EMAT Sensor for Small Diameter and Unpiggable Pipes: Prototype and Testing

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Presentation Outline

1. **Background – funding motivation**
2. **Objective**
3. **Schedule, tasks and funding sources**
4. **Target Specifications**
5. **Problem definition/Our approach**
6. **Development summary (Phase I, II and III)**
7. **Testing for in-house and field**
8. **Current activities and commercialization**
9. **Summary**

Kudos:

We would like to thank PHMSA, OTD, GTI, Q-Inline and Qi2 for the ongoing financial, management, and technical support for this work. It takes a lot of faith and support by many people to turn an idea into a solution.

More than a dozen Qi2 people have contributed to this effort over the last several years which include scientists, mechanical, electrical and software engineers, technicians as well as other support staff. We would also like the thank the engineering staff at Q-Inline.

Project Background

Program Motivation

- In-line inspection (ILI) is identified by the NTSB as the preferred method for detecting flaws or anomalies compared to hydrotesting or direct assessment.
- The industry need for inspection tools to locate and size cracks in small diameter, difficult-to-inspect gas pipelines; specifically distribution lines.
- Provide an ILI alternative for federal regulations to hydrotest lines without post-construction pressure test records.

Specific Solution

- A circumferential guided wave EMAT tool for crack-like defect detection and sizing in small diameter pipelines.
- Initial target: 8" diameter, 1.5D bends.
- Platform independent: robot towed, wireline. ultimately free-swimming (currently independently in progress)

Project Objective

Project Title:

EMAT Sensor for Small Diameter and Unpiggable Pipes: Prototype and Testing

PHMSA Project ID: DTPH5615T00018L – The third of three phases. Phase 1: DTPH5613T000007

Sponsors:

PHMSA and OTD through the Gas Technology Institute with OTD, Qi2 and Q-Inline cost sharing. Licensed to Q-Inline.

Overall Program Objective:

The industry need for inspection tools to locate and size cracks in traditionally small diameter, unpiggable gas pipelines; specifically *distribution lines.*

- Low flow rates - minimize tool length and drag force
- Good collapse factor + 1.5 D bend navigation + bi-directionality
- Initially 8" diameter but eventually 10" and 12"
- Wireline (battery + storage)

Project Schedule/Tasks/Funding

Overall Program Timeline

	2013	2014	2015	2016	2017	2018				2019				2020
Tasks/Phases	~Q4	Q1-4	Q1-4	Q1-4	Q1-4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
Phase 1 - Bench demonstration														
Interim Phase - Qi2 Activities														
Phase 2 - Integrated Electronics/Umbilical														
Phase 3 - Self-contained/towed														
Integrated Design and Specifications														
Detailed Electrical/Mechanical Design/Fab														
Detailed System Design/Fab														
In-house testing														
Field testing														
Final Report														

Funding/Cost Sharing:

Phase 1 - gov't \$315k, 3rd party cost share \$165k (OTD/Qi2)

Interim phase - Qi2 funded

Phase 2 - Overall Qi2 Budget: \$754k, OTD/Qi2 cost share

Phase 3 - OTD/PHMSA portion: \$445k, Q-Inline cost share: ~\$550k + Qi2 contribution

Original Phase 1 Target Specifications

Main points:

- 8” diameter has the most mileage without hydrotest records per OTD members.
- We initially set the target crack resolution goal to 0.5 mm for phase 1 testing. (not reporting resolution)
- Originally intended for slow speed with towing type vehicle or wireline. Less than 1 ft/sec.
- Hydrotest crack study was running in parallel. PHMSA funded. Settled on 2” crack length and larger for sizing. Detection length is less.
- Lower operating pressure, good collapse factor, bidirectional, 1.5D bends.

Table 1. New Hydrotest EMAT tool requirements

Direct Requirements	Low Flow
Product temperature range	40F - 90F (4.4 - 32.2 C) (1)
Product flow rate	Not Applicable (2)
Product operating pressure	Up to 1,000 psig (6,894,757 Pa) (3)
Acceptable axial tool speed range	< 1 foot/sec (30.5 cm/sec)
Maximum inspection length	A function of the locomotive platform
Typical wall thickness	0.375 inches (9.5 mm)
Maximum wall thickness	0.500 inches (12.7 mm)
Minimum wall thickness	0.25 inches (6.4 mm)
Pipeline diameter range	6 – 16 inches (15.2 – 40.6 cm); Initial target: 8 inches (20.3 cm)
Multiple wall thicknesses in a single inspection run	Not typical
Critical flaw (crack) length	Typically > 2 inches (will refine from hydrotest study) (4)
Length sizing tolerance (near critical)	TBD (from Hydrotest study) (4)
Crack depth resolution at the critical flaw length.	Typically 0.02 inches (0.5mm) at 90% POD
Crack orientation	Axial, ±10°
Crack depth resolution at small crack depths: < 3 mm	TBD (4)
Crack depth resolution at larger crack depths: > 3 mm	TBD (4)
Collapse Factor/ID clearance (percent of OD) to account for unpiggable features	85% or better (5)
Minimum bend radius	1.5xD
Bi-directionality	Yes
Crack/Metal loss/Pipe feature discrimination (POI)	Yes
Wall thickness measurement (derived requirement)	Yes
Coatings	CTE, FBE, Wax, Tapes and Wraps
Locomotion	Tethered/Crawler

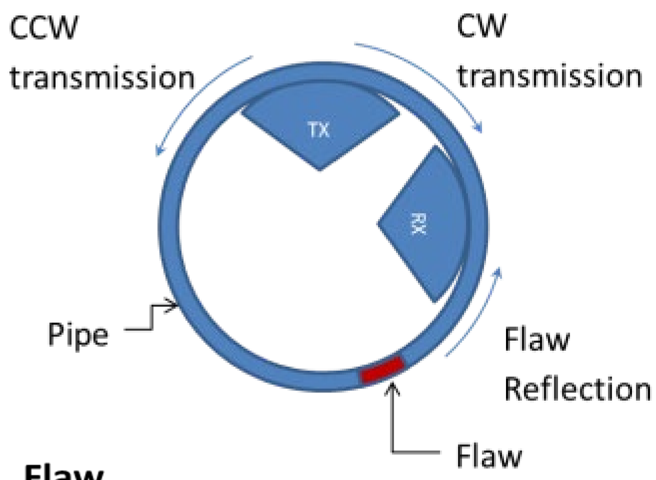
Notes:

