Development of an Inspection Platform and a Suite of Sensors for Assessing Corrosion and Mechanical Damage on Unpiggable Transmission Mains

Quarterly Report

For the period of

July 1, 2003 to September 30 , 2003

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October 2003

Revised January 14, 2004

DOE Award Number: DE-FC26-02NT41645

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ABSTRACT

This development program is a joint effort among the Northeast Gas Association (formerly New York Gas Group), Foster-Miller, Inc., and the US Department of Energy (DOE) through the National Energy Technology Laboratory (NETL). The total cost of the project is $772,525, with the National Energy Technology Laboratory of the US Department of Energy contributing $572,525, and the Northeast Gas Association contributing $200,000.

The present report summarizes the accomplishments of the project during its fourth three-month period (from July 2003 through September 2003). The efforts of the project focused during this period in completing the assessment of the tether technology, which is intended to be used as the means of communication between robot and operator, in designing the MFL sensor module, in completing the kinematic studies, and in initiating tractor design. In addition, work on the ovality sensor progressed significantly, while work on system integration was initiated focusing at this point in time on module coupling.

Results to date indicate that the robotic system under design will be able to meet most of the design specifications initially specified. Earlier concerns regarding the portability of the system are shown to be a non-issue, with new more detailed analysis showing that from a locomotor point of view an inspection of a 16”-24” pipe size range with a single platform is most likely possible However, the limitations imposed by the sensor are more restrictive, preliminary results indicating an inspection range of 16”-20” pipe sizes. In addition, tether use will most likely have to be limited to medium and low flow conditions in order to preserve tether integrity.

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EXECUTIVE SUMMARY

The project has progressed well during this reporting period with some minor deviations from the original schedule. However, the overall project schedule has not been affected and work is expected to be completed by December 2003. Tether analysis and lab tests, and winder module design are practically complete. The analysis of the impact of the MFL sensor on the design of the system is complete, thus allowing the overall preliminary design of the robotic system to be undertaken. This last effort is well in progress. The design of the MFL deployment mechanism is also in progress, with more than fifty percent of this effort completed. System integration was initiated with review of coupling requirements between modules. Preliminary design of individual components is underway. Once these individual components are well defined, system integration will be completed (completion expected in November 2003). During the period of October 1, 2003, to mid-November 2003, all sub-assemblies will be integrated into a single platform design. The final report is expected to be available by the end of December 2003 for review..

INTRODUCTION

With the recent advances in robotics and sensor technology, and the occurrence a few unfortunate pipeline accidents, the Office of Pipeline Safety (OPS) of the US Department of Transportation has endorsed the concept that all oil and gas transmission pipelines should be capable of 100 percent inspection. This can be accomplished through the elimination of pipeline obstacles that would allow for pigging, or through the development of innovative inspection technologies, hydro testing, or use of direct assessment techniques. Problems arise when the piping network is older and/or constructed without pigging as a design consideration. This is the situation with countless miles of transmission pipelines owned and operated by local gas distribution utilities. There are many physical “obstacles” in the piping network that makes pigging impossible. The most intractable of these obstacles include:

- Bends/elbows with bend radius less than 1.5 D. This is a very common obstruction.
- Mitered joints/elbows greater than 10 deg. This is an obstacle found in older systems.
- Back to back combinations of bends/joints. Commonly found in tightly spaced areas.
- Reduced port valves. This includes valves with ports smaller in diameter than the pipeline. This is also a very common obstacle.
- Reduction/expansion in pipe diameter greater than 2 in.
- Unbarred branch connections. Pigs are not designed to turn down branch lines, and therefore, branch lines must be barred to prevent the nose of the pig from crashing into the lateral and jamming itself in place.

The Gas Research Institute in a report issued in 1995 (entitled “In-Line Inspection of Un-piggable Natural Gas Pipelines”) noted that the cost to replace just two of the most common obstacles would be substantial, costing over $3 billion. Therefore, the development of tools to inspect un-piggable transmission and/or distribution pipelines presents a both a formidable technical challenge as well as a significant financial incentive to the gas industry. The adaptation of current pigging technology may not be viable given the geometric challenges of existing interstate and utility owned pipelines. External direct assessment techniques have not been shown to be universally adequate, accurate or cost-effective. Use of an innovative robotic approach would apparently be dictated.

