Development of Inspection Tools for the AY-102 Double-Shell Tank at the Hanford DOE Site -16383

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Abstract

Florida International University (FIU) has been developing inspection tools to assist in identifying the location of the leak in the primary tank of AY-102. This effort has led to the development of a magnetic miniature rover and a pneumatic pipe crawler. The rover will travel through the refractory cooling channels and the crawler will travel through the air supply lines to the central plenum underneath the primary tank. Both tools will provide visual feedback and potentially identify the location of the leak. The magnetic miniature tool is a remote controlled rover with four wheels driven by independent micro DC motors. The rover will have to navigate through over 40 feet of channel that vary in width from 1.5 to 3.0 inches with four 90° turns to reach the center of the tank. To avoid debris in the channel, the device will travel upside down magnetically attached to the bottom of the primary tank. The pneumatic pipe crawler is a worm type robot with a modular design, composed of interchangeable cylindrical modules connected with flexible links. The design is an evolution of previous peristaltic crawlers developed at FIU, and uses pneumatic actuators to emulate the contractions of the peristaltic movement. The crawler must travel approximately 100 feet through three and four inch piping and traverse through vertical risers, elbows and reducers to reach the central plenum. Prototypes for both the rover and the crawler have been designed and manufactured. Initial bench scale testing has validated the design concepts, demonstrating their ability to navigate through complex geometries. Future work will include full scale testing and evaluation of the systems' reliability.

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

Introduction

In August of 2012, traces of waste were found in the annulus of the AY-102 double-shell tank storing radioactive waste at the Hanford DOE site, prompting the need for developing inspection tools that can identify the cause and location of the leak. To assist in this effort, Florida International University is investigating the development of inspection tools that are capable of accessing the bottom of the tank floors, while providing live visual feedback in the double shell tanks. This effort has led to the development of two inspection tools: (1) a *magnetic miniature rover* that will travel through the refractory air slots, and (2) a *pneumatic pipe crawler* that will travel through the air supply lines to the central plenum. These inspection tools will assist site engineers at Hanford in understanding the source of the material found in the annulus space of AY-102.

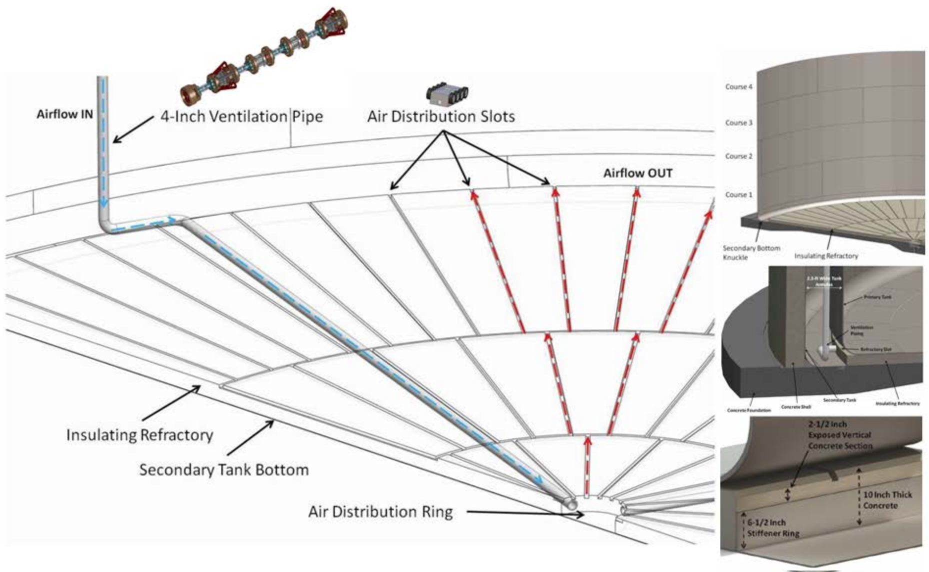

Figure 1. AY-102 insulating refractory pad cooling system.