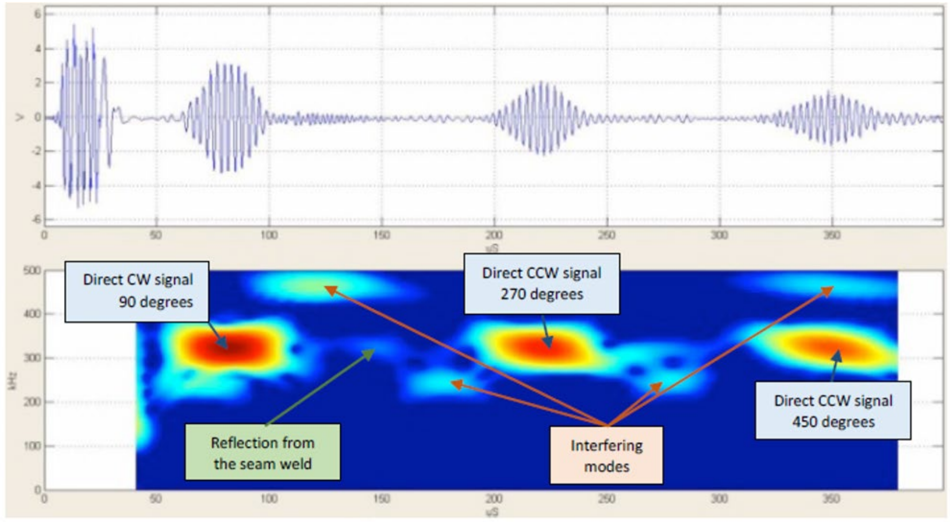
(1) **Temperature**: Range should fall between these ranges. There may be upset conditions with slightly higher or lower temperatures.

(2) **Flow Rates**: The LDC transmission pipeline network does not lend itself to free swimming pigs (ILI).

EMAT based guided wave ILI for small diameters is a challenge:

- Compact inspection module to support collapsibility, bidirectionality and 1.5D bends.
- Remaining space for packaging is small.
- Acoustically small, creating what we call signal congestion. Need to separate flaw reflections from other signals such as CW/CCW signals and multiple modes.

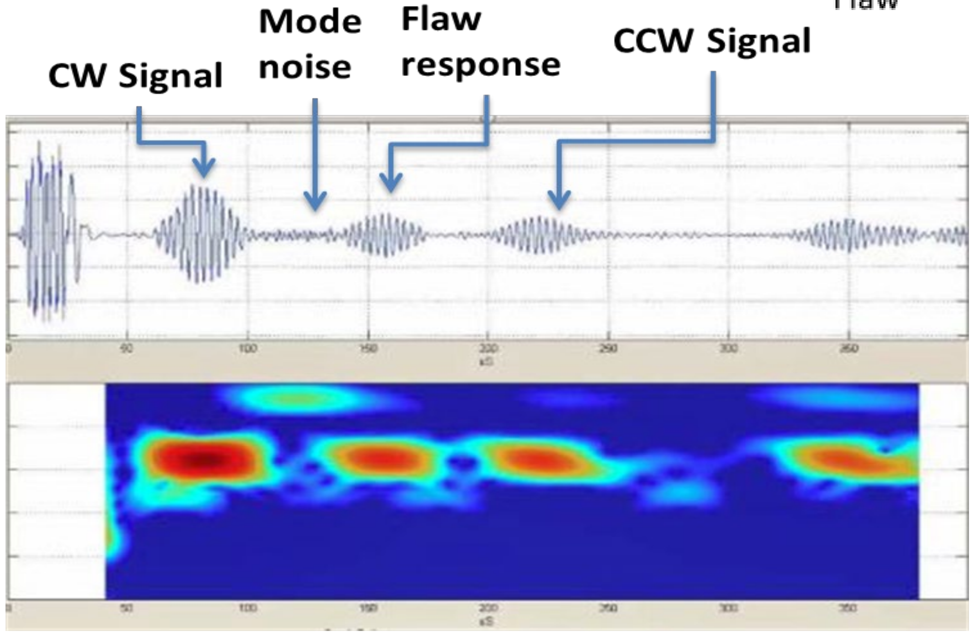




No Flaw

AScan

Spectrum



Flaw

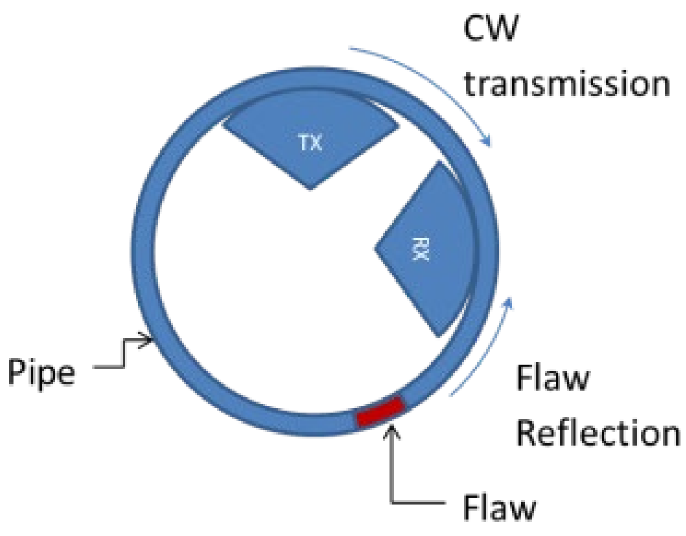
Our Unique Solution

Suppress the CCW component

- Use a real-time unidirectional EMAT.

Combined with special EMAT receiver

- Decompose received signal into CW and CCW waves.
- CW wave is the interrogation signal.
- CCW wave contains flaw information.

