FINAL REPORT
Project WP#474: Integrated Internal Inspection and Cleaning Tool Technology for Pipelines

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Prepared For:	United States Department of Transportation Pipeline and Hazardous Materials Safety Administration Office of Pipeline Safety
Project Title	Project #474, "Integrated Internal Inspection and Cleaning Tool Technology for Pipelines"

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Technical Status

PHMSA provide notification to Electricore that Other Transaction Agreement (OTA) DTPH56-10-T-000011 was terminated in July 2011. Prior to the decision to terminate the project, a number of tasks and activities were completed by the Project Team as described in the approved technical proposal and scope of work. This report provides a final description of work completed and accounting of funds spent prior to the formal termination date of August 26, 2011.

Task 1 Project Kickoff:

The project kick off meeting was completed in Houston December 8**,** 2010 (with participation by some team members via teleconference) and comprised PHMSA, PRCI, Electricore and a number of other PRCI supporting members. The team scheduled the kickoff meeting to establish a clear understanding among all project participants on the scope and goals for the project. It included a complete review of project activities and tasks (including work completed to date **-** i.e., development of preliminary specifications for the integrated tool), schedule and payment milestones, responsibilities and lines of communication, and project deliverable and expected outcomes.

Meeting participants included:

- Al Schoen, DOT PHMSA AOTR
- Ian Wood, Electricore, Program Leader
- Spencer Quong, Electricore, Project Manager
- John O'Brien, Principal Investigator, PRCI Program Leader
- Albert van Roodselaar, PRCI Technical Leader
- Shawn Miller, Dominion Pipeline, PRCI Project Team Member
- Mario Pezzi Filho, Petrobras, PRCI Project Team Member (via teleconference)
- Evelyn Choong, Enterprise Products, PRCI Project Team Member (via teleconference)
- Rick McNealy, Applus RTD, PRCI Project Team Member (via teleconference)
- Mark Piazza, PRCI Program Technical Coordinator

Task 2 Requirements Development

The development of the functional target specification went through multiple review cycles culminating in a final presentation to members of the Project Team and invited vendors at the PRCI Research Exchange meeting in Atlanta, GA in February 2011. This meeting had representatives from Dominion, Petrobras, NiSource, Applus RTD, T D Williamson, GE PII, Rosen, Subsea Integrity Group, JENTEK Sensors, PRCI and Electricore. The completed specification is shown below.

Functional Target Specification – Final

Cleaning capability	The changes to the cleaning tool must not compromise its ability to pass through and remove debris from the pipeline
State of Technology	The team will not consider any tools which are not already available to the pipeline industry
Launchers and Receivers	The tool should fit within existing industry footprints and require no launcher/receiver modifications; target tool diameter is 16 inch
Maintenance	The tool must be simple, rigid, light, and only have low maintenance requirements and replacement parts cost

Environmental Compatibility	• Components will need to be CO_2 and H_2S compatible • The tools shall be suitable to run in gas, liquid and multi-phase environments
Radioactive	All designs shall be free of any radioactive elements
Dimensional Capabilities	The target is that modifications to the tool will not prevent it passing a 1.5D bend radius The sensors should allow for varying diamter situations with target reductions of 15 – 25% of ID to allow growth into multi-diameter pigging situations
Certifications	The tool shall be capable of receiving ATEX/UL IS certifications in the future
Weight	Sensors and support items shall not increase the weight of the tool by more than a factor of x 5
Tool Velocity	Target velocity: 15-18 feet/second (4.5-5.4 m/s) Stretch goal of 45 feet/second (15 m/s)
Operating Temperature	125^{o} C
Operating Pressure	Target operating pressure: 1800 psig Stretch goal up to 2500 psig
Data Storage	• Data storage and on-board power shall be able to accommodate target pipeline run lengths of 120 miles • All data must be acquired and stored but data processing on-board and externally will be considered
Sensor capability	The cleaning tool must be able to carry and use multiple sensors. This project funding will strive towards that goal but may not fully achieve in first tool iteration
Temperature Sensors	Resolution of 0.1^{o} C
Differential Pressure Sensors	Resolution of 1 kPa
Metal Loss Detection	The tool should be capable of reliably detecting the lowest wall loss and smallest changes. Proposals that cannot achieve 20% wall loss as an initial target will be ranked lowest. The metal loss 'box' shall also be defined in terms of circumferential and axial length resolution at the target speeds

Task 3 Sensor Evaluation:

The research team completed activities on Task 3 with assessment of existing sensors and through discussions with inspection/service companies and sensor vendors and technology developers. These companies were identified through a preliminary interview process and screening of the sensor technologies relative to the Task 2 requirements shown in the table above.