Magnetic Miniature Rover

A number of inspection devices have been developed for visual inspection of small diameter pipeline structures including the MRINSPECT [1], MICROTUB [2] and Explorer [3]. The primary application for these devices has been visual inspection and nondestructive evaluation of urban gas pipelines [4], [5]. Additionally, some of the highly compact designs are intended for inspection of power plants [6]. However, these in-pipe inspection robots are not specifically designed for implementation in air refractory channels where the channel material must not be subjected to pressures greater than 200 psi. The restricted dimensions of the refractory air channels requires the device to have a miniature design which is also a significant challenge.. Additionally, the device will have to be radiation hardened and equipped with a fail-safe tether

In this section, the design of a remotely operated magnetic miniature rover is provided. The inspection tool is designed to maneuver through small air cooling channels in the AY-102 refractory pad and provide live video. The device will enter the air channels as shown in Figure 1 and have to navigate through approximately 40 feet of square channels to reach the center of the tank. Our initial goal is to develop a device that can travel 17 feet to the first concentric circle, although the ultimate goal is to reach the center of the tank. The first 17 foot section has a width and height of 1.5 inches. When the device reaches the next section, the width increases to 2.5 and then to 3.0 inches. To reach the center, the device will also need to negotiate multiple 90° turns. Previous inspections in AY-101 air channels have shown that there could be significant amounts of refractory debris in the channels [7]. To avoid the debris, our device will travel upside down magnetically attached to the bottom of the primary tank. Depending on the final deployment system, the device will likely need to travel down the side of the primary tank to reach the refractory slot. This will require the system to have to navigate past the 1 foot curvature of the primary tank bottom. A summary of the design requirements are as follows;

- Navigate through channels ranging from 1.5 to 3.0 inches in width and with a height of 1.5 inches
- Withstand radiation levels up to ~ 80 rad/hr
- Withstand elevated temperatures up to 170°F
- Limit loads on refractory pad to under 200 psi
- Remotely operated with minimal electronics on board
- Provide visual feedback
- Deployed through annulus riser

The design of our insepction tool includes a primary body which contains four interchangeable and independently controlled DC metal gear motors secured with a bracket assembly. The body also houses an inspection camera with LED lights and has a tether which includes 8 wires for powering the motors, a digital video communication line and a fail-safe line for the retrieval of the device. Since the inspection tool will be deployed in a radioactive environment, it does not carry any embedded electronics with the exception of the camera.

Figure 2 shows an initial conceptual design and a rendering of a first prototype of the inspection tool. In the early prototype, four wheels were motor driven and four of the wheels were free-rolling with the expectation of emulating a continuous track.

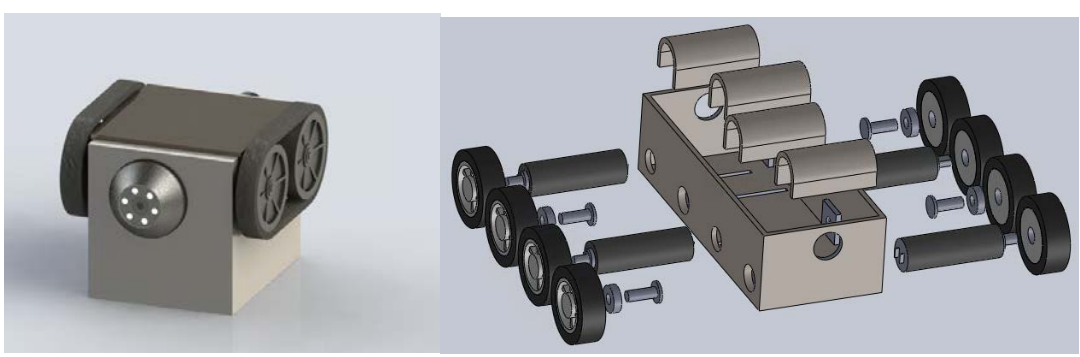

Figure 2. Initial proposed concept (left), rendering of an early prototype of the inspection tool (right).