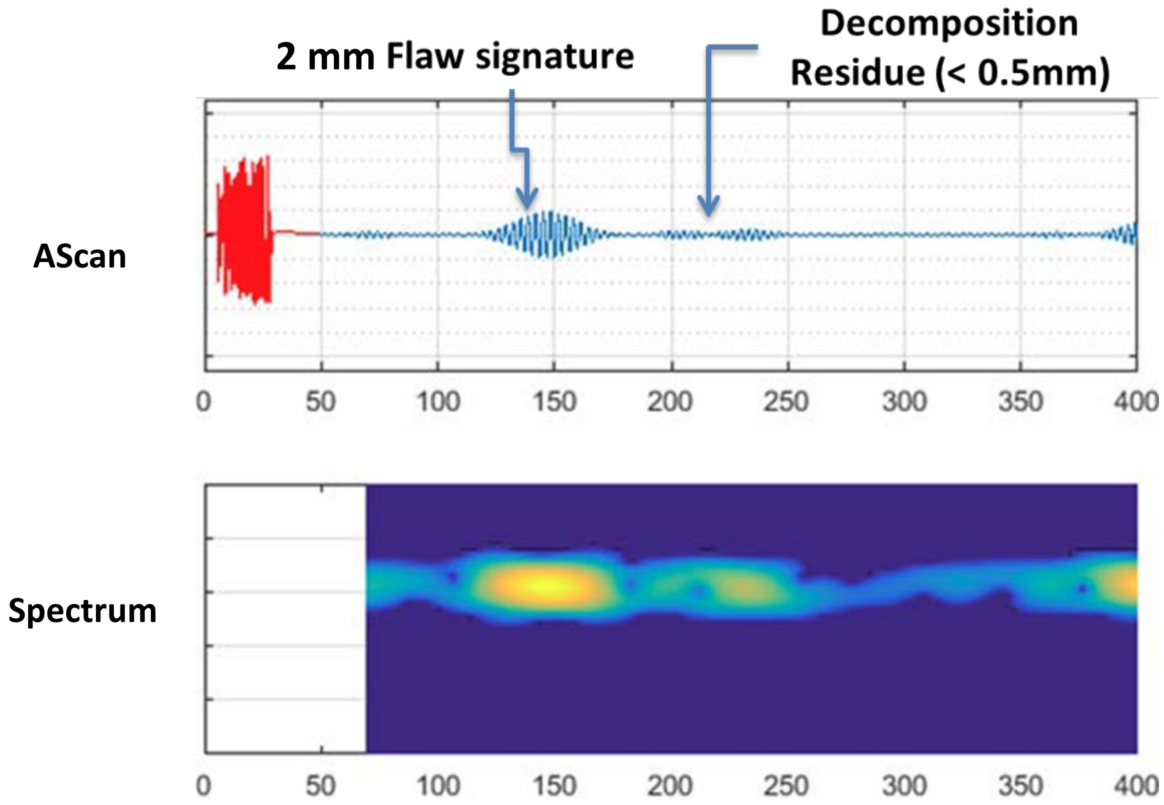


Patent Pending

Reduced overall tool footprint!

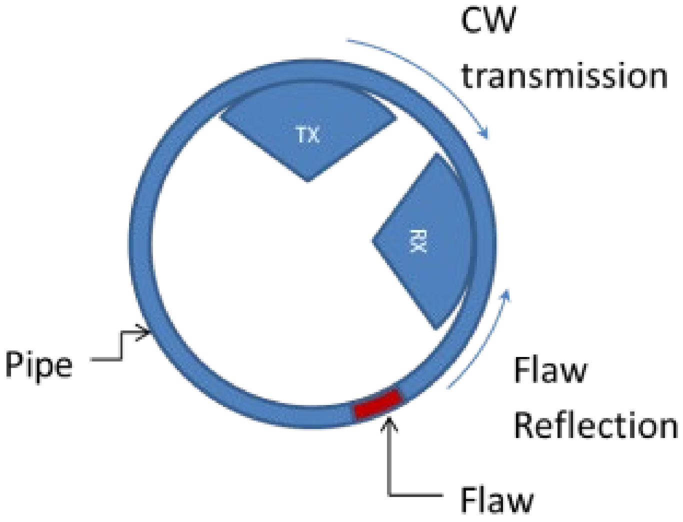
Spurious mode reduction + unidirectionality = simplified post data analysis

Automated Flaw Detection



Our Unique Solution Advantages

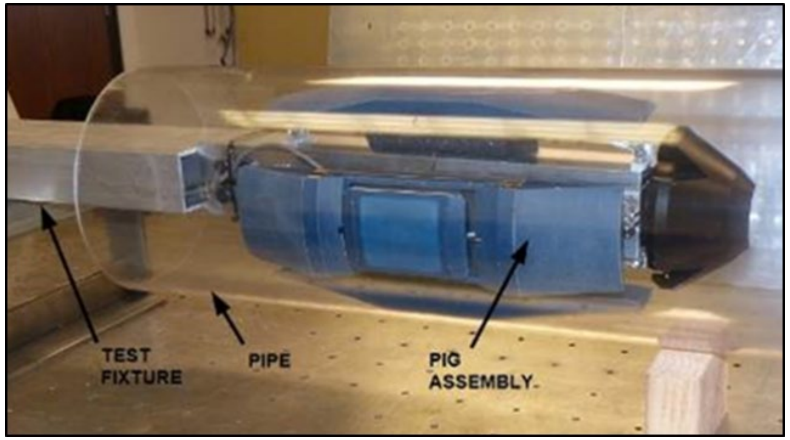
- Zero blind spots: sizing and detection.
- Improved discrimination between crack-like and non-crack like flaws.
- Multi-crack detection.
- Significant reduction in spurious mode generation.   Simplified data analysis.
- 10x or larger improvement in flaw-to-noise ratios. Lossy coatings.
- Adapted for small diameters, solving signal congestion problem.
- Enables short overall tool length. Minimize tool drag for low flow.
- Two measurement modules be used with different operating modes and/or interrogation from two directions and will be clocked. Not absolutely necessary for 8” pipe but will improve POI.
- Clocked modules will mitigate temporary loss of sensor surface contact.
- Two measurement modules will be required for 10” and 12” tools.



Patent Pending

Development Summary

Development activity spanned 3 phases



Phase I

- Developed a bench-scale EMAT ILI measurement module.
- Demonstrated ability to detect and size flaws.
- Sensors allow negotiating a 1.5D bend .
- Identified further issues to address for implementing in small diameter pipe:
  Signal congestion and mode control – Guided wave EMAT's in confined spaces.

Interim Phase

- Internally funded.
- Developed a unique solution for signal congestion and improved guided wave mode control.

  Higher data quality and ease of data analysis – Only normalized flaw information is displayed for analysis.
- Patent applications.