Based on the functional specifications developed and an evaluation of platforms that would meet the need of the project, the Project Team decided to select a standard 16-inch diameter ILI cleaning tool manufactured by Rosen Inspection (ROSEN) as the platform on which sensors would be placed for the testing of the prototype system. The team chose this particular design because the construction allows easy disassembly and re-assembly of component parts which will enhance the researchers' the ability to experiment with different potential sensor and power solutions. These were made available to potential sensor solution providers who were not familiar with cleaning PIGs in order for them to test concepts and enhance their understanding before submitting their proposal to the project team for consideration. Two potential developers, JENTEK Sensors, Inc. (JENTEK) and Subsea Integrity Group (SIG) took delivery of PIGs and experimented with their potential solutions. More information on development work by JENTEK and SIG is presented in this report.

1. *itRobotics/Applus RTD.*

The itRobotics device is small segmented MFL solution applied primarily for the inspection of small bore coiled tubing for downhole well applications. Its design is compact and relatively low weight and can be seen in the figure below. The device also appears to be very robust and has been field proven in its current application.

itRobotics Compact Wedge Design (Small Bore)

In order to fit the needs of the project, itRobotics would increase the size of the segmented wedge design. This presents a challenge because the gap between segments would increase as the pipe diameter grows which means that part of the pipe surface would not be covered. The vendor explains that tool rotation over a number of runs through a particular pipeline would ensure full coverage to the extent that over time in a trending application the device would not miss any significant portions of the pipeline wall loss. This design consideration would need to be balanced with the frequency of inspections.

Another challenge of the -itRobotics solution is the fact that the tool footprint and their ideal proposal would incorporate two cleaning tools linked together to meet the full performance requirements. This approach would take the team away from their ideal footprint configuration.
The proposal does however address many of the required components of the project, including the ability to identify both inside and outside diameter material loss. There are a significant number of unknowns in the proposal and realistically it is based around creating a tool and not retrofitting an existing design. The expected weight of the tool is 600 lbs which is closer to the original ILI tool weight. The table below compares the parameters of the itRobotics device to the target specifications.

Target Specifications	itRobotics Capabilities
Metal loss (corrosion, no cracking)	Corrosion, pitting, transverse cracking
Wall thickness measurements	+/- 0.1t
Pipe OD 16”, wall thickness up to 15 mm, support of 1.5 D turns	Feasible
Total weight under 5 times pig weight	Feasible
Could drag a tool behind the pig	Odometer unit(s) mounted on the pig and MFL tool dragged (total length < 2 m)
Max inspection distance: 120 miles	Batteries support up to 94 miles (@ 5 m/s)
Zone 1 ATEX	Feasible, subject to further investigation
Operating temperature: 125 °C	85 °C
Operating pressure: 1800 psig, stretch goal up to	Feasible

2500 psig	
Velocity: 5 to 6 m/s and up to 15 m/s	Feasible
ID reduction -15% ~ -25%	Up to -20%

2. *ROSEN Group.*

A meeting was held with technical specialists from the ROSEN Group to discuss them upgrading a traditional low resolution MFL cleaning tool. Subsequent to the discussions, ROSEN submitted a more complete proposal. The elements of the proposed approach are summarized below.

Magnetization Unit

The conceptual design of the Rosen magnetization unit will consist of two sets of ring brushes, two sets of encapsulated rare earth magnets and a central tool body which will be used as backing iron and as battery and electronic housing.