The inspection of un-piggable gas transmission and distribution pipelines requires the innovative marriage of a highly adaptable/agile robotic platform with advanced sensor technologies operating as an autonomous or semi-autonomous inspection system. The work being conducted under this program is based on a robotic platform that is train-like in nature and is based on Foster-Miller's Pipeline Inspection System (PipeMouse) developed in early to mid 1990's. Both front and rear tractors propel the train in the forward and reverse directions inside the pipeline. Like a train, the platform includes additional "cars" to carry the required payloads. The cars are used for various purposes including the installation and positioning of sensor modules, the power supply, data acquisition/storage, location/position devices and onboard micro-processors/electronics. The onboard intelligence gives the platform the benefit of an engineer steering the train through complicated pipe geometry. The system includes launching and retrieval stations that are similar to that used for conventional pigging systems, but much simpler in design and operation.

The Pipe Mouse was built to a strict set of performance criteria appropriate for low-pressure gas distribution networks. The Mouse was designed to be highly mobile and agile, had the ability to travel long distances from the entry point and steer down branch line of pipe tees, negotiate mitered (zero degrees) elbows, navigate in both the horizontal and vertical planes, pass through partial section valves, and adapt, by a factor of two, to changes in pipe diameter. These same types of obstacles create problems for inspecting un-piggable transmission mains.

General Electric Power Systems (previously PII North America; a subcontractor for this project) has extensive experience designing and working with sensors based on ultrasonics, electromagnetism, eddy-currents and optical methods. For this program, sensor development will be considerably more challenging than for conventional pigging due to the greater variance of pipe diameter and the more difficult obstacles encountered in un-piggable pipelines. The ability to actively expand and retract the onboard sensor will be needed, not just for obstacle avoidance, but to allow upstream (reverse direction) travel.

The robot will be controlled via a fiberoptic tether system, which will be analyzed, designed, and tested as part of this project. The tether is expected to provide sufficient range for the robot to inspect a substantial length of the pipe without the need of many expensive tapings of the pipeline

To power the computer, sensors, data acquisition and drive wheels, some form of energy storage and electrical power supply is required. Of all the various possibilities (e.g., batteries, fuel cells, ultra-capacitors, flywheels, etc.), the battery approach is clearly the simplest, safest and most reliable. To minimize the number of launch and retrieval stations, the batteries should have maximum energy density. The modular platform concept has an advantage in that battery "cars" can be added as needed, up to the length of the launch tube. Certain obstacles (e.g., mitered corners) also impose a length constraint. Different battery and charging modules may also be swapped in and out based on the range requirement, power and availability of recharging stations.

The anticipated benefits derived from the use of this platform include the following:

- Ability to inspect otherwise inaccessible pipelines (transmission and distribution).
- Cost savings from not having to remove pipeline obstacles for conventional pigs.
- Inspection cost much lower ($/mile) than direct assessment or hydro testing.
- A more versatile platform capable of performing a variety of inspection services.

EXPERIMENTAL

During the period of July 1, 2003 to September 30, 2003 work on the project continued at a pace mostly consistent with the timetable presented in the previous report. Some deviations were experienced; however, no impact on overall project timetable is anticipated.

Task 1: Program Management

Task 1.1. Research Management Plan

Completed

Task 1.2. Technology Assessment

Completed

Task 1.3. Technical Oversight

The latest schedule of tasks calls for a completion of all component preliminary design work to be completed by mid-November 2003, with system integration to be completed by the end of November 2003. December will be devoted to writing the final report and reviewing the results of the projects with the sponsors.

Task 2: Mechanical Design: Robotic Design and Sensor Module

Task 2.1. Robotic Platform

Task 2.1.1 System Engineering

Task 2.1.1.1 Kinematic Analysis

During this period the kinematics/mockup-testing portion of the program was completed. This effort included the following tasks:

- Physical testing of mockup robot within 16” pipe (15”ID).
- Establishing control motions & required sequences through obstacles.
- Verifying overall robot volume based on high-risk obstacles
- Estimating maximum triad/tractor sizes, and ultimately system portability.
- Further establishing coupling requirements.

The required motions of the tractor (2 triads and intermediate module) were simulated by moving the kinematic model by hand through 16” pipe. The tractor model was designed and built as a highly adjustable scaled model with equivalent degrees-of-freedom. Sections of straight pipe, mitered bend, and back-back in and out-of-plane pipe sections were assembled (Figure 1). The triad/tractor and module section was incrementally moved by hand through each obstacle, while the position and relative sequencing of each degree-of-freedom was recorded. Simulated tractor components (motor drive, steering, and clamp mechanism) were attached to the triad skeleton to verify that the system could physically fit through the pipe obstacles.