The early prototypes of the inspection tools were used to demonstrate the concepts of the magnetic miniature rover. Although this was considered successful, additional improvements were made. The motors were initially adhered to the housing via an adhesive. In the event that a motor failed the entire unit would have to be remanufactured. In later prototypes, the motors were not permanently affixed to the housing, but secured with a bracket assembly. To minimize contact with the refractory walls, the device needed to be able to maintain a straight path over the course of the length of the channels. The path adjustments necessary required a significant amount of power to overcome the transverse friction at the wheels. Tests demonstrated that the first prototypes could not execute sharp turns due to insufficient power from motors. These sub-micro plastic planetary gear-motors were replaced with high-power carbon brush (HPCB) micro metal gear-motors. The new motors provide approximately 10 times the power output at 6 V than the previous motors and were significantly more durable since they utilized metal gear boxes. Specifications of the two micro motors are shown for 6V operations in Table 1.

Table 1. Comparison of DC micro motors

Motor type	Operative voltage	Gearbox ratio	RPM	Free-run Current	Stall torque	Stall current
HPCB Metal Gear Motor	3 – 9 V	298:1	100	120 mA	70 oz-in (2.9 kg-cm)	1600 mA
Plastic Planetary Gear Motor	3 – 6 V	136:1	500	45 mA	8 oz-in (0.6 kg-cm)	400 mA

Early prototypes also utilized a single magnet in the bottom of the housing to attach the tank. This magnet was replaced by an array of four neodymium magnet bars that distributed the normal force over the entire unit. The neodymium-iron-boron magnets resist demagnetization up to 300° F. Figure 3 shows a rendering and the current prototype of the inspection tool.

The control circuit in the current prototype consists of two DRV8835 dual motor driver carriers (H-bridge) and a Parallax 2-axis joystick. Each DRV8835 dual motor driver can deliver 1.2 A per channel continuously (1.5 A peak) to a pair of DC motors, and it supports an operating voltage range up to 11 V from the power source. The device is remotely controlled using a dual-axis 10 K potentiometer joystick. With the independent control of the DC motors, the inspection tool has a full range of maneuvering capability that improves the response of the unit to navigation challenges such as refractory wall contact, tank undulations (weld seams) and navigating through 90° turns.

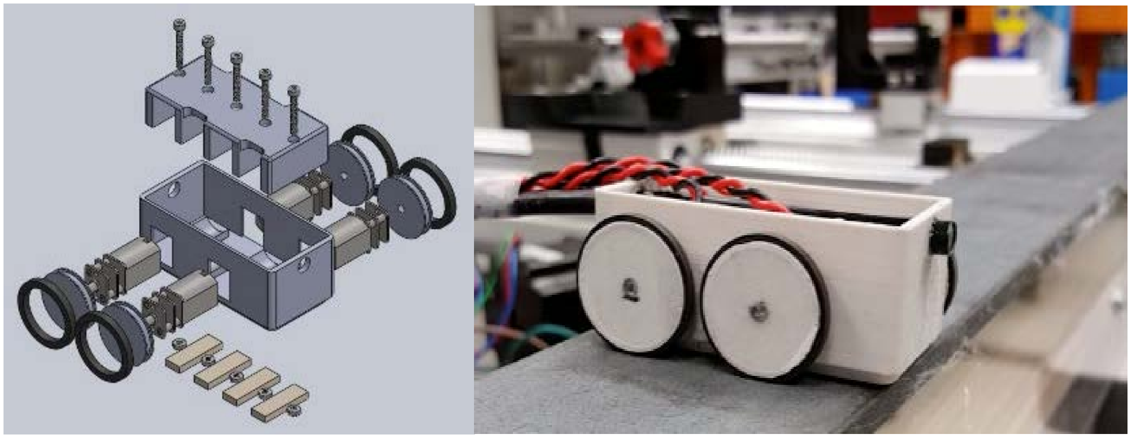

Figure 3. Current prototype of inspection tool.