Development Summary - *continued*

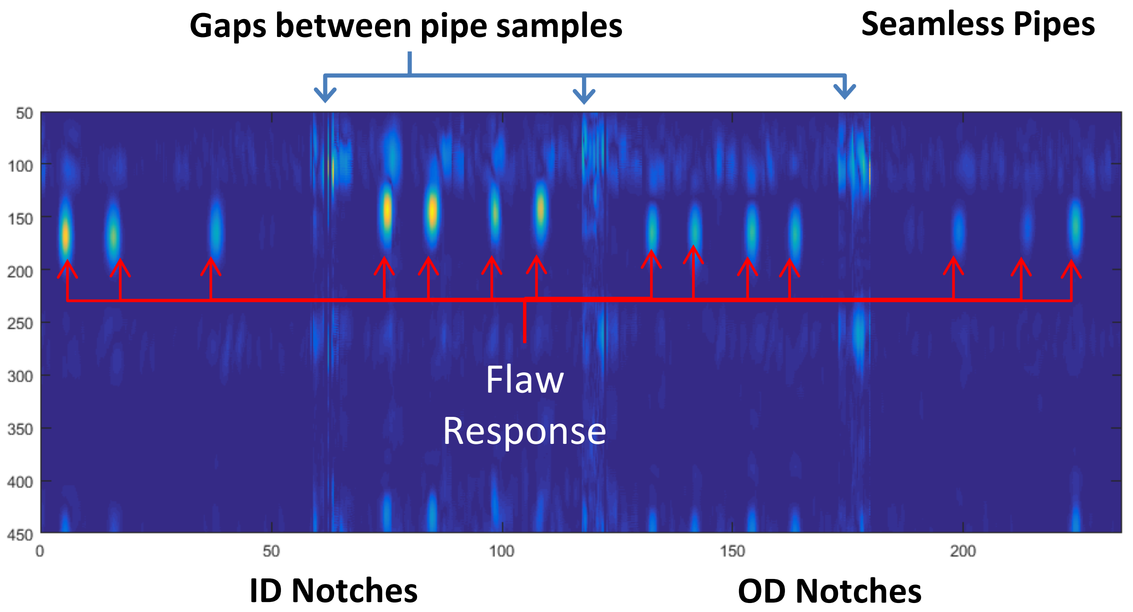
Phase II

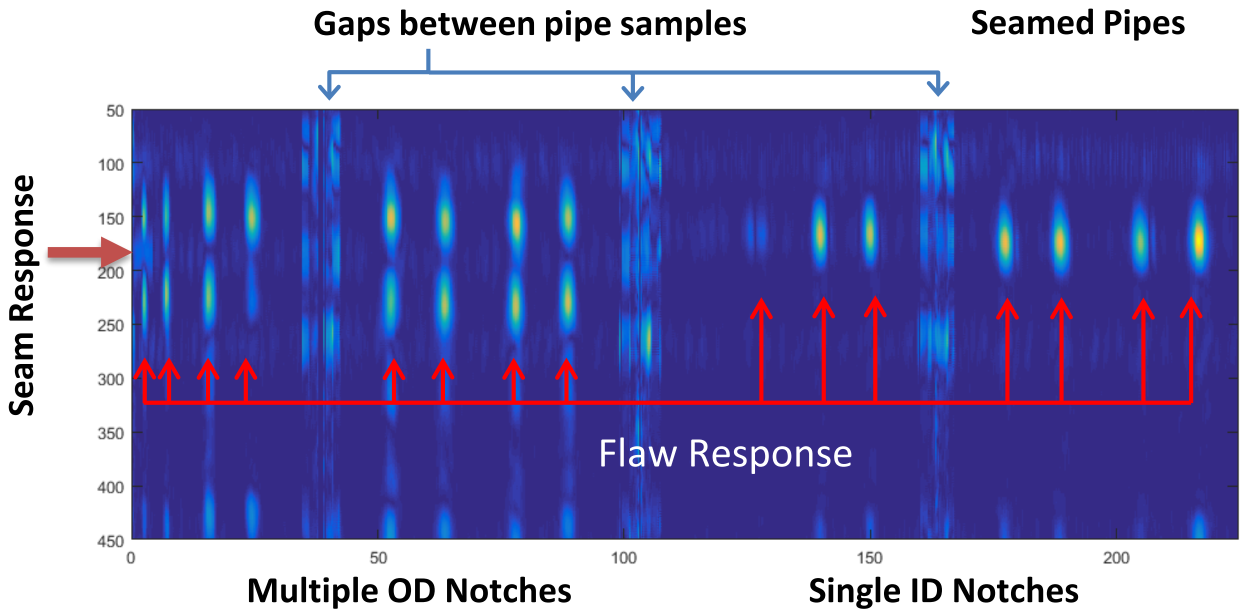
- Developed a more robust tool for extended testing.
- Developed embedded electronics - single inspection module
  Important for a short overall tool length.
- Implemented the signal congestion solution.
- Developed umbilical based tool for short pull testing (~7 m).
- Considerable in-house testing plus successful remote demonstrations at two locations with unknown flaws.
- In-house testing on both ID and OD EDM notches on FBE coated samples. X42 and X52. Limited testing on 3LPE coated pipes.
- Improvements in the sizing algorithm.

Sample Preparation

- Obtaining samples with real-life crack in pipes of this dimensions has been a challenge – Discussed with PRCI.
- First, EDM notch samples were prepared. ID, OD, and side by side OD notches. ID notched in seams.
  - Discovered the fabrication was inaccurate and non-uniform in depth.
    This was detected by the tool and subsequently confirmed with PAUT and manual gauging.
  - Alternate measurement methods have a tolerance of +/- 1 mm (seems the best that PAUT can do).
  - A 2 mm or greater error in an 8.5 mm thick sample is unacceptable for tool development and calibration.
- Saw-cut-notches were machined in new samples, OD only.
  - Idealized but precise depth.
  - In seamed pipe samples, flaws were placed away from seam.
    Seam response was present but did not impact the sizing results.
    Sizing algorithm is designed to accommodate for seam response and residual modal noise.
    Good sizing results – will show unity plot results later.
- A commercially fabricated sample with thermal-fatigue-cracks was also obtained.
  - Still not controlled enough because manufacturer eroded scaling from the inside of the pipe.
  - Depth tolerance: +/- 1mm – At least that is what is quoted, impossible to confirm except with the tool .
- Primary sample focus was schedule 40. Notch samples will be fabricated for a variety of schedules for testing the free-swimming version.
- We are always looking for test samples. A pulled pipeline section has been identified for testing later this year.

