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QUARTERLY REPORT – PUBLIC PAGE

Investigate Fundamentals and Performance Improvements of Current In-Line Inspection Technologies for Mechanical Damage Detection

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Prepared For: United States Department of Transportation
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Milestone and Deliverable Accomplishments this Reporting Period

Task No.	Task	Scheduled Completion Date	Completed Date	Milestone
B-7.2	Reporting/Meetings-Phase I Report	5/31/2007	6/30/2007	MS
B-4	Supplemental Testing – Confirm Activities	7/31/2007	7/31/2007	MS
B-8.1	Fourth Quarterly Status Report	7/31/2007	7/31/2007	MS

Technical Status

The Phase I report is complete. The report summarizes the findings of the project completed to date (Tasks B-1, B-2, and B-3) and makes recommendations for Phase II testing. This report was circulated to the Project participating vendors for comments prior to posting on the PRCI website.

Results and Conclusions

Current technologies for detecting and discriminating mechanical damage all consist of a process combining one or more sensor technologies, integration of multiple inspection data streams, specialty data analysis, and subject matter expert interpretation. Caliper, MFL and UT technologies (total of seven) were presented by the participating ILI vendors, claiming various capabilities for detecting mechanical damage of the following types:

- **All caliper technologies defined dent depth, length, width and shape.**
  - DAMC(EM) calipers provided the best validated performance
- **Coincident damage in the form of Dents with Metal Loss claimed by all MFL technologies.**
  - All but one technology requires caliper data stream
  - Subject Matter Expert Analysis Required
  - Validation data available for confidence interval analysis (POD.POI,POFC)
- **One technology (E) qualitatively demonstrated capability to detect cracks within dents, within limitations of orientation, but insufficient data was available to quantify performance.**

The validation of current technologies for the detection and discrimination of metallurgical changes in the form of localized residual stress and strain were not offered by any of the vendors.

The performances of current technologies are evaluated in terms of their sizing, probabilities of detection, identification and false call (POD, POI and POFC) based on the availability of data. Two methods are used for the evaluation: (1) binomial distribution and confidence interval method for sizing, POD, POI and POFC analyses and (2) linear regression method for analyzing correlations between ILI predictions and field measurement and standard errors in ILI sizing. In the section, the findings and conclusions from the data analysis are summarized and presented.

Plain Dents

- The current technologies, based on the vendors' data, accurately predict dent depths.

- Data from the operators showed a much larger depth tolerance. Reasons for the larger tolerance are most likely associated with re-rounding and rebounding of dents and the accuracy of field measurements.

- On average, the current technologies based on the vendors' data accurately predict dent length and width, but scatter in the measurements places a large uncertainty on the accuracy of any individual measurement.

- Regression analyses are used to characterize correlations between ILI predictions and field measurements and show that the sizing data, both vendors' and operators', generally deviates from the normality requirement for linear regression analysis. Modest departures from normality are known not seriously disturbing the values of confidence coefficients for interval estimates. Therefore, linear regression analyses are performed and tested in terms of normality of errors/residual distribution for each of the technologies.

- Regression analyses suggest that Technology G- DMAC(EM) from above ground pull test provides the best correlation between dent dimensions predicted by in-line tools and direct validation measurements. This result is expected given the potential for re-rounding and rebound of pipeline dents and the challenges surrounding the physical measurement of mechanical damage in field excavations. Even under the well controlled conditions of a pull through test, the regression analysis for Technology G indicated a bias affecting the relationship between depth prediction and validation depth.

- Technology E, utilizing an MFL 3-axis sensor, coupled with special SME analysis, demonstrated possible application for detection of dents and sizing of length, width and depth. The validation data provided by the vendor was from the results of a DAMC caliper in-line tool run (Technology D) in the same pipeline segment. Linear regression analyses show that its depth sizing performance comparable to that of caliper technology on mechanical damage assessment. The significance of the analysis is that a full confirmation of the depth sizing performance for Technology E is required to reliably characterize the performance of this technology.

- No laboratory pull-through data was made available for the metal tip contact DAMC technologies.

- No data is available for plain dents POD, POI and POFC analysis.

Dents with Metal Loss

- All MFL technologies demonstrate capacity to detect metal loss within dents. Data provided for 5 technologies allowing for estimate of reliability regarding dents with metal

loss using binomial distribution and confidence interval methods neglecting feature size effect. Two technologies (J and C), combining MFL and Caliper data, demonstrate capability for detecting Dent-Coincident-With-Metal-Loss with POD and POI.