Results

A bench scale test bed was designed and manufactured to evaluate the navigation capability of the inspection tool inside the refractory air channels. The current test bed is designed to emulate the first 17 ft of the refractory channel with 1.5 in x 1.5 in cross section. In the future, we plan to add sections that will represent the additional channels needed to reach the center of the tank including the 90° turns. Results from the testing demonstrated that the unit could successfully navigate through the first 17 ft of the channel (Figure 4).

Figure 4. Bench scale mock-up testing of the refractory pad.

Pull force tests were also conducted in order to determine the maximum amount of force the unit can pull. This will assist in understanding how much tether and ultimately how far the unit will be able to travel. Figure 5 shows two experimental set-ups to measure the maximum pull-force during the development of inspection tool.

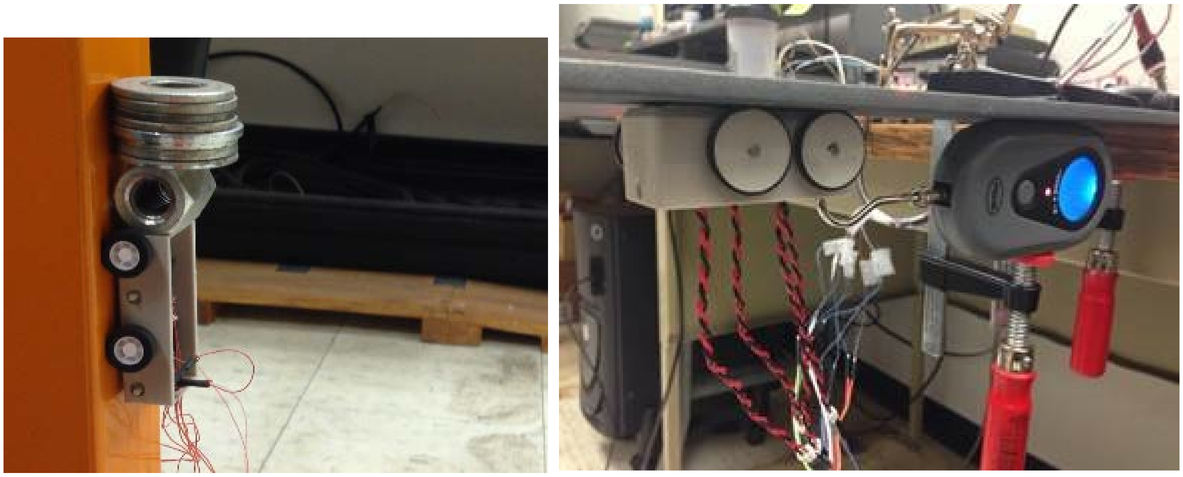

Figure 5. Maximum pull force measurement set up.

A number of trials were conducted to evaluate the unit pulling force. The results show that the device has an average pull force of 4.75 lbs with a 5V external power supply. Given that the weight of inspection tool is 0.18 lbs, the power to weight ratio of the tool is approximately 26. Since the motors are rated for operating within 3-9 V, more torque is available from the motors if needed. However, in order to convert the torque into available pull force, stronger magnets will be required.

Pneumatic Pipe Crawler

The pneumatic pipe crawler is designed to travel through the air supply line, leading to the central plenum of AY-102, and provide live video feedback. To reach the central plenum, the crawler will have to navigate down from grade approximately 100 ft, as shown in Figure 6. We will need to tap into the header and travel down through one of the drop legs and then travel laterally to the central plenum of the tank. The path is made up of schedule 40 pipes which are 3 and 4 inches in diameter, with reducers and several elbows. The four drop legs branch from the “header ring” with a diameter of 3 inches, transitioning to 4 inches.

