Development and Testing of Robotic Inspection Tools for the Hanford High-Level Waste Double Shell Tanks

Michael DiBono, Anthony Abrahao, Dwayne McDaniel, Yew Teck Tan

Florida International University Applied Research Center
10555 W Flagler Street
Miami, FL 33174

mdibono@fiu.edu, aabrahao@fiu.edu, mcdaniel@fiu.edu, yetan@fiu.edu

ABSTRACT

Florida International University (FIU) is in the process of developing inspection tools capable of inspecting the tank floors of double shell tanks through two main entry points, the air supply lines and air refractory channels. Two types of tools are being developed as a result: a pneumatic pipe crawler and a miniature rover. The air supply lines consist of an inspection path of approximately 100 feet of piping from grade, down through one of the drop legs and then lateral to the center bottom of the secondary tank containment. The route consists of pipes with varying diameters of 3 and 4 inches, reducers, and several elbows. The pneumatic crawler is being developed in an effort to properly inspect these lines. Resembling that of an inchworm in both motion and appearance and utilizing a modular design, it uses pneumatic actuators to emulate the contractions of peristaltic movements. The air refractory channels are located at the bottom of the tanks with channels as small as 2.5x1.5 inches and multiple 30˚ turns. The miniature rover is a remote controlled 4-wheeled vehicle utilizing skid steering through 4 micro DC motors designed for the inspection of these channels. There are no embedded electronics except for the camera in order to make the tool suitable for highly radioactive environments. It is designed to magnetically attach to the bottom of the primary tank (top of the air refractory channels) in order to avoid the debris that lines the bottom of the channels. Engineering scale testing of both systems is presented, with slight modifications being made based off of these tests. In order to test the pneumatic crawler, 100 feet of piping with the same lengths, dimensions, and fittings as the air supply line of the double shell tank (DST) named AY-102 was used. Testing for the crawler yielded satisfactory results, showing that the crawler was able to successfully navigate the air supply line. In regard to the testing of the miniature rover, brick pavers were used for the testbed to provide more realistic coefficients of friction between the tether and the channel. The rover proved to be able to overcome these frictional forces, although further modifications need to be made in order to ensure a consistent pull force.

Keywords

AY-102, leak detection, inspection tools, crawler, rover, robotics

1. INTRODUCTION

In August of 2012, traces of waste were found in the annulus of the radioactive waste storing AY-102 double-shell tank at the DOE Hanford site. This prompted the need for the development of inspection tools capable of identifying both the cause and location of the leak. The three possible points of entry for inspection in the tank are noted by Figure 1:

1.) The refractory air slots through the annulus
2.) The leak detection piping
3.) The ventilation header piping

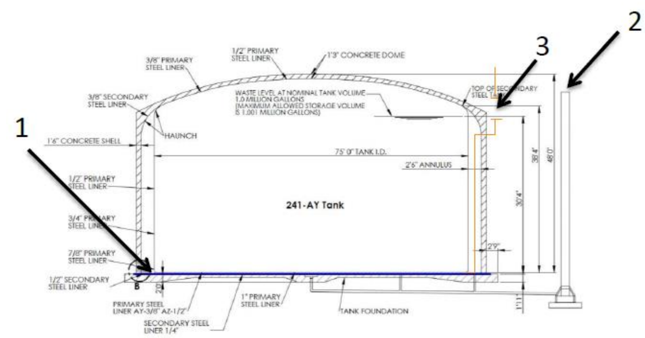

Figure 1. Inspection entry points of the AY-102 double-shell tank

Florida International University is developing inspection tools that are capable of accessing the tank's secondary containment, with the primary goal of providing live visual feedback. A magnetic miniature rover was developed for the inspection of the refractory air slots, and a pneumatic pipe crawler was developed for the inspection of the ventilation header piping.

2. RELATED WORKS

Multiple inspection devices have been developed for the visual inspection of small diameter pipeline structures, such as the MICROTUB [1], MRINSPECT [2], and Explorer [3]. These devices are primarily used for visual inspection [4] and nondestructive evaluation [5] of urban gas pipelines. Other applications of the more compact designs are intended for inspection of power plants [6]. These in-pipe inspection tools are not specifically designed for deployment in air refractory channels, as the material that makes up the channels must not be subjected to pressures greater than 200 psi. In addition to this limitation, the dimensions of the refractory air channels restrict the size of the device to a miniature size. The device must also be radiation hardened and equipped with a fail-safe tether.