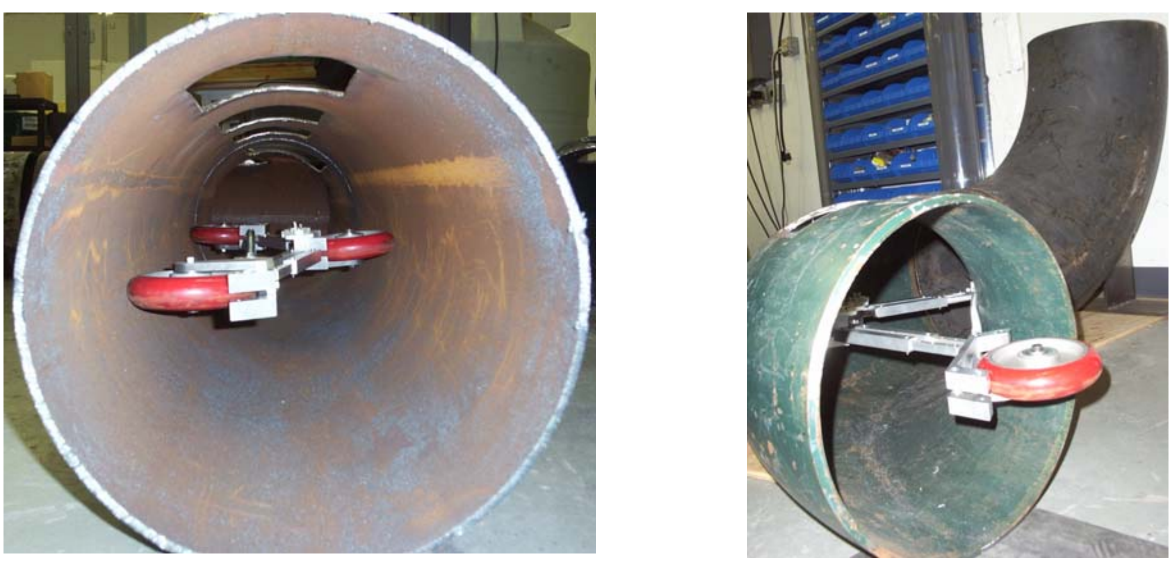

Figure 1. Mockup tests

The "limiting" obstacles in the design process are the back-back out-of-plane bends and the mitered bend. Since the triads are sized to fit through a plug valve, and given the fact that the required control sequence has been verified with the Pipe Mouse, it was decided that further verification of plug valve passing was not required. The results of the back-back out-of-plane bends and the mitered bend passing tests are detailed below.

Back-Back Out-of-Plane-Bends

The control sequence for moving a triad through a back-back out-of-plane bend was simulated. The actual system will consist of 2 triads separated by an intermediate module. Mockup tests verified that the tractor unit (2 triads and module) could pass through with the appropriate couplings. The intermediate module, like all modules on the inspection platform, will be optimized in shape to pass through all obstacles, and because of its symmetric cross-section will be position-independent. Proper positioning within the bend is key to optimization of platform portability.

The back-back out-of-plane bend was identified early in the program as the limiting factor in platform portability (number of pipe sizes a given platform could negotiate). Portability of the platform is determined by the maximum pipe size (at minimum wheel base) and minimum pipe size (at maximum wheel base) that a tractor can negotiate. In large pipe the wheel base must be long enough to remain stable, while in short pipe the wheel base must not be so long as to limit bend passing. Preliminary indications are that with optimization, a range of 16"-24" may be possible with a single platform.

Mitered Bends

Control of this motion is fairly straight-forward, and has been verified with the Pipe Mouse. Using the same criteria as applied to the back-back out-of-plane situation, it is anticipated that with optimization a single platform may cover the 14"-24" pipe size range. Since the mitered bend is less limiting than the back-back out-of-plane situation, our best estimate of total system portability at this time, and as dictated by the back-back out-of-plane obstacle, is 16"-24" with a single platform.

Task 2.1.1.2: Brainstorming Session

Completed.