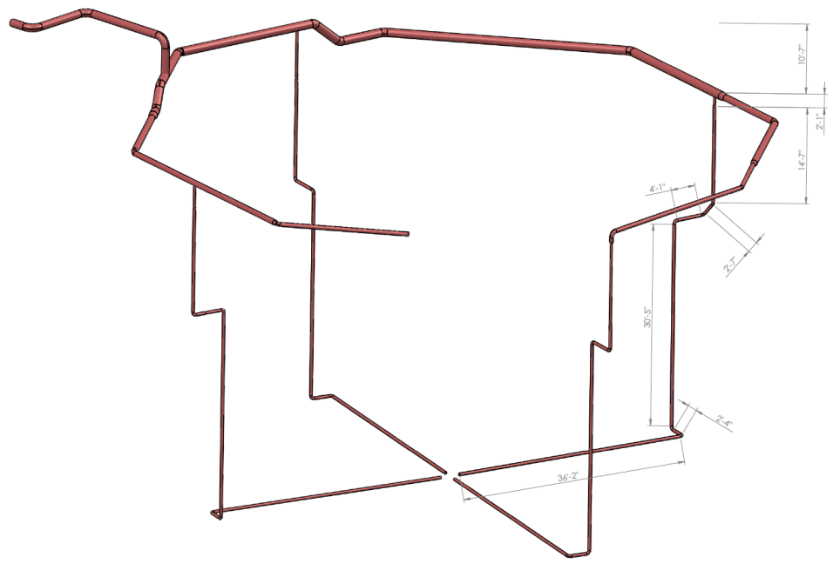

Figure 6. The ventilation header of the AY-102 tank at Hanford.

The pneumatic pipe crawler is a worm type robot with a modular design, composed of interchangeable cylindrical modules connected with flexible links. The design is an evolution of previous peristaltic crawlers developed at FIU [8], and has the following design requirements:

1. Crawl thru pipes and fittings which are 3 and 4 inches in diameter;
2. Climb vertical runs;
3. Provide live visual feedback;
4. Tolerate elevated temperature (170 F);
5. Tolerate moderate radiation levels (85 rad/hr);
6. Provide a means for removal in the event of a malfunction.

Figure 7 below shows an early design of the pipe crawler. The design utilizes pneumatic actuators to produce the contractions of the peristaltic motion, which is suitable for highly radioactive environments by not requiring embedded electronics, with the exception of the camera.

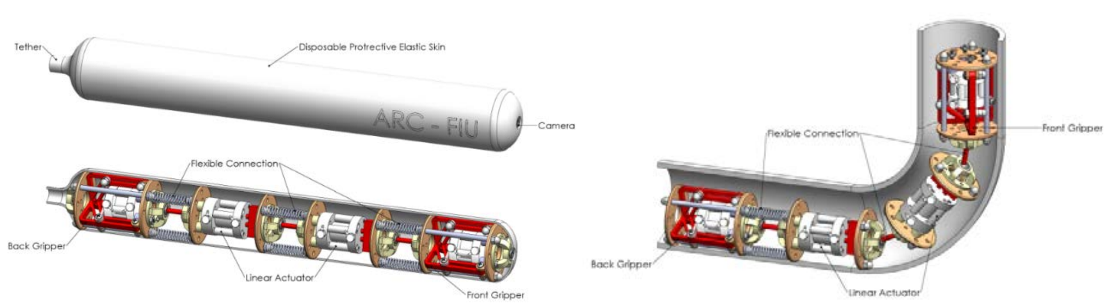

Figure 7. Pneumatic pipe crawler conceptual design.