Phase II In-house EDM Notch Results





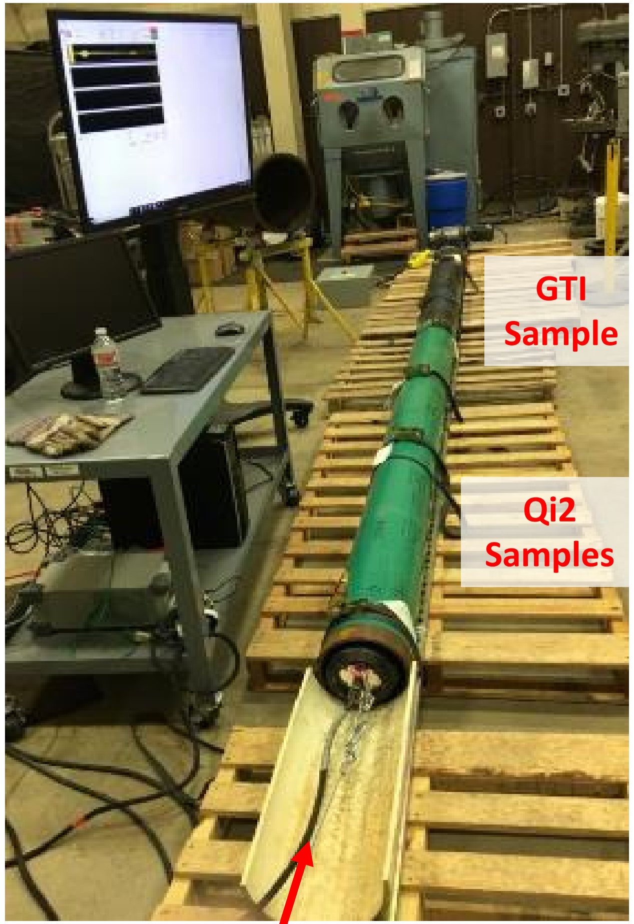
- *EDM notch fabrication was not accurate (see slide 12); hence sizing results are excluded*
- Notch axial length: 2”
- Notches were 10” apart along axis of pipe (x-axis above)
- Intended flaw depths (mm): 0.5, 2.0, 2.5,3.0, 3.5, 4.0, 4.5 and 5.0

Due to depth issues - samples largely used for repeatability testing

- Single ID notches were machined from inside the pipe *in identifiable seams* (0.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5 and 5.0 mm)
- Multiple OD flaws were machined from outer surface of pipe straddling the seam and 3” apart along circumference
- Depths:
  - On one side all OD flaws were intended to be 2mm
  - On the other side same as “Single ID” notches
- Absence of seam response is a feature of tool not a bug
- Sizing algorithms can accommodate any seam response

Field Test Setup: Phase II @ PG&E Facility

- Hardware & test samples were shipped to PG&E from Qi2.
- An additional schedule 20 sample was shipped from GTI with unknown flaws (and hidden).
- Achievements:
  - The tool functioned well in an unfamiliar environment.
  - All unknown flaws were identified.
  - The sizing results were in the same range as lab results.
  - Tool was functional, although not designed for a schedule 20 pipe (at the time).