Task 2.1.1.3: Tractor Design

The drive power requirements of the tractor locomotion system have been revised based on drag and weight data provided by PII from their MFL sensor development efforts. The previous power budget estimates were made based on an earlier study, and have since been cut in half due primarily to rolling friction elements provided for by PII in their MFL sensor design. Although the MFL sensor requires 2 passes to complete an inspection (out and back to launch tube), the reduction in sensor drag still cuts the power requirements from the previous assessment in half. A summary of the revised power requirements is included below in Figure 2. As stated in the Figure, we estimate that 4 battery modules will be required. Foster-Miller will start the process of designing the battery module in the next reporting period.

Total Estimated Battery Capacity for 2.5 Mile Mission - Sensing in Both Directions

Operational State	Power (watts)	Time (hr)	Total Energy Required (W hr)
Quiescent	300	16	4,800
Inspection	260	15	3,900
Bends/Elevation Changes	950	0.5	475
Obstacle Negotiation/MFL Deployment	460	0.5	230
Total Estimated Battery Capacity:			9,405

@ 2,500 W hr/module (estimate): 4 battery modules required

Assumptions:

1. *Based on stated mission profile for 2.5 mile inspection*
2. *16 hr mission time: 7.5 hr forward (inspecting), 7.5 hr return (inspecting), 1 hr for obstacle negotiation*
3. *380 lb system drag during inspection (sensor, modules, traction)*
4. *Negligible flow drag (nominal conditions)*
5. *Bend power includes elevation change (20 feet) @ 1,400 lb x 30 ft/min; neglected power to descend bends*

Figure 2. Revised power requirements

Power requirements of the triad/tractor drive system were calculated on two levels:

- Steady-state inspecting in level pipe where 1 triad (3 wheels) would share the load.
- Peak load condition where 2 triads (6 wheels) would share the load.

The total drive force required will be equal to the sum of the steady-state drive force and the peak drive force. The system will be designed such that a single triad can pull the train under steady-state conditions. Motor sizing was determined by the worst case condition where a tractor (2 triads, 6 wheels) would pull the train under peak load conditions. Highlights of this analysis are included below.

Steady State Driving Force:

$$F_{d\_steady} = F_{elec\_modules} + F_{bat\_modules} + F_{sensor} + F_{shear\_drag} + F_{pressure\_drag} + F_{triads} + F_{mag}$$

Where:

$F_{elec\_modules} = 55\ lb_f$ Frictional drag of payload modules to pipe wall

$F_{bat\_modules} = 142\ lb_f$ Frictional drag of battery modules to pipe wall

$F_{sensor} = 108\ lb_f$ Rolling friction, total for 4 MFL magnetizers

$F_{shear\_drag} = 0.5\ lb_f$ Shear drag on eight modules in straight pipe

$F_{pressure\_drag} = 0.4\ lb_f$ Pressure drag on leading module

$F_{triads} = 72\ lb_f$ Rolling friction of all 12 driven triad wheels

$F_{mag} = 20\ lb_f$ Magnetic eddy current forces

$$F_{d\_steady} = 398\ lb_f$$

Peak Driving Forces

$$F_{d\_peak} = F_{step} + F_{climb} + F_{valve\_pressure\_drag}$$

Where:

F_{step} = 132 lb_f Force of driving wheel over plug valve step

F_{climb} = 1280 lb_f Force to pull train through 20 ft elevation

$F_{valve\_pressure\_drag}$ = 6 lb_f Pressure drag upon entering plug valve

Since it is highly unlikely that a plug valve will be positioned in a vertical section of pipe, and the fact that the force to pull the train through a 20 ft elevation (F_{climb}) is the highest peak force encountered, the peak power was calculated solely on F_{climb}.

Total Drive Force

$F_d = F_{d\_steady} + F_{d\_peak}$ = 398 lb_f + 1280 lb_f = 1,678 lb_f

Total Drive Power

$P_{total} = F_d \times V_{pig}$ = 1.53 hp (where Vpig = 30 ft/min)

Wheel Speed = 19 rpm

Assuming that only six of the twelve driven wheels provide driving power at any instance (thus introducing a safety factor of two), the torque on each wheel is:

Wheel Torque = 839 in-lb_f (based on six of 12 driven wheels providing power)

Wheel Power output = 0.25 hp

Assuming that Drive Train Efficiency = .75

Individual Motor Power = 0.34 hp

Thus, **total power for all twelve drive motors is 4.08 hp**, as compared to 2.04 hp required to drive the robot (1.53 / 0.75).