The crawler is designed for use in highly radioactive environments with potential exposure to flammable gases. The primary advantage of using a peristaltic propelled crawler is that the device can navigate inside a pipeline without using any external moving parts, such as wheels and continuous tracks. Thus, if needed, the device can be fully encapsulated with a disposable protective skin which is suitable for decontamination. In addition, a pneumatically propelled crawler is easily radiation hardened and ignition proof. Pneumatic actuators are not likely to produce electric sparks typical of electric motors and actuators. Another advantage over previous versions is associated with its modular design. With the addition of extra modules in the system, it has the potential to be customized for specific tasks, such as instrumentation, material sampling, and pipe repair.

The current design is composed of four linear actuators, two of which propel the device and two actuate the gripping mechanisms located at each end of the crawler. The key components of the crawler are:

1. the linear actuators,
2. the gripping mechanism,
3. the tether,
4. the camera, and
5. the overall control system.

The linear actuators propel the device forward, using compact nonrotating tie rod air cylinders. These cylinders have two parallel piston rods that prevent the head from twisting as they extend and retract which prevents the crawler rotation, and consequently, prevents the rotation of the live video feedback as well. The gripping mechanism, shown in Figure 8, was designed to grip pipes with internal diameters varying from 3 to 4 inches.

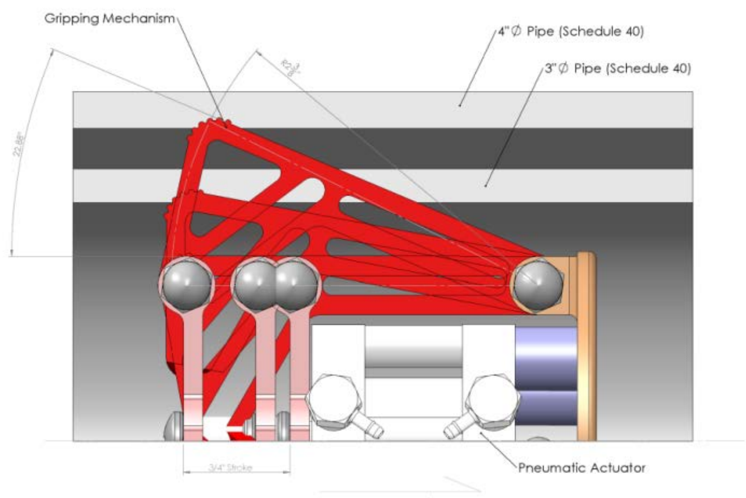

Figure 8. Gripping mechanism.

The tether required for the proposed inspection will be approximately 100 feet in length and consists of the following lines:

1. 8 pneumatic lines,
2. 1 digital video feedback cable, and
3. 1 retrieval steel cable.

During dragging, the retrieval cable will be responsible for carrying out the pulling load, relieving any tension in the other lines of the tether. The bundle will also be enclosed by an abrasion-resistant sleeve, which will reduce drag and protect the cables from wear and tear.

The front camera module carries a day-night 1.0 megapixel (720p) digital camera, with infrared cut-off filters and LEDs. Being an independent module, the camera can be easily replaced depending on the specific application.

The crawler movement is fully automated. The subsystems involved in its operation are shown in Figure 9 below. The portable control box is suitable for the field deployment of the crawler. The crawler is controlled remotely using any handheld device connected to its secure wireless private network, running a custom-made application which makes the inspection tool highly customizable, not having any dedicated control interface.