Rosen's magnetization unit is primarily used to measure the pipeline wall thickness by determining the point at which the magnetic saturation is still achieved. Experience has shown that the MFL measurement is most consistent at magnetic saturation. At lower magnetization levels, the MFL field is still generated, but with a lower repeatability. Fortunately, the loss in repeatability is predominantly created by a systematic deviation of the magnetization level and the MFL-amplitude. This effect can be compensated, to a certain extent, by the repeated and frequent usage of an intelligent cleaning tool. Nevertheless, the operation of MFL tools below magnetic saturation has to be considered as a low fidelity process.

Receiver Probe

The purpose of the receiver probes is to map out the electromagnetic field at the pipewall generated by the magnetization unit. For this purpose, the device would typically use receiver probes consisting of hall elements. The probes will achieve optimal results if the field probe is guided along the pipeline surface in a repeatable and consistent manner. Therefore, the sensor receiver suspension system is an important element in achieving an acceptable result. The conceptual design of the receiver probe focuses on a robust suspension system, which will address the challenges of an intelligent cleaning tool. If the device can maintain an ideal circumferential resolution and axial sampling distance, it will achieve a high resolution level.

Odometer

In the ROSEN device an odometer system is optional, and the proposal emphasizes the advantage of using a system without odometer. The data of the intelligent cleaning tool without odometer will be correlated to a high resolution MFL baseline survey, girth weld by girth weld. This process can be highly automated. This system avoids the issues caused by a dirty pipeline (which is a valid assumption for the operation of a cleaning tool).

ROSEN believes that an odometer system represents additional moving parts which need to be maintained and repaired frequently to guarantee the desired performance. Furthermore, the presence of an odometer system will deviate from the typical operation of a cleaning tool. The research team understands this approach but envisages difficulty in getting the broader industry to accept a device without an odometer and recommended that it be part of the proposal.

As mentioned previously in this report, ROSEN's 16-inch cleaning tool was selected as the frame and platform for the sensor systems. The ROSEN cleaning tool exceeds the target specifications for weight. The following table highlights the current weight of standard ROSEN cleaning tools:

Tool Size	Weight (kg)	Weight (lbs)
8"	12	26
12"	30	66
16"	67	148
20"	137	302
24"	180	397
32"	335	739
40"	680	1499
48"	1200	2646

Weight of ROSEN cleaning tools

This highlights that a 16 in. tool would typically be 148 lbs before the addition of more sensors etc. This draws to attention a lack of clarity over weight targets in the project's specifications and the team has now amended it to be clear that the target is a 50 lbs incremental increase in weight due to added sensors.

The ROSEN approach is initially appealing as they have a long history in the existing ILI market especially using MFL. Their proposal is based on a new MFL sensor approach, but currently only extends as far as a proof of concept pull test. The live line trial was not envisaged within their proposal.

3. *Invodane Engineering*

The researchers conducted a preliminary evaluation of MFL ILI technology from Invodane Engineering through a review of development work under DOT Contract DTRS56-05-T-0002, which included MFL sensors for deployment on the TIGRE robotic pipeline platform. The sensor technology initially sounded promising, so the team held a face to face discussion with Invodane. During the discussion they discovered that the sensors still needed heavy and power intensive magnets and sensing systems. The weight and power issues coupled with the magnetic drag the large magnets can create led the investigators to determine that this solution was inappropriate for the cleaning tool add on concept. In light of this, both parties made a decision not to pursue this technology and did not request a full proposal.

4. *JENTEK Sensors Inc.*

The project team has made a full evaluation of JENTEK's proposal. JENTEK provided, at its own expense, a proof of concept test and CAD design work based on the Rosen cleaning PIG provided to them.

JENTEK is advancing their Meandering Winding Magnetometer (MWM) technology under a number of existing projects funded by some of the PRCI members and DOT PHMSA. In the near term, technology development is focused on the high frequency array which will be ideal for detecting near surface (internal corrosion) and mechanical flaw data (from the changes in magnetic permeability). Through wall detection will require a low frequency array under development.