- The metal loss data from Technologies C, H and I together with individual case study examples from Technologies E and J indicate the MFL based technologies have success in detecting metal loss less than 10% wall thickness coincident with plain dents in the range of 2% to 6%. However, the data is insufficient to quantify a detection performance.

- Technology E utilizing radial and circumferential magnetic vector data claimed capability to detect axially cracks and gouges depending on magnetic field orientation. However there isn't any quantitative data of statistical significance to draw concrete conclusions. Discrimination between corrosion and gouges was claimed for MFL technologies using single and multi-axis Hall sensors with Subject Matter Expert Analysis.

Implications

- The data provided from both vendors and operators did not indicate multiple inspections of the same pipeline segments or repeated pull tests of the same test piece. Therefore, a complete determination of reliability measures, such as POD and POI for both plain dents and dents with metal loss, was not possible. An understanding of the population of mechanical damage conditions, or features, subject to detection and discrimination by a technology along with multiple opportunities to detect and measure the population is essential to provide full understanding of reliability.

- The evaluation of validation data also provided insight into the potential for errors in validation measurements themselves. The physical direct measurement of depth, length and width of dents from the outside the pipes for comparison with ILI measurements is complicated by the selection of datum from which measurements were compared. There are analogous considerations for validation measurements of metal loss, corrosion or gouges within deformations. Complete understanding of the reliability and performance of current technologies should include an understanding of the performance of the externally applied validation measurement technologies.

In summary, a complete understanding of reliability requires a common population of mechanical damage features and conditions that can be inspected multiple times with multiple technologies. In addition the potential for errors arising from changes in dent dimensions due to re-rounding, rebounding and validation measurements must be controlled or fully understood.

The considerations outlined above helped to develop the recommendations for further research and testing in Phase II of this project.

Schedule

The Project is on schedule. Coordination is underway with Project A to ensure project schedules remain aligned.

Plans for Future Activity

The following scope is planned for Phase II Supplemental Test Activities for this project:

1) Perform a study of performance and tolerance for validation external measurements of mechanical damage. The above-ground pull tests offer an opportunity to fully develop performance and tolerance for external validation measurements. Examples of technologies proposed for study include; dial indicators and bridge bars, caliper measurements from appropriate arc templates and possibly laser mapping tools. Project A, within DTPH56-06-T-000016 ECT #203, is scheduled to fabricate a sample of 30 inch x 3 meters line-pipe with 13 manufactured mechanical damage features. A dual field MFL inspection tool for improved mechanical damage capability being built under Project A will incorporate DAMC(EM) caliper technology. Detailed validation measurements of these features will be conducted using multiple techniques and technicians. Data from multiple caliper pulls will be evaluated against the caliper inspection tool to identify refined caliper performance.

   Depending upon available schedule and budget resources, the pull through segment may be made available to the other participating technologies for comparison tests.

2) Project A, within DTPH56-06-T-000016 ECT #203, is anticipated to run the newly developed dual field tool with a 30-inch pipeline in 2007. This new ILI tool will have incorporated, within the vehicle, the DAMC(EM) technology G. Detailed validation excavations will be conducted by the Pipeline Operator in 2007-2008. Direct Examinations would be conducted considering the controls and protocols developed from 1) above. Critical comparisons between technologies would be conducted from evaluation of predicted measurements (prior to excavations and thus negating re-bound effects) and control of validation measurement error would be possible. As with the above ground testing, only one size of inspection tools could be accommodated with this trial pipeline approach, but from the bias observed in the operators' databases it has been concluded that a full understanding of performances and tolerances for current technologies may not be possible from continued data mining alone. Technology E (three axis Hall Sensor) provides a technically unique approach to detection and discrimination of mechanical damage limited to geometric changes (dents and local changes). With a complete understanding of the population of mechanical damage in the 30-inch trial pipeline, the other technologies will be invited to run their mechanical damage technologies in that pipeline segment, with first priority being Technology E. In this way a true system performance for dent measurement can be validated for Technology E (using Tech G data) as well as POD, POI and POFC for Technology E.

3) Based on the results and findings from Phase I study and the above tests, Topics associated with developing consistent methods/models for fitness-for-purpose assessment using the validated ILI data from the current technologies for mechanical damage measurements will be identified and discussed.