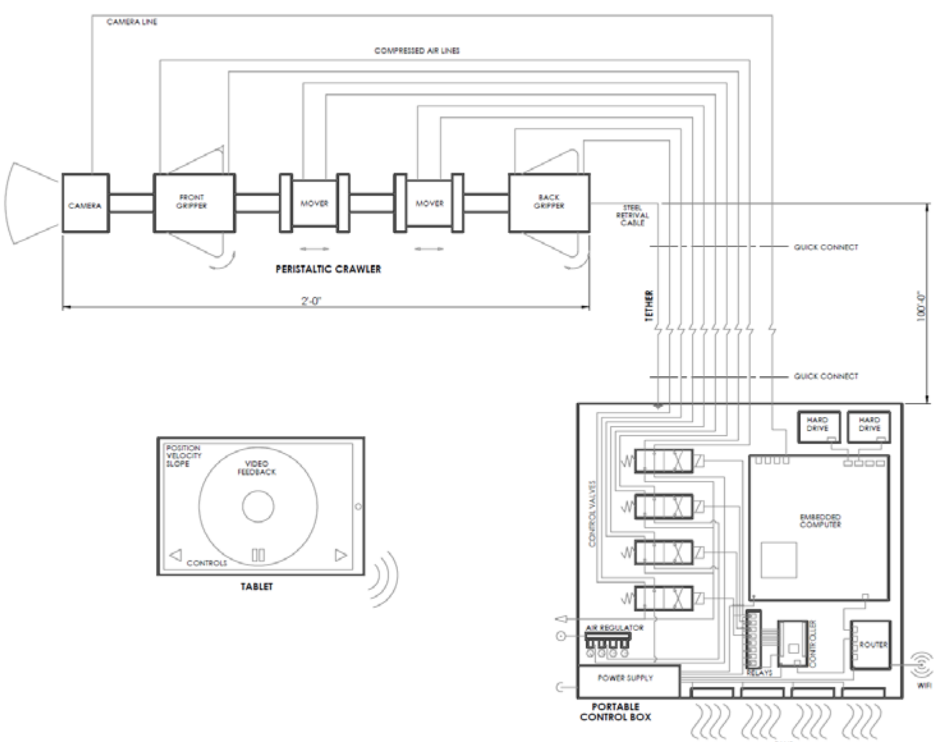

Figure 9. Schematic of the pneumatic pipe crawler control system.

Results

Figure 10 shows a 3D printed version of the crawler. The use of 3D printed thermoplastic parts has expedited the designing and testing process of the inspection tool.

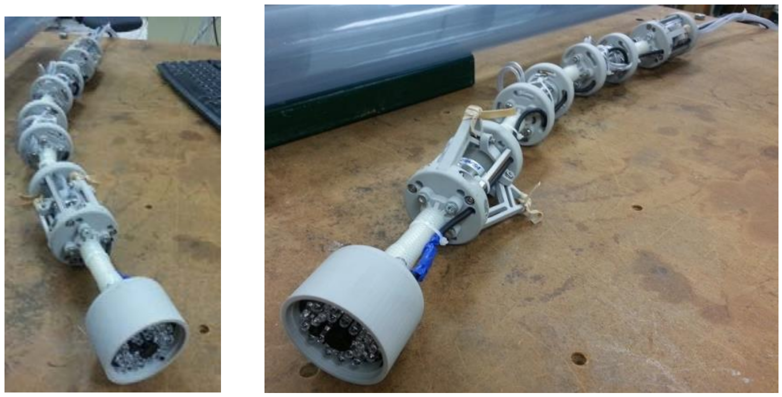

Figure 10. Pneumatic pipe crawler prototype.

To validate the design concepts, testbeds were manufactured to evaluate various parameters of the crawler including the maximum pull force of the unit as well as its navigational ability. Figure 11 below, shows the modular bench scale testbed used in the crawler design process. The testbed consists of 3 and 4 inch clear PVC pipe, including elbows and reducers.