Remaining tasks to complete the tractor/triad design include the packaging of the revised wheel drive assembly, the specification of the clamping system based on the revised drive power requirements and the integration of the clamping motor and lead-screw into the triads. Once these tasks are complete, the triad link arms will be designed, completing the design of the tractor/triad systems.

Task 2.1.1.4: Winder Design

Winder design is complete. This design is proprietary to Foster-Miller. The winder module will be integrated into the inspection system once the triad, battery modules, and coupling/curling link designs are complete.

Task 2.1.1.5: Module Design

Individual module design has been initiated but is still in early phases, awaiting the completion of the preliminary design of individual components.

Task 2.1.1.6: Sensor Deployment Mechanism Design

Upon evaluating the top three MFL sensor concept options detailed in the last report (rotating, helical, and axial – all single magnetizers), PII determined that an axial motion is preferred, and that 2 magnetizers could be fit on a single module. Two modules with 2 magnetizers each would be required. The helical and rotational concepts were eliminated due to the fact that the rotational speed would need to be 7 to 10 times the forward velocity, and that eddy current generation (due to the high rotational velocity) would further increase drag and tractor power requirements.

The 2-magnetizer module, referred to as the "Bear Trap", has gone through a design evolution. The specifics of the design are proprietary to GE/PII and for this reason are not presented here. However,it can be said that the concept currently considered utilizes support/centralizing wheels that actuate with the sensor and retract for obstacle negotiation.

Mockup studies were conducted by PII to evaluate the MFL sensor module's obstacle passing capabilities. Performance limitations due to overall length, frictional drag reduction, and passing orientation were evaluated.

Task 2.1.1.7: System Integration

Two critical component of the platform are the inter-module couplings, and the curling links (adjacent to the tractors for assistance around bends). The inter-module couplings must be capable of transmitting tension and compression through the platform (front and rear tractors providing locomotion), torsion, and in some cases must allow rotation between modules. Unlike the Pipe Mouse design, where passive springs were sufficient to "curl" the lightweight platform, this inspection platform will require active curling links due to the high turning moments required. The inter-module couplings and curling links remain as the only major components left to be addressed in this design study. Once the inter-module couplings, curling links, and the major system subassemblies discussed previously are complete, the integration or "assembly" of the inspection platform will commence. The integration tasks will include:

- Packaging of the emergency sonde.
- Packaging of the winder module.
- Layout of the launch tube/charging-data interface
- Integration of motor drivers, sensors, controllers, and wire harnesses
- Integration of camera and lighting
- Integration of ovality sensor

Electrical components, both COTS and custom, will be specified. The System Interconnect Diagram (electrical wiring) and Component Interconnect Diagram (block diagram of mechanical, electrical, and control components and their functional interface) will also be completed.

Task 2.2 Sensor Module

Task 2.2.1 MFL Sensor System Design

PII's efforts to develop an MFL sensor for detecting pipe wall corrosion may be divided into the following areas:

- Magnetizer optimization for 16" to 20" pipe.
- Shunting of magnetizer to reduce disengagement force and ease obstacle negotiation.
- Drag force reduction.

The magnetizer has been optimized and consists of 3 segments connected by a common strip of flexible material to allow flexing and conformance along the circumference of each pipe size (16" – 20"). Based on the FEM analysis, PII is confident that a 20/40 inspection specification may be met with pipe wall thickness less than 12.7 mm (0.5"), but that inspection accuracy will drop to a 30/50 specification in 12.7 mm pipe. One option for improving the inspection accuracy of 12.7 mm pipe is to perform multiple passes. There will be two MFL modules, each with 2 magnetizers. This requirement is dictated by the need to pass plug valves.

Shunting of the magnetizers, where the magnetic field is "short-circuited" to reduce the magnetic attraction force, is being studied as a way to reduce the disengagement force required to pull the magnetizers off the pipe wall, and reduce attraction to the pipe wall and plug valves when in a retracted position. The force required to pull the magnetizers off the pipe wall is 4 kN (900 lbs.) each, which equates to an axial force of 2,500 lbs at each module to retract the 2 magnetizers into a plug-passing position. The issues with shunting are the reduced effectiveness of the magnetizer due to the bushings required for supporting the rotating shunt magnets, the force required to rotate the shunting magnets, and the volume required for a mechanism to rotate the magnets. PII is currently evaluating these tradeoffs and other options, which include a "brute force" approach where a motor and lead-screw may be used to disengage (and engage) the mechanism, and other mechanical means to keep the magnetizers away from obstacles during passage. A design recommendation will be made in the next reporting period.