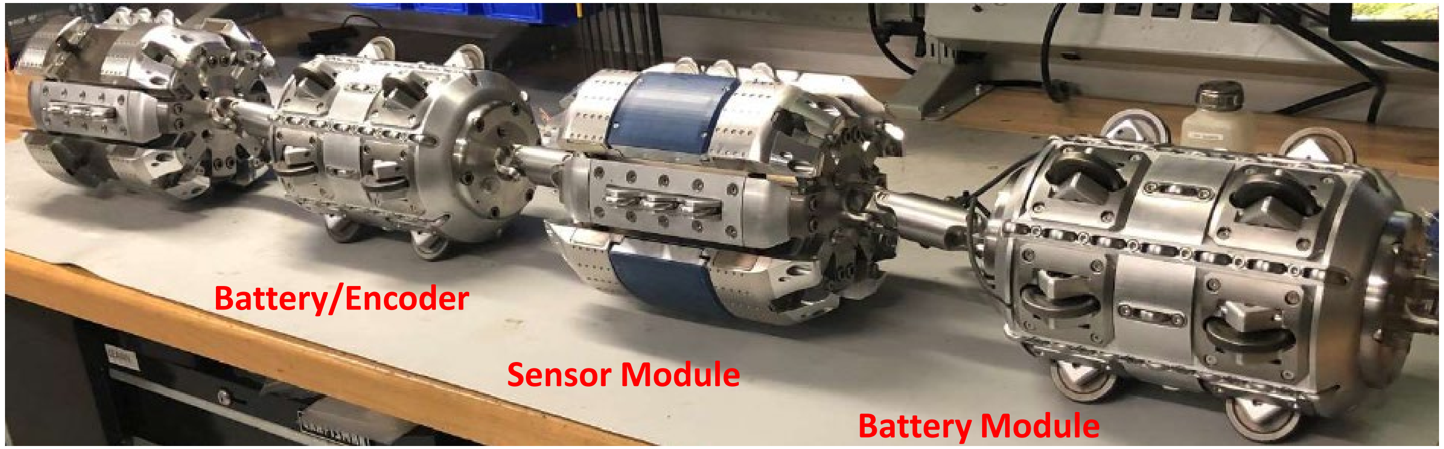


Sensor Module/Umbilical

Development Summary – Phase III

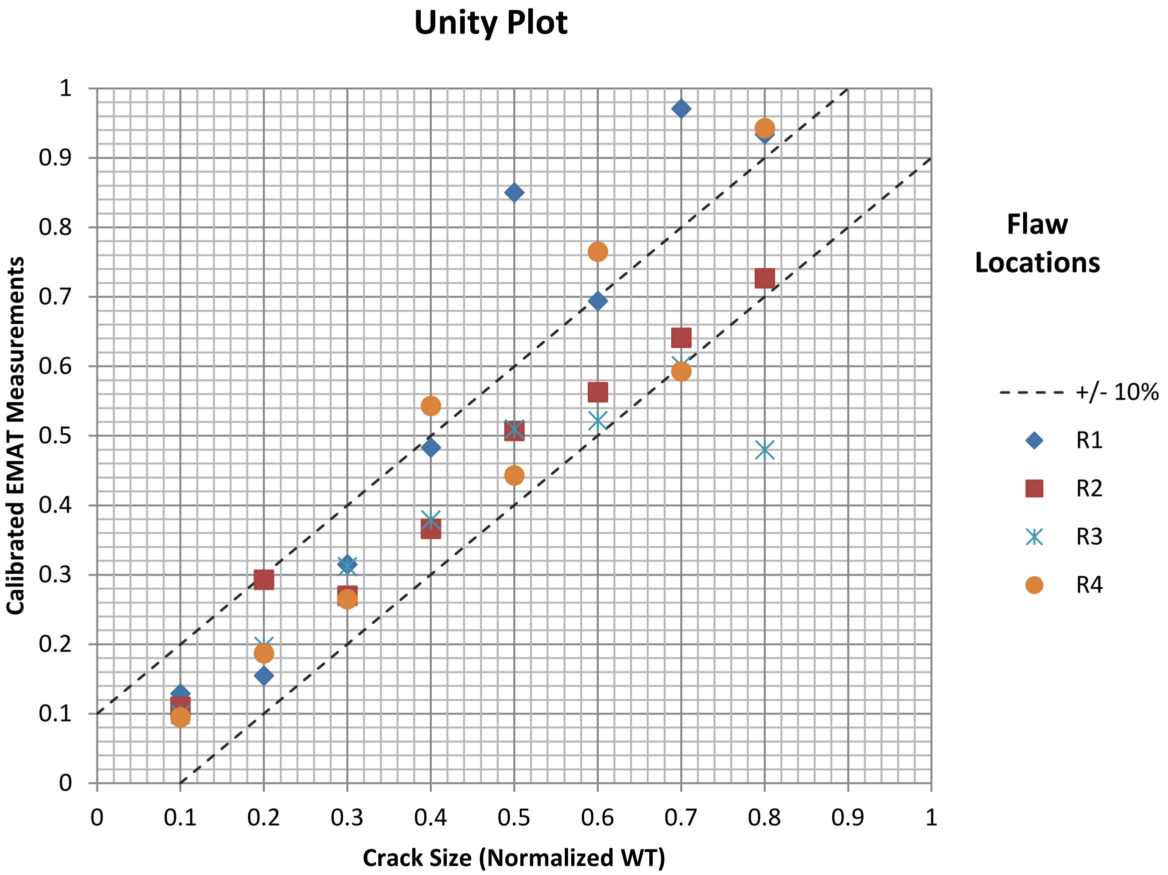
Phase III – this program

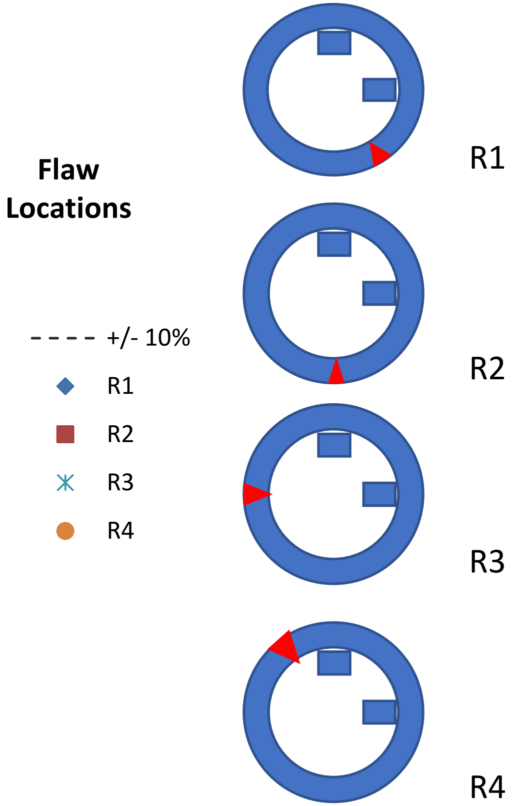
- Further tool hardening – Begin targeting free swimming version.
- Increase inspection speed – mostly electronics improvements (initial target 0.5 m/s, increasing to >2 m/s for free swimming version).
- Eliminate umbilical using on-board data storage and battery. >1.5 km inspection length.
- Deploy and test initially in the field as wireline operated tool - exposure to a wider variety of anomalies and pipe conditions.
- Improvement in sizing algorithms with an eye on large data handling.
- Improve collapse factor for navigability.
- Electronics is sized for pressured tool.
- Minimize tool friction and length.



Phase III In-house Sizing Results - Seamed

- Seamed pipes – FBE.
- Multiple runs with different flaw/sensor orientations as show on the far right.
- Demonstrates insensitivity to flaw location vs sensor location.
- Demonstrates sizing capability, particularly for flaws < 50%.
- Flaws were outside the seam-weld.
- Had to use saw cut notches to assure known depths.