3. PNEUMATIC PIPE CRAWLER

The pneumatic pipe crawler is an inspection tool capable of providing live video feedback while traveling through the air supply line leading to the central plenum of a typical DST at Hanford. For AY-102 specifically, the proposed inspection path is approximately 30.5 m from grade, down through one of the drop legs, and then lateral to the center bottom of the tank secondary containment. The tool must also travel through several reducers and elbows, with diameters ranging from 7.62 to 10.16 cm (Figure 2).

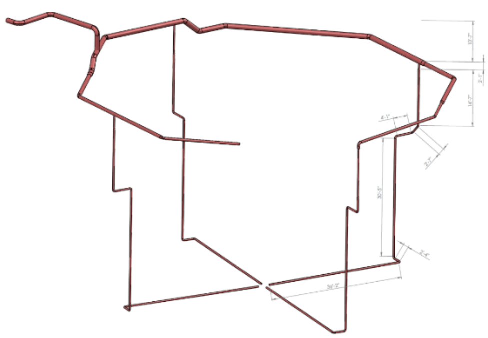

Figure 2. AY-102 air supply lines

Other requirements include:

1.) Tolerate elevated temperatures (76.6℃)

2.) Tolerate moderate radiation levels (85 rad/hr)

3.) Provide a means for removal in the event of a malfunction

The current design resembles that of a worm with a modular design, composed of interchangeable cylindrical modules connected with flexible links (Figure 3). The basic design is composed of five modules: a.) the front camera, b) the front and back grippers, c) the two middle expansion modules. The crawler also utilizes a control box, a tether, and an instrumentation module (currently being designed). The expansion modules use compact nonrotating tie rod air cylinders to proper the crawler forward during the peristaltic movements of expansion and contraction. Grip strength is vital as without sufficient grip strength, the tool would be incapable of travel as it wouldn't be able to grip the sides of the pipes.

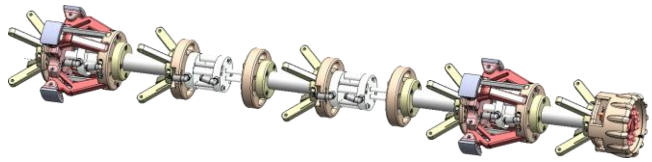

Figure 3. FIU's pneumatic pipe crawler

A full scale mockup of the ventilation system for AY-102 was manufactured, with the primary difference from the actual ventilation system being that FIU's version lays horizontal (Figure 4). This design makes it more difficult for the crawler as it wouldn't be assisted by gravity for the vertical segments. The crawler was able to successfully traverse the test bed, with the pull force of the crawler being approximately 178 N and the average recorded drag force around 22.2 N (peaking at 35.6 N).

Figure 4. Preliminary tether pull and drag testing

The path forward for the development of the pneumatic crawler includes a) finalizing the instrumentation module design, b) continuing validation of the device in full scale tests, c) continuing the modification of the design as needed, d) developing a cable management system, and e) integrating various non-destructive sensors.

4. MAGNETIC MINIATURE ROVER

FIU is developing a miniature rover that will access the primary tank floor of DSTs at Hanford through the annulus and refractory air slots (Figure 5), providing visual feedback of their condition. With widths ranging from as small as 2.54 cm to as large as 7.62 cm, the configuration of the air slots are maze-like, with four 90˚ turns needed to be traveled to reach the center of the tank (Figure 6). AY-102 has the most difficult inspection path due to the layout of the refractory cooling channels, as pictured; the other DSTs contain channels with much larger angles in contrast to the 90˚ turns of AY-102.