One of the issues with the JENTEK system is the resolution of the flaws, especially at the anticipated speed of 3 ft/s. At these speeds, with the 1.5 in. sensing element, reasonable circumferential resolution can be obtained however axial resolution will not meet the requirements in terms of image to real flaw size. Initially this might be improved in three ways:

- Reduce the tool speed to achieve more sampling points

- Extend the barrel of the cleaning tool to fit more sensors. This may affect the tool's ability to negotiate 1.5D bends but is worth evaluating.
- Couple two cleaning tools together.

JENTEK has placed considerable thought and work into the integration of the tool together with the 16 inch cleaning tool supplied by the project. JENTEK is confident that a reduced version of their new digital instrument can be made that fits inside the barrel of a 16 in tool because it will not require a screen or keyboard. JENTEK believes that based upon their calculations, data storage is not a significant issue and are confident they can use existing off the shelf high capacity data storage devices.

Battery power has also been considered as an available solution. Through the review, JENTEK and Electricore both identified an opportunity for the team to investigate other energy storage developers outside the pipeline industry. The JENTEK GridStation is moving into production now based on orders from Chevron and others under parallel programs and therefore will be available in the time frame of this project.

JENTEK's MWM Array is not purely theoretical and is being tested on ILI tools. It is also important to note that this proof of concept was achieved in partnership with an existing ILI vendor (NDT Systems) which demonstrates that JENTEK understands their technology and how to integrate it into an effective integrated tool for the pipeline industry. Current JENTEK software can be utilized in the application under consideration to show not only location of flaws but also orientation, shape and depth information.

5. *Det Norske Veritas – Acoustic Resonance Technology*

This technology appears to have tremendous value in the proposed application especially as it has already been conceptually tested in a gas pipeline with GASSCO Norway. However, the technology is confidential and therefore the team decided to exclude it from evaluation due to potential limitations on its use and Intellectual Property concerns.

6. *Rosen Inspection – Pipeline Data Logger (PDL).*

A review of the PDL by Rosen Inspection has been conducted by the Project Team. The PDL can be purchased and flanged onto standard ILI cleaning tools, including the ROSEN 16-inch cleaning tool selected as the platform for the project. Different manufactured tools may need adaptor plates but this is something the team believes can be easily designed and manufactured.

Pipeline Data Logger 14

The PDL comes in two sizes: below 14 in. diameter and greater than 14 in. diameter pipelines. The lowest diameter pipeline that can be accommodated with the PDL id 4 inches. The standard tool design measures the following parameters:

- Temperature
- Absolute and differential pressure
- Tri-axial acceleration (inclination and tool rotation)

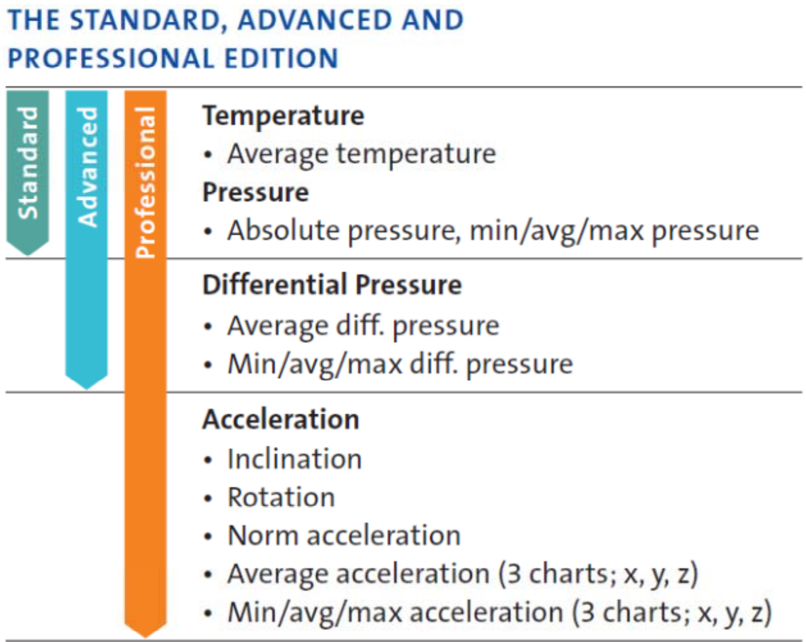
The functional specifications shown below fit very well with the project requirements and target profile and the tool is already designed for the pipeline environment.