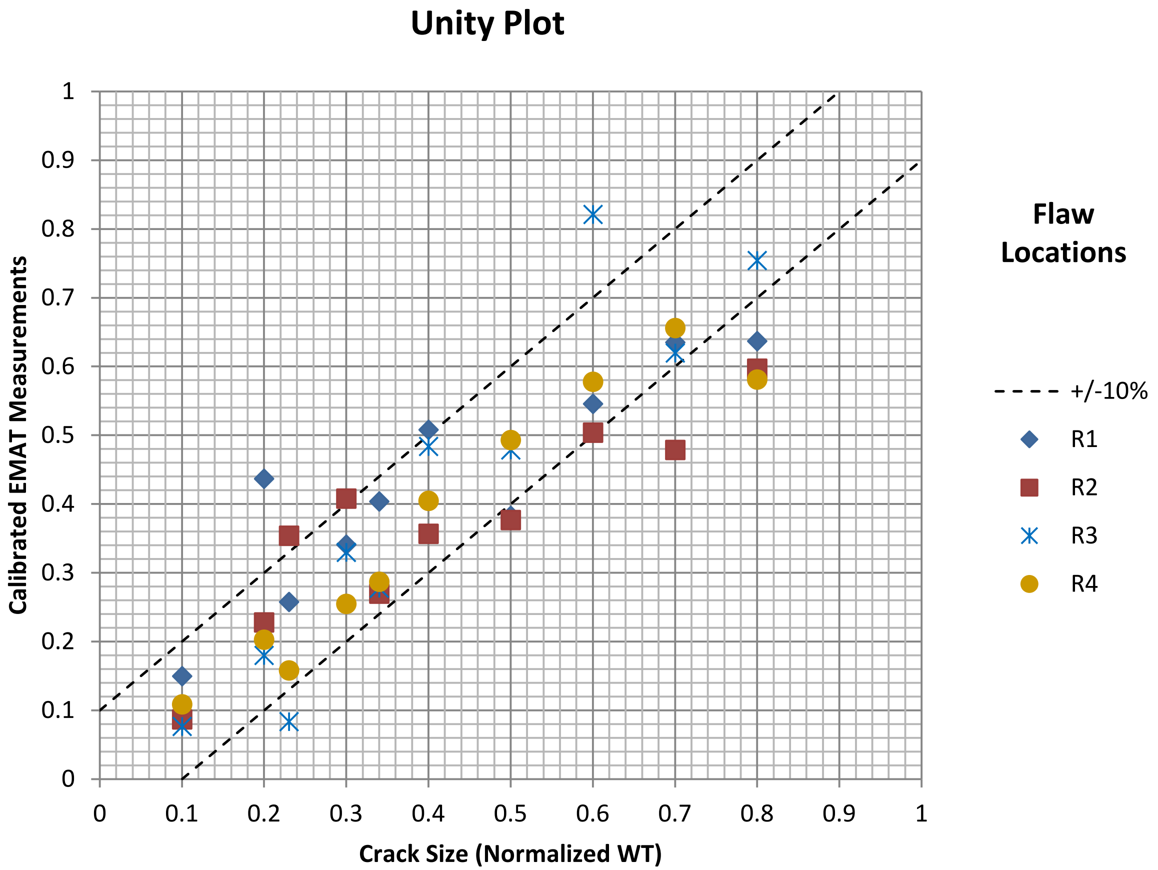


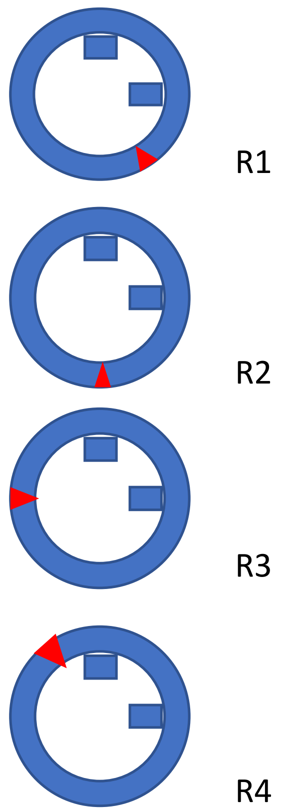


These results we before some noise mitigation efforts were completed

Phase III In-house Sizing Results - Seamless

- Seamless pipes - FBE
- Multiple runs with different flaw/sensor orientations as show on the far right.
- Demonstrates insensitivity to flaw location vs sensor location.
- Demonstrates sizing capability, particularly for flaws < 50%
- Flaws were outside the seam-weld
- Had to use saw cut notches to assure known depths





These results we before some noise mitigation efforts were completed

Field Test Setup: Phase III @ Q-inline Facility

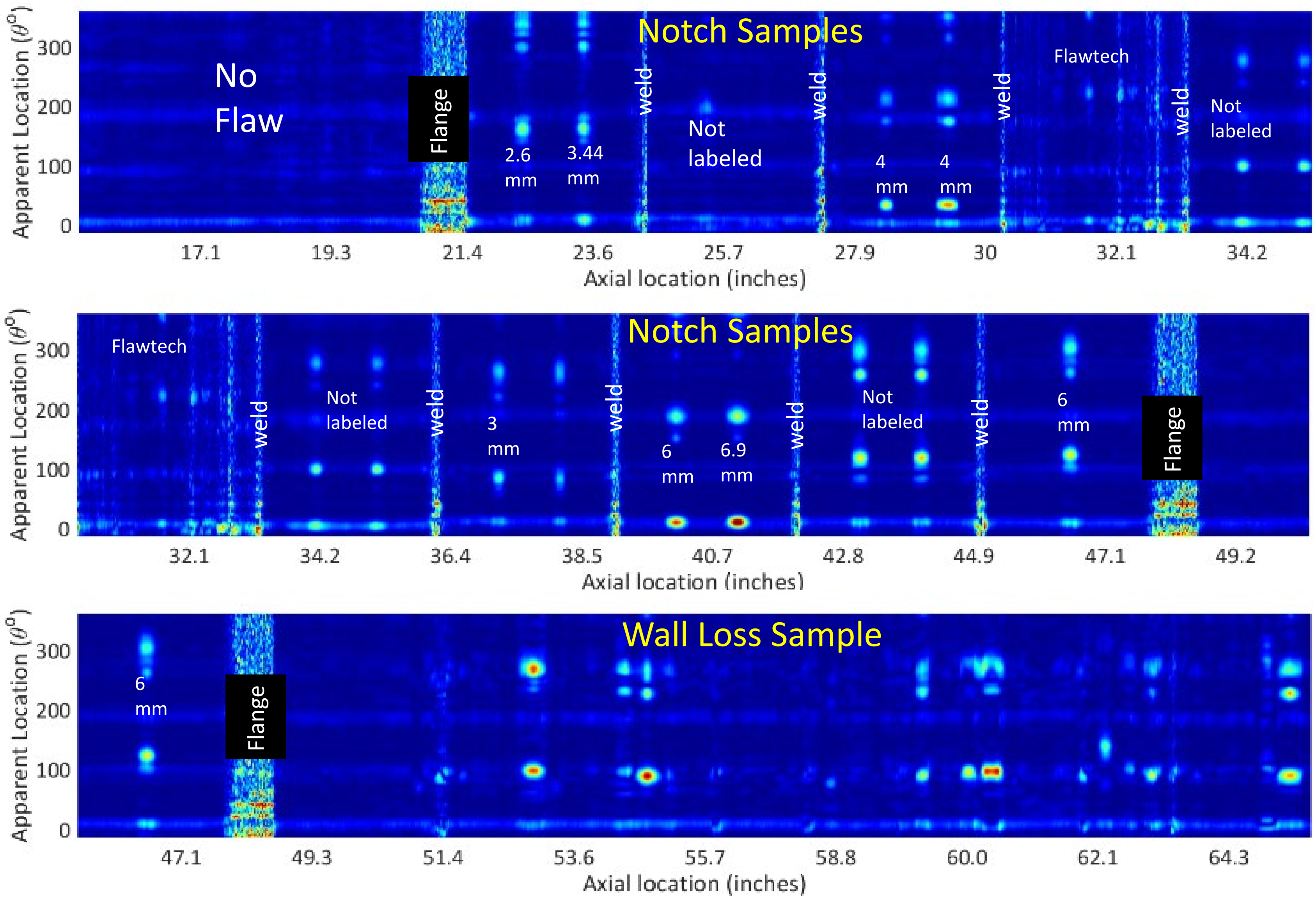
- Overall sample length was 106’ including
  - Seven 3’ long pipes with two saw-cut notches each.
  - A 3’ long pipe with a one saw-cut notch.
  - A 3’ long pipe with four thermal fatigue (Flawtech) cracks.
  - Two pipes with several wall-loss flaws (manufactured).
  - Rest were flaw-free.
- Wire line pullers on both ends.
- Thermo-electro-mechanical testing included
  - Insertion/bend survival and collapsibility.
  - Thermal and electronics performance evaluation.
    - Continuous scanning for over 2.5 hours.
- Tested ceramic wear pads.

