Robotic End Effector For Inspection of Storage Tanks

(FETC DE-AR21-93MC30363)

Using Robotics for Non-Destructive Examination & Characterization of Hazardous Storage Tanks

R. Beer (rbeer@oss.oceaneering.com, 281-228-5414)
Oceaneering Space Systems
16665 Space Center Blvd
Houston, TX 77058-2268

Abstract

Oceaneering Space Systems (OSS) has supported robotic non-destructive evaluation (NDE) inspection and characterization initiatives in partnership with the Federal Energy Technology Center (FETC). During the program OSS developed a robotic electromagnetic NDE system that successfully deployed in February 1999 inside INEEL's Tank WM188. A similar fast-track design and development approach yielded another highly successful waste inspection and retrieval tool deployed in Savannah River's tank 16 in June 1998. Close communication between FETC, OSS, and the DOE sites allowed technology development on a short schedule and ready to go 'out of the box'. Preparation for these deployments included: user-based design evaluation, extensive systems integration, & operations planning, all of which contributed significantly to deployment success. Even with these strategies, however, uncertainties in deployment, shifting customer requirements, and difficulties in manipulator integration posed unique challenges. These lessons will be explored so they may be applied to new programs seeking to advance a technology's state-of-the-art within the multi-site/multi-user environment of the DOE.

Introduction

Beginning in 1993, OSS began developing a non-destructive testing end effector for inspection of hazardous underground storage tanks in the Tanks Focus Area. Several DOE sites contain suspected leaking underground tanks, all of which need inspection. The tanks are predominantly stainless steel or carbon steel, and many are approaching the end of their operational lifetime. Given the magnitude of the problem, automated and efficient inspection methods utilizing site-specific robotics platforms were required.

To meet this challenge, FETC and OSS agreed to the following criteria: The electromagnetic inspection system must introduce no secondary waste, it couldn't be a spark or ignition hazard due to the combustible gasses in certain tanks, and had to deploy on existing robotics platforms within the DOE. The system was expected to be radiation hardened, sealed for decontamination showers, and contain both an NDE sensor suite and a video camera with lighting. The NDE system had to be capable of accurate, repeatable detection and sizing of crack and pit tank-wall defects as small as 1/8 inch in length or diameter.

Approach

This technology deployment program obviously had to meet rigorous design specifications for a difficult job within a harsh deployment environment. In addition, universal acceptance from numerous stakeholders within the Tanks Focus Area, many of which came from different labs, was vital. Weighing these significant challenges led OSS to pursue an aggressive strategy ensuring inspection success, customer acceptance, and consistent design direction for a technology development program that could land at any DOE site within the Tanks focus area.

To aid in this matter, numerous meetings at Hanford, INEEL, and Houston occurred during the development process – ensuring that all relevant parties had an appropriate level of design input. For example, Light Duty Utility Arm operators & NDE experts from both Hanford & INEEL met with OSS engineers at various stages in the design and development processes. These meetings proved time well spent when the system's hot deployment was completed without any delays, interruptions, or difficulties.

Another success strategy involved a heavy emphasis on testing – from the subsystem level up to integration tests between the end effector and the LDUA. Rigorous software and hardware 'burn-in' testing throughout the program enabled delivery of an inspection system that was ready to go 'out of the box' with no surprises.

Additionally, close communication between OSS and FETC minimized 'feature creep' -- the steady addition of product features and requirements that can plague a multi-year technology development program.

Finally, the importance of vivid, well-lighted video was not overlooked. Care was taken during the design process to include a color video camera and lighting to ensure the NDE inspection data was coupled with a clear view of the surface being tested.

Technology

Oceaneering Space Systems chose Alternating Current Field Measurement, or ACFM, to meet the DOE's inspection challenge because of the technique's inherent suitability for inspecting ferrous materials. The OSS-developed system performs a non-contact inspection by energizing coils to excite a uniform current field in the tank wall. As the current field flows around cracks or pits, it creates a disturbance in the magnetic field normal, or perpendicular, to the tank wall. An array of sensing coils and the control electronics 'read' the disturbance, resolving its location and the crack length or pit diameter. This information, along with material properties of the tank-wall alloy, is then used to compute defect depth from a three-dimensional electromagnetic field model of the disturbance. This technique eliminates the need for calibration runs typical to eddy-current applications, and is much less sensitive to sensor-to-wall standoff and orientation issues.