Drag force from the magnetic attraction of the MFL magnetizers to the pipe wall has been greatly reduced by the incorporation of roller elements within the face of the magnetizer. This design improvement allowed the drive power requirements of the tractors to be reduced by approximately one-half.

Task 2.2.3 Ovality Sensor Design

To minimize development costs and time, a commercial off-the-shelf single point optical displacement sensor will be used as the core of the ovality sensor. A rotating mirror or prism will be used to scan the measurement point around the circumference of the pipe and data will be continuously collected as the robot moves forward. The ovality sensor module should be located in a center section of the robot placed away from the front or rear ends where bright lights for the video camera could interfere with the measurement. The demands on this device are considerable and only a few available sensors will satisfy all the requirements. In summary, the requirements include:

- The sensor must be small enough to fit within the space constraints of the platform.
- The sensor is not designed for high pressures and must therefore be contained in a pressure housing with an optical window for the laser beam.
- All optical triangulation sensors operate over a fixed range, for example the OMRON ZX-LD300 has a particularly wide sensing range from 100 mm to 500 mm (3.94 to 19.68 inches). Therefore, for a 12 to 24 inch pipe diameter range, the sensor must cover a 6 to 12 inch measurement range. Allowing distance for the scanning mechanism of 4 inches, the ZX-LD300 covers a maximum range of 15.68 inches and therefore the ovality sensor, if the ZX-LD300 is selected, must remain within 3 inches of the centerline of the pipe. These values will be tighter with some alternative commercial sensors.
- A high sample rate is required to achieve good coverage of the pipe surface during the 30 ft/minute forward scanning speed.
- Resolution of at least ½ of the required 0.25 inch ovality measurement resolution is required. The ZX-LD300 has a 0.3 mm (0.012 inches) resolution which is adequate.

- Capability to measure a wide range of surface colors and finishes.
- Either an analog or a digital signal output with maintainable calibration.

One suggested design of the ovality system requires that the module be split into two sections physically connected by multiple rods. The right hand section will contain a stepper motor that rotates the scan mirror. The displacement sensor will be located in the left-hand module, which has an optical quality window to transmit the laser light to and from the sensor.

The ovality sensor also requires:

- External amplifier for the displacement sensor.
- A/D converter or digital interface for the distance data.
- Driving circuits for the stepper motor with a means to detect a reference position each revolution.
- Computer to control steeping motor position and record the optical displacement, motor angle, time, and robot position in a data file.

If sufficient space does not exist in the ovality measurement module, the support electronics may be placed in an adjacent module. Candidate sensors have been identified and their characteristics ar been reviewed, prior to final selection.

Task 2.3 Camera/Illumination Design

A state-of-the-art review of camera and lighting options for the robotic inspection platform is underway. The camera system will be used to accomplish two important tasks: (a) robot navigation through pipeline obstacles, and (b) inspection of the condition of the pipe walls. The use of an extremely wide-angle lens mounted on a fixed camera is probably a compromise solution that may be inefficient for both these needs. Sidewall inspection will be limited and the wide-angle lens distortion may affect navigation. The option of using a narrower lens with a single axis tilt mechanism is also a poor choice because the large and complex robot must be rotated to accomplish the wall inspection. We believe that using a camera lens with no more than a 90 degree beam width together with either a pan and tilt or tilt and rotate system will provide effective inspection and navigation without compromise. These systems, even when placed in a suitable pressure housing, can be very compact. The camera and illumination systems will be incorporated into the robotic platform (as a separate module or integrated into an existing module) once the packaging of the tractor/triads, batteries, sonde, MFL Sensor, and associated electronics are complete.

Task 3: Electrical/Control Design

Design of the electrical and control systems has been initiated and progressing in parallel with the design of the modules.

Task 4: Communication

Task 4.1 Tether Assessment

The tasks remaining to conclude the tether assessment as of the last status update included:

- Attenuation tests on wound fiber under 1 lb tension.
- Repeat of corner abrasion test on bend-insensitive fiber.