6’ Flaw-Free Sample	20’ Flaw-Free Sample	9x3’ Crack Samples	20’ Wall Loss Sample 1	20’ Wall Loss Sample 2	20’ Flaw-Free Sample

Insertion

Phase III Field Test Results

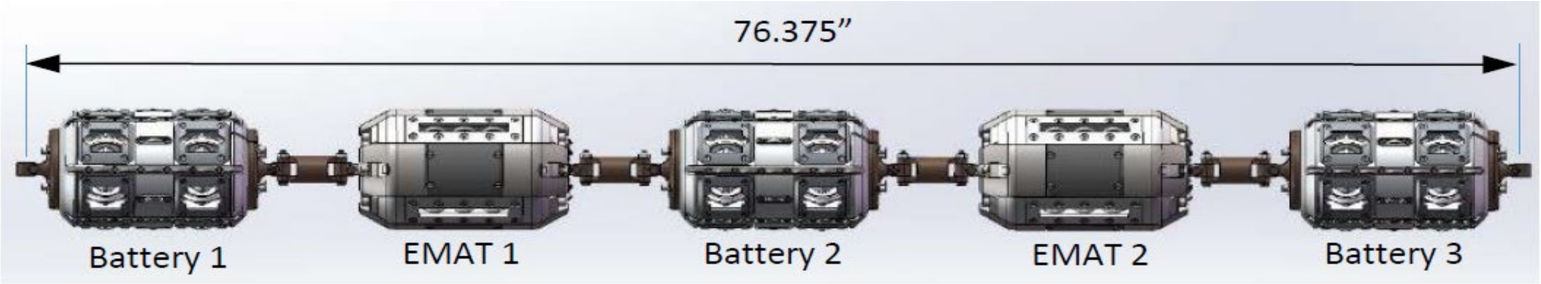
- Only a section of results shown.
- The notch-sizing results were as anticipated.
- We are able to detect thermal-fatigue-cracks despite severe erosion inside the pipe.
- We could detect most if not all wall-loss features. MFL machined flaws (steep edges).
- In some cases the labels got erased possibly due to mechanical handling.



Free Swimming Version

Phase IV - In process, post PHMSA/OTD contract

- Further tool hardening – navigability testing/pressurized connectors/sensor pad hardening.
- Increase inspection speed (initial target 0.5 m/s, increasing to >2 m/s for free swimming version).
- Will provide tow as well as free-flowing capabilities.



- Begin development of 10 and 12” designs – easy to extend.
- Integration of post processing and display into existing Q-Inline MFL analysis and display software.
- Minimize power dissipation to minimize heat and increase battery life. Battery > 25 miles per battery module per sensor depending on coating loss.
- Battery and sensor modules are bi-directional.
- Early customer outreach efforts have begun (Q-Inline) – 4th quarter this year.

Current Activity – Tool Geometry Verification

Navigability Testing of the Phase III/IV Tool Design at the Q-Inline facility

1.5 D back-to-back bends

- S-curves
- U-curves

20% restrictions

- Full-bore restriction (6.9”)
- Plane bore restriction

Tool collapsible to 6.5” + further collapse by sensor pads

Low friction through bends – minimizes pressure spikes

Commercialization

The technology has been licensed to Q-Inline for commercialization to augment their MFL inspection business.

- Both free swimming and wireline applications.
- Early customer outreach efforts through Q-Inline have begun – 4th quarter this year.
- We are always looking for pipeline samples for testing.

Qi2 continues to support the transition from a wireline version to a free-swimming version.

- Qi2 and Q-Inline engineering continues to collaborate for tool improvement.

Summary

- An EMAT crack tool has been developed for 8” schedule 80 and lower pipes.
- Initial development target was for shorter distribution lines. Design expanded to accommodate longer lines and higher pressures for free swimming.
- The tool successfully navigates 1.5D U and S shaped curves and 20% plane and full-bore restrictions.
- Low flow friction for smooth transitions through bends to minimize pressure spikes.
- Short tool length (~6 foot) with only two sensor modules + 3 battery/encoder modules. This provides 35 miles of inspection length. More with additional battery modules.
- Compact, light weight, low drag and bidirectional for traditionally difficult to inspect pipelines.
- Acoustic operating mode agile for different wall thicknesses.
- Good spurious mode control + unidirectionality = simplified data analysis and higher quality data.
- High operating power for lossy coatings as needed.
- Can be wireline and will be free-swimming (2 m/s). Free swimming max. pressure 2200 psi.
- The design in scalable to 10- and 12-inch diameter pipes.

Project Information

The public final report and these slides can be found using the following link

https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=653

EMAT Sensor for Small Diameter and Unpiggable Pipes; Prototype and Testing

Main Objective

The objective is to build a field-ready EMAT sensor prototype and perform controlled field tests to assess its performance requirements and capabilities in identifying and characterizing pipe defects. The field-ready prototype will be designed for 8 inch diameter pipes and mounted on available platforms commonly used in the natural gas transmission and distribution systems. Sensors for smaller diameter pipes from 8 to 12 inches will be developed based on the success of the prototype.

Public Abstract

The objective of this project is to build and test an Electro-Magnetic Acoustic Transducer (EMAT) sensor prototype to detect and quantify wall loss and longitudinal cracks in metallic pipes. The sensor will be used to assess small-diameter and unpiggable pipes containing fittings and other restricting features. The initial target pipe diameter is 8 inches, however the commercial goal is to build tools that can navigate in 6- to 12-inch pipes. These sizes are typically used in unpiggable natural gas transmission and distribution systems. Other sizes will be considered based on industry needs.

A laboratory assembly (bench-scale unit) has been successfully completed and tested in Phase-1. The work tasks in this proposal build on the results from Phase-1 and include:
- Build a prototype of the unit with the data management system and a pull-out mechanism for internal testing of pipe sections with controlled and natural cracks and flaws.
- Establish the performance criteria and assess the minimum flaw sizes to be reliably detected by the device

FINAL REPORT

Final Report - Public version

TR-1588_EMATCRACK_FINAL_PUBLIC_REV1.PDF (2,201,074 bytes) [VIEW] [DOWNLOAD/SAVE...]

Fast Facts	
Research Award Recipient:	Operations Technology Development NFP 1700 South Mount Prospect Road Des Plaines, IL 60018
AOR:	Joshua Arnold, joshua.arnold @ dot.gov, 202-366-6085
Contract #:	DTPH5615T00018L
Project #:	653
Researcher Contact Info:	Dr. Maureen Droessler Phone: 847-768-0608, Fax: 847-483-1286 Email: Maureen.droessler @ otd-co.org Principal Investigator: Dr. Khalid Farrag, Phone: 847-768-0803, Fax: 847-789-9201 Khalid.farrag @ gastechnology.org
Peer Review	More than Effective (PHP-11-2016, May 18-25, 2016)
Peer Review	More than Effective (PHP-12-2017, May 3-10, 2017)
Peer Review	More than Effective (PHP-13-2018, May 21, 2018)
Downloads of Project Reporting	
Since Jan 1, 2017	697
Technology and Commercialization	
Technology Demonstrated?	Yes
Commercialized (in whole/part)?	TBD
Financial and Status Data	
Project Status:	Completed
Start Fiscal Year:	2015 (09/30/2015)
End Fiscal Year:	2020 (03/31/2020)
PHMSA $$ Budgeted:	$1,070,690.00

Thank You!




QUALITY IN ENGINEERING, SCIENCE & TECHNOLOGY