Since electrical contact with the tank surface is not required for ACFM, pre-inspection cleaning of the tank-wall surface is unnecessary. Other inspection methods were not considered due to their inherent disadvantages, such as requirements for surface cleaning (dyepenetrate), use of secondary waste (coupling fluid for ultrasonic scans), or ambiguous data interpretation (reading x-ray films.)

The 'hot' tank environment also drove the system's design. Since the end effector is deployable into extremely radioactive tanks, radiation tolerance is vital. The operating environment was assumed to be at least 1.0×10^6 rad. Thermal variations resulting from seasonal deployments in the Tanks Focus Area also had to be accounted for. The expected thermal environment ranges from 0 to 50º C. System specifications are listed in Table 1.

Table 1: End Effector Specifications

Defect Sizing Range*	0.25 to 1.8 in.
*Smaller or larger defects sizable with different coil configurations	
Defect Sizing Accuracy	± 0.060 or 10%
Operating Environment	
Radiation Tolerance	1.0×10^6 rad
Operating Temp.	0 to 50° C
Size	10.5 in. OD x 19.4 in.
Weight	45 lbs.
Umbilical	1.25" by 300'
Power	500 Watts
Interface	mounts to robot tool plate

A detailed description of the end effector's design, operational history, performance, and specifications are described in detail in Reference 2.

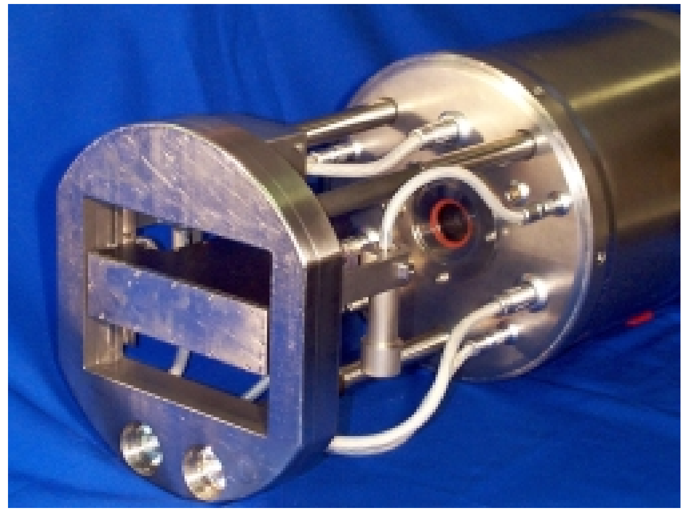

Figure 1. Non-Destructive Evaluation End Effector produced by Oceaneering Space Systems.

The end effector, pictured in Figure 1, was designed to interface with the Light Duty Utility Arm (LDUA) described in Reference 1. To ensure integration success, tool interface plates between the end effector and the LDUA were provided by Hanford and INEEL during hardware development.

Figure 2 shows a schematic of the end effector's major components. Obviously, deploying robotic inspection systems involves much more than just the remote inspection tool. The complete system includes the end effector, 'at-tank' electronics modules, remote inspection workstation, umbilical data & power lines, and an intuitive, windows-based, custom NDE software package installed on the operator's console.