Izumi International Co., a subcontractor of Stocker-Yale (manufacturer of bend-insensitive fiber) was contracted to wind 1 km of the fiber on a mandrel under 1 lb of tension. A mandrel was manufactured to accept the fiber and mount to Izumi International's winder/tensioner. The mandrel was sized such that the inside diameter and final outside diameter (wound) were equal to the dimensions of the winder module (2.5" and 4.25" respectively). The measured attenuation of the 1 km of fiber will be extrapolated (linear relationship) to a length of 2.5 miles to determine total signal degradation.

The winding of the fiber onto the mandrel was attempted in early September, but could not be completed due to a component failure on the winder/tensioner machine. The winding/tensioning operation will be resumed in mid-October upon repair of the machine.

Once the mandrel is wound, it will be shipped to Stocker-Yale for attenuation tests. Upon completion of the attenuation tests (2 day turnaround), Foster-Miller will repeat the mitered corner abrasion tests (discussed in the last report), measuring attenuation pre and post-test. This test will conclude the tether analysis portion of the program.

Task 5: Auxiliary Components

The design of the various auxiliary components was initiated and will continue rapidly through the months of October and November.

PROJECT STATUS BY TASK (*as per June 30, 2003*)[1]

Task 1: Program Management	On-going
Task 1.1: Research mangement Plan	Completed
Task 1.1.1: Requirements Document	Completed
Task 1.2 Technology Assessment	Completed
Task 1.3 Technical Oversight	On-going
Task 2: Mechanical Design: Robotic Platform and Sensor Module	On-going
Task 2.1: Robotic Platform	On-going
Task 2.1.1: Systems Engineering	On-going
Task 2.1.1.1: Kinematics Analysis	On-going
Task 2.1.1.2: Brainstorming Session	Completed
Task 2.1.1.3: Tractor Design	On-going
Task 2.1.1.4: Winder Design	**Completed**
Task 2.1.1.5: Module Design	On-going
Task 2.1.1.6: Sensor Deployment Mechanism Design	On-going
Task 2.1.1.7: System Integration	**Initiated**
Task 2.2: Sensor Module	On-going
Task 2.2.1: MFL Sensor System Design	On-going
Task 2.2.2: Module Design Support	On-going
Task 2.2.3: Specify Ovality Sensor	On-going
Task 2.3: Specify Camera/Illumination	On-going
Task 3: Eletrical/Control Design	On-going
Task 4: Communication	On-going
Task 4.1 Tether Assessment	On-going
Task 4.1.1: Analysis	Completed
Task 4.1.2: Choose/procure candidate materials	Completed
Task 4.1.3: Test Plan	Completed
Task 4.1.4: Lab Test	On-going
Task 4.1.5: Tether Test Report	On-going
Task 4.2 Specify Communication Components	**Initiated**
Task 5: Auxiliary Components	**Initiated**
Task 6: Management and Reporting	On-going

[1] Items indicated in bold were initiated during this reporting period

RESULTS AND DISCUSSION

Tether assessment is nearly complete awaiting results of the testing of the latest version of the bend-insensitive fiber. Results indicate that the tether option is viable in the case of low and moderate transmission pipeline pressures and flows, i.e. flows of less than 20 ft/sec and pressures less than 350 psig. These conditions cover more than 70% of operating conditions of Local Distribution Company (LDC) transmission pipelines (details provided in the previous progress report for this project). Final studies and testing are underway to determine the abrasion characteristics of the bend-insensitive tether under various flow conditions. Winder design is complete.

Sensor design continued during this period and is nearing completion. PII is now in the final stages of selecting the module design to be integrated in the robotic platform.

The kinematics testing in the mockup built in the laboratory is complete with positive results.

Components for the camera and illumination system have been selected. Integration of these components into the inspection platform will commence once the tractor design is complete. A 90-degree field of view camera with a pan and tilt mechanism appears to meet the specifications.

Regarding the ovality sensor, the choice was made to adopt a commercially available light sensor, due to the reduced development time and costs, established calibration procedures, and minimal computer processing/data storage required. Components have been selected, and will be integrated into the platform once the tractor design is complete. The preliminary design of the module is nearing completion.

CONCLUSION

The project is progressing rapidly in all fronts, i.e. platform design, sensor design, and tether evaluation.

The tether option appears to be viable for low and medium pipeline pressures and flows. Advanced tether coating options are being explored that will minimize tether abrasion problems.

The MFL sensor has been designed and is meeting industry standards. The MFL sensor module is under design, various options having been explored. A final decision on the module design is to be made in the very near future.

REFERENCES

None.