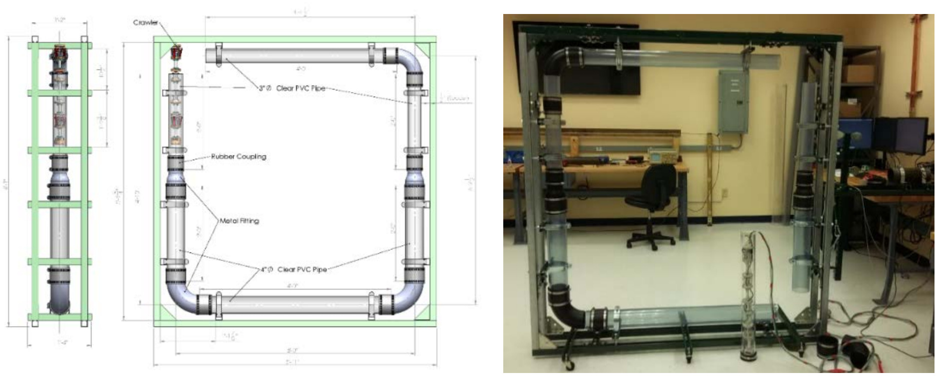

Figure 11. Modular bench scale testbed.

Figure 12 shows the crawler successfully going through the 3” elbow in the pipe loop, where several levels of misalignments where tested.

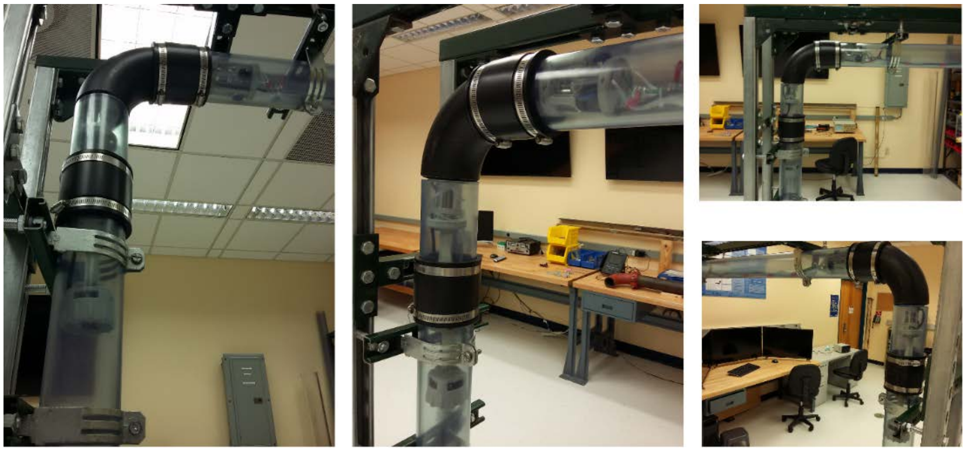

Figure 12. Crawler going thru a 3” elbow.

Maximum pull force tests were also conducted as shown in Figure 13 . Several gripper designs have been investigated and we are currently looking to finalize the design to maximize the pull force. This is important since the distance the crawler can navigate is directly proportional to it maximum pull force.

Figure 13. Pneumatic pipe crawler preliminary pulling tests

Discussions and Conclusions

Two inspection tools have been developed at FIU with the goal of providing visual information of the AY-102 tank floor. Based on initial bench scale testing, both systems appear to have great potential to accomplish the goal.

The magnetic miniature rover will travel upside down magnetically on the tank bottom through the refractory air channels. A simple design concept was developed and multiple modifications to the design has led to increased pulling forces, improved reliability and improved navigation capability. Although the validation has been completed, future work includes finalizing the design of the tether and ensuring that unit will meet all necessary requirements for deployment at Hanford. This will include full scale mock up testing at FIU and possibly cold tests at Hanford. The pneumatic pipe crawler will have to travel through approximately 100 feet of 3 and 4 inch diameter pipes with a number of elbows, verticals and reducers to reach the central plenum. Bench scale tests at FIU have demonstrated the tools ability to handle these challenges. Similar to the rover, the tether for the system needs to be finalized and a full scale mock up test bed will be developed to demonstrate the units ability to travel the 100 ft, providing visual feedback. Future efforts may also include incorporating sensors into the unit to provide information on radiation levels or possibly on the structural integrity of the tank and transfer system.

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