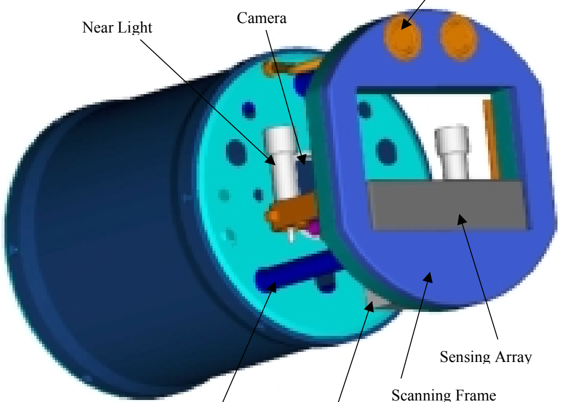

Figure 2. End Effector Schematic

Results

The first prototype of the end effector was successfully demonstrated at Hanford in February of 1997. Suggestions for operational improvements and modifications for increasing radiation hardness led to a design revision that produced the end effector pictured in Figure 1. Following production of the updated end effector, the complete system was delivered to INEEL in May of 1998. Testing at OSS prior to delivery and upon receipt at INEEL confirmed the inspection system was able to detect and size 100% of the cracks and pits within the customer's requested defect-sizing range. For verification purposes, stainless steel and carbon steel test coupons with stress-induced flaws were produced and their defects verified using X-ray characterization.

INEEL-requested operational modifications to the design were also completed - allowing surface inspection below the liquid/sludge layer. Lines were pressurized, seals upgraded, and the end effector was dunk-tested. (It should also be noted that significant shipping damage occurred during delivery. Repair on-site rectified the situation, but future deployments warrant shipment by OSS personnel.)

Final deployment occurred at INEEL in February of 1999 inside tank WM188. The system performed flawlessly, returning excellent NDE scans of tank surfaces and weld lines, along with detailed video of the inspected surfaces. The uniform acceptance of both the inspection system and its control software confirmed the importance of including operators, site representatives, and safety personnel early in the design process. Furthermore, the ease of operation for site personnel proved our threefold strategy of providing: an intuitive icon-based graphical user interface, a detailed Users Manual (Reference 4), and frequent training opportunities with OSS personnel at the site prior to deployment.

Benefits

Benefits of employing non-destructive evaluation to inspect underground hazardous waste storage tanks, especially those suspected of leaking radioactive waste, are obvious. The particular electromagnetic NDE method chosen by OSS was deemed optimal for the DOE's needs. ACFM is the only inspection system currently capable of performing 'fly-by' inspections that quickly sweep the interior of a tank -- logging suspect sites and returning to only those sites for the more time-consuming detailed scan. This benefit alone will save the DOE significant time and expense during labor intensive hot tank deployments. The other technical benefits, including superior performance and no secondary waste introduction, as compared to other inspection modalities were summarized above in the Technology section. A detailed explanation of ACFM and comparison to other NDE techniques is included in Reference 3.

Benefits from Oceaneering Space Systems' project management strategy of including site operators, NDE experts, and safety representatives in the design, testing, and fielding phases of the technology development program included: universal acceptance, fast-track scheduling, smooth deployment operations (including no inspection delays), and bilateral confidence in OSS inspection data.

Future Activities

The NDE End Effector resides at INEEL within the Tanks Focus Area inventory. Any future deployments at the site where vivid visual inspection and accurate defect sizing are required, will no doubt employ this highly useful tool.

References

1. Innovative Technology Summary Report: Light Duty Utility Arm, DOE/EM-0406, OST Reference #85, December 1998
2. Final Report: Robotic Tank Inspection End Effector, Contract No. DE-AR21-93MC30363, Document # 21100-70004, October 1991
3. Hughes, G., and Gittleman, M.M., "A Robotic End Effector for Visual and Electromagnetic Inspection of Waste Storage Tank Walls," *Proceedings of the ANS 6th Topical Meeting on Robotics and Remote Systems*, 347-354. American Nuclear Society, Inc. La Grange Park, IL, 1995.
4. Robotic Tank Inspection End Effector (RTIEE) Software Users Guide Version 2.0, Contract No. DE-AR21-93MC30363, Document #21100-70003, April 1998

Acknowledgements

OSS would like to thank Ms. Maria Vargas, the FETC Contracting Officer's Representative (COR), for her guidance and support. OSS would also like to thank the personnel at Hanford and INEEL who, through their input, helped transform the NDE End Effector from a technology demonstration into a vital inspection tool.