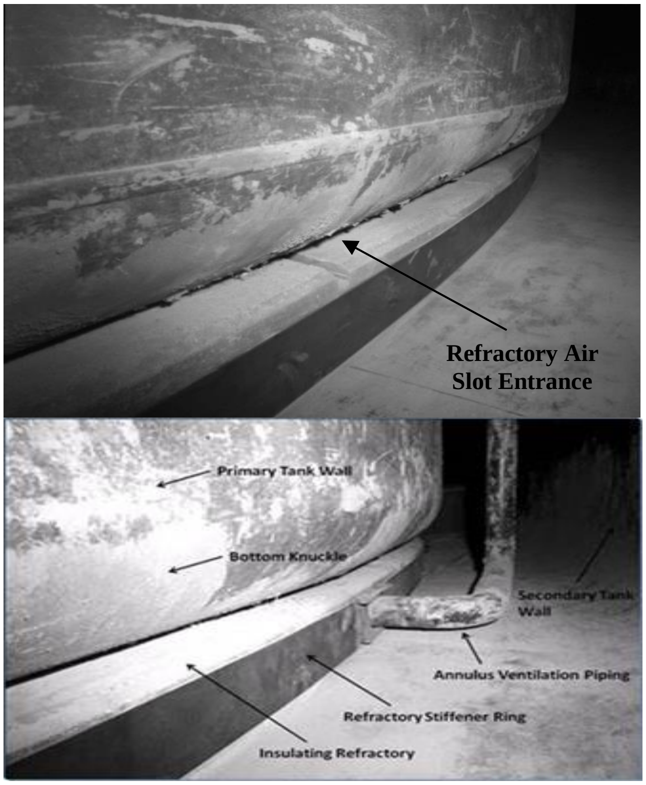

Figure 5. Primary tank and refractory air slot

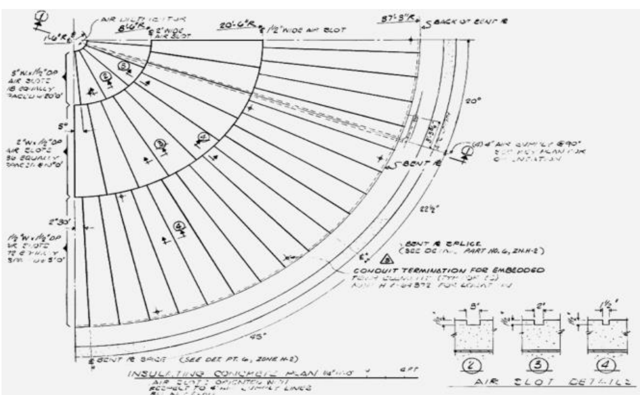

Figure 6. The AY-102 refractory air slot configuration

Through collaboration with site engineers, FIU has gathered information for the design specifications of the inspection tool, including annulus and refractory air slot geometry and maximum temperature/radiation limits for the device. Videos of the tank bottoms of other tank configurations (AW-101, AZ-102, and SY-103) from inspections done by an articulated robot ten years ago were viewed, providing FIU with a general idea of the conditions to be encountered along with the condition of the tank bottom surface. The video provided FIU with a better understanding of the refractory pad's low shear strength, along with how quickly debris builds up when the tool comes into contact with the walls of the air slots (Figure 7). The tool is designed to magnetically attach to the bottom of the primary tank (top of the air refractory channels) in order to avoid the debris that lines the bottom of the channels.

Figure 7. Screenshots from video of refractory air slots showing debris

A variety of prototypes were developed to take on this challenge, with the majority of the parts for the prototypes being designed in a 3D modeling software and 3D printed on site. With each prototype came a series of improvements, ranging from the strengthening of the wheels to reduce the effects of cyclic stress to the reduction of the overall size of the unit in order to be able to traverse the angles experienced in the channels (Figure 8). One of the design restrictions set by Hanford was the requirement of the unit to be tethered (in case of failure so as to have a way to retrieve the unit). This restriction was used to the advantage of the tool, as it was dual-purposed to also provide power. This voided the need to have the majority of integrated circuitry on the tool, thus making the tool more likely to survive the radioactive environment. A cable management system is also necessary for the storing/supplying of the tether, in order to ensure a tangle free deployment. A first prototype was developed with a stepper motor as the primary driving force and a timing belt used to adjust the gear ration of the system (Figure 9).

