotic system was operated by a licensed Federal Aviation Administration (FAA) Remote in Command Certified Pilot (commonly known as a FAA section 107 pilot). The pilot conducted a preflight inspection, which included specific aircraft and control station systems checks, to ensure the aircraft was in a condition for safe operation. The pilot also ensured the aircraft complied with the existing registration requirements specified in § 91.203(a)(2). A final safety briefing was conducted to those present at the location immediately prior to take off. The pilot navigated the aircraft to ten randomly selected areas of the tank to perform UT readings. The onboard computer of the aerial robotic system signaled prior to each contact to apply the gel couplant to the probe tip using a small onboard pump. Once the aircraft was positioned near the desired measurement area, autonomous flight was activated. The onboard computer programmatically flew the aircraft to the material surface to achieve contact with the wall. Once the onboard software obtained a UT reading, the aircraft backed away from the targeted wall and returned to a safe position awaiting navigation to a new area by the pilot. The pilot obtained the UT readings at different heights, on the Southwest side of the tank.

The inspector reviewed data collected by the aerial robotic system in real time via a user interface that displayed readings as they were obtained. A text based comma separated value (.csv) file was exported at the completion of the flight as a historical record for the inspector to review and was uploaded via a cellular modem onboard the aircraft to an online data repository.

RESULTS

As a reference measurement, a certified API 653 tank inspector, working for the facility and asset owner, measured one wall thickness reading at arm's height (approximately 5ft) to be 0.219 inches using an Olympus 38DL PLUS. The pilot navigated the aircraft to ten separate random locations at various heights and locations along the Southwest side of the tank. Under autonomous control, the pilot had the aerial system fly in and touch the tank wall to collect a UT reading. The first five of ten thickness reading attempts were unsuccessful due to too short of interface between the probe tip and material surface. After the unsuccessful attempts were recognized, the pilot adjusted flight such that the aircraft would hold contact on the material surface for a longer

Thickness (in)	Height (ft)
0.177	8.4
0.193	8.6
0.195	10.2
0.208	10.6

Table 1: UT Thickness Readings Performed by Aerial Robotic System

period of time. This modified technique was able to produce valid readings. A total of four thickness readings were obtained, which are recorded in *Table 1*. Eight minutes were required to perform the ten (successful and unsuccessful) contacts with the tank wall.

Several false readings were included in the data set, which had to be filtered out by the reviewing inspector. Two false readings (0.066 inches and 0.072 inches) were attributed to the probe measuring the couplant as it was dispensed to the probe tip. The readings were confirmed to be invalid by reviewing flight data which indicated that the probe was not in contact with a material surface when the readings were obtained.

DISCUSSION

The aerial robotic device successfully achieved contact to obtain ultrasonic thickness readings of an aboveground storage tank. The ability of an aircraft to take readings is especially important, as it establishes that UT readings can be performed by an aerial robotic system.
As with any new technology, further developments are required to enhance the functional ability. Adjustments to the end effector should be made to facilitate the probe coupling with the material surface. The user interface and data files should be automatically filtered to eliminate obviously erroneous data.

Now that the feasibility of taking UT readings utilizing an aerial robotic system has been established, a more robust study is required to validate the readings as statistically equivalent to measurements performed manually. Our next case study will evaluate the validity of UT thickness readings recorded by an aerial robotic system by individually validating by hand the UT thickness readings recorded by the aerial robotic system. The author's observance of the attendees is UT readings via an aerial robotic system will be a welcomed future of the inspections industry.

CONCLUSION

Using handheld digital testing devices to take UT Nondestructive Testing measurements at height can be dangerous and time consuming. When possible, working at heights should be eliminated as part the hierarchy of fall protection stipulated by both OSHA and ANSI. There are several drone companies that have successfully provided visual inspection to the oil and gas industry, and the system described in this paper provides evidence of at least one aerial robotics company that take contact-based NDT measurements at height. An Aerial Robotics system includes a "robotic arm" and an "end effector" allowing for software control as opposed to drone-based systems that are manually flown. The system described in this paper operates under full computer control (no manual input allowed) to fly in, touch the surface with the probe, and takes UT measurements. Companies should give serious consideration to a changing paradigm wherein they utilize robotic systems instead of human for UT measurements at height.

REFERENCES

1. *National Census of Fatal Occupational Injuries in 2016.* Bureau of Labor Statistics, U.S. Department of Labor. December 19th, 2019. https://www.bls.gov/news.release/pdf/cfoi.pdf.

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