TECHNICAL SPECIFICATIONS

			Pipeline Data Logger 4	Pipeline Data Logger 14
Physical characteristics	Weight operational		2.7 kg (5.6 lb) (+1 kg (+2.2 lb) mounting plate)	7.9 kg (17.4 lb)
	Dimensions		208 mm (8.18") length	269.5 mm (10.61") length
			Ø 72 mm (2.83") Pipeline Data Logger	Ø 89 mm (3.50") Pipeline Data Logger
			Ø 127 mm (4.99") mounting plate	Ø 125 mm (4.92") mounting plate
Electrical characteristics	Battery type		4 x 1.5V Alkaline Size AA (LR6) or 4 x 3.0 – 3.9V Lithium Size AA (LR6)	4 x 1.5V Alkaline Size D (LR 20) or 4 x 3.0 – 3.9 V Lithium Size D (LR20)
	Battery life-time		approx. 115 h (Alkaline) approx. 250 h (Lithium) The given specifications apply to an ambient temperature of 20 °C (68 °F)!	approx. 1000 h (Alkaline) approx. 2000 h (Lithium) The given specifications apply to an ambient temperature of 20 °C (68 °F)!
	Memory		24 megabytes (MB)	24 megabytes (MB)
Sensor specification[1]	Pressure		0 to 200 bar (0 to 1740 psi) optional up to 300 bar (4351 psi)	0 to 200 bar (0 to 1740 psi) optional up to 300 bar (4351 psi)
	Differential Pressure		-10 to +20 bar (-145 to 290 psi)	-10 to +20 bar (-145 to 290 psi)
	Temperature		-55 to +125 °C (-67 to +257 °F)	-55 to +125 °C (-67 to +257 °F)
	Acceleration		-5 to +5 g	-5 to +5 g
Environment	Operation	temperature[2]	-20 to +75 °C (-4 to 167 °F)	-20 to +75 °C (-4 to 167 °F)
	Storage	temperature	+5 to +40 °C (41 to 104 °F)	+5 to +40 °C (41 to 104 °F)
	Shipment	temperature	-20 to +75 °C (68 to 167 °F)	-20 to +75 °C (68 to 167 °F)
		humidity	0 to 100 % R.H. for < 3 month	0 to 100 % R.H. for < 3 month
		altitude	up to 15000 m (49200 ft)	up to 15000 m (49200 ft)

[1] Sampling frequency 500 Hz
[2] Please carefully check temperature specification of used batteries.
These values vary depending upon manufacturer.
Alkaline battery temperature range is normally -10 to 55 °C (14 to 131 °F), Lithium -20 to 75 °C (-4 to 167 °F).

The tool also comes with analysis software to allow user data interpretation.



After completing the initial sensor evaluation, the team requested and received proposals from four vendors including itRobotics in conjunction with Applus RTD using magnetic flux leakage (MFL), ROSEN using variant of MFL, JENTEK based on their MWM-array sensors, and SIG using EMIT sensing technology. A full project team meeting was held in early July 2011 to review the grading of all proposals received. The project team selected the following sensors, but did not purchase them under the DOT funded project due to project cancellation.

- Purchase and integrate the ROSEN pipeline data logger. Match the system to the previously purchased existing 16 in. cleaning tools, run the PDLin pipelines to acquire data related to temperature, velocity, differential pressure, girth weld location, etc. and evaluate performance for long-term application and trending.
- Provide funds to JENTEK sensors to evaluate their MWN sensor technology. The program will include work up to the pull test validation of an integrated cleaning and inspection tool that is based on their sensor.
- Financially support Subsea Integrity Group EMIT's internal wall loss technology (EMIT).

Future Activities

The team completed activities on Tasks 1, 2 and 3.

As of the end of the program, PRCI and Chevron planned to continue the program because it showed considerable near-term promise and benefits to the pipeline industry.

Business Status

Electricore and its subcontractors had total project costs under this agreement of $88,739.63 through the final close-out. Final project cost distribution included $32,000 USDOT funds and $56,739.63 team cost share.