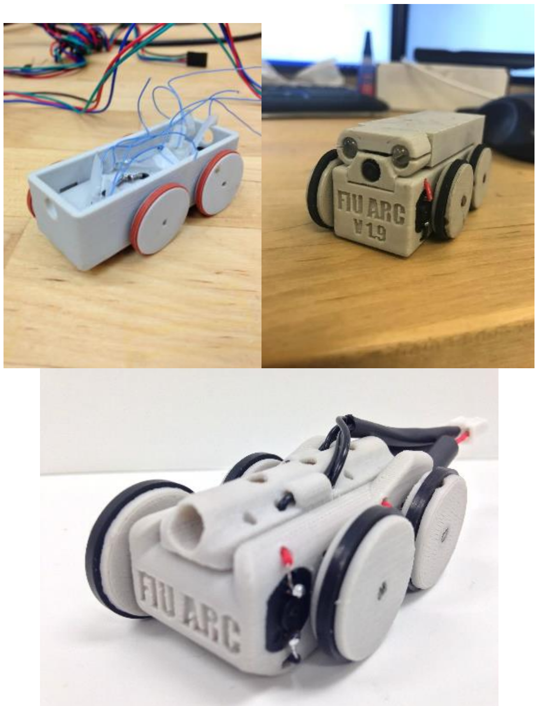

Figure 8. Evolution of the tool, with the most recent version on the upper right

Testing was done regarding the pull-force of the tool, with the conclusion of the tool pulling with approximately 5.3 N of force. The pull-force of the tool is important due to the tether that it must pull. A strong pull force is necessary to overcome the frictional forces created by the turns within the channels. Bench scale testing proved that the tool was capable of overcoming these frictional forces. A transparent test bed was also made in order to see the tool in action, proving that the geometry of the tool was fit for travel within the air refractory channels.

Future endeavors for the tool include the development of a deployment robot, as the entrance to the refractory air slots is unreachable by humans (approximately 80 feet underground with traces of radiation). There is also motivation for the integration of other sensors, including temperature and radiation sensors. A full-scale mockup will also be developed to more effectively test the inspection tools.

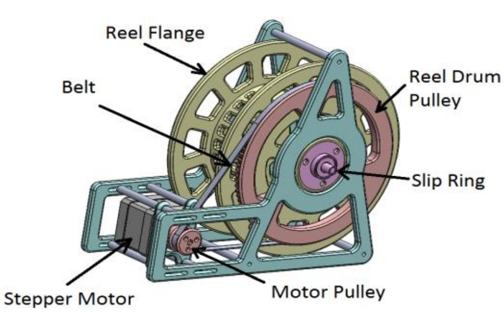

Figure 9. Cable management system

5. CONCLUSION

In this paper we presented the various inspection tools in development by Florida International University for the inspection of the double-shell tanks in Hanford. A pneumatic pipe crawler designed to carry out the inspection of the ventilation header piping of the DSTs was created with the goal of providing real time video feedback. A functional prototype was successfully manufactured and tested. Based off of the results the crawler has great potential to accomplish the proposed inspection. As the project progresses, non-destructive sensors will be added, along with the finalizing of the instrumentation module and more full-scale testing performed. A magnetic miniature inspection tool was designed for the inspection of the refractory air channels of the DSTs at Hanford. Lab-scale mock up tests identified various areas for improvement, including geometry of the inspection tool and wheel strength. A cable management system was also developed to make sure there is no tether entanglement during operation. Future work includes the development of a deployment robot to assist with the deployment of the inspection tools, as well as integration of environmental sensors for inspection purposes. A full-scale mockup facility is currently being developed to further test the readiness of the inspection tools before the final field deployment.

6. REFERENCES

[1] Gambao, E. M. Hernando, and A. Brunete. Multiconfigurable inspection robots for low diameter canalizations. in 22nd International Symposium on Automation and Robotics in Construction ISARC, Ferrara Italy. 2005.

[2] Roh, S.-g. and H.R. Choi, Differential-drive-in-pipe robot for moving inside urban gas pipelines. Robotics, IEEE Transactions on, 2005. 21(1): p. 1-17.

[3] Schempf, H., et al., Visual and nondestructive evaluation inspection of live gas mains using the Explorer™ family of pipe robots. Journal of Field Robotics, 2010. 17(3): p. 217-249.

[4] Dertien, E., S. Stramigioli, and K. Pulles. Development of an inspection robot for small diameter gas distribution mains. in Robotics and Automation (ICRA), 2011 IEEE International Conference on. 2011. IEEE.

[5] Hirose, S., et al. Design of in-pipe inspection vehicles for 25, 50, 150 pipes. in Robotics and Automation, 1999. Proceedings. 1999 IEEE International Conference on. 1999. IEEE.

[6] Caprari, G., et al., Highly compact robots for inspection of power plants. Journal of Field Robotics, 2012. 29(1): p. 47-68.