Overcoming Operational Obstacles: A Collaborative Approach to an In-Line Inspection of a Unique Mexican Gas Pipeline

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Abstract

TC Energy operates a 430 km (267 mile) nominal pipe size (NPS) 24 pipeline through the Sinaloa state of Mexico, supplying natural gas to a main client power plant near Mazatlán. The system is configured with a compressor station 507 km (314 miles) upstream of the NPS 24 pipeline, and the final delivery station is located at the end of the pipeline near the power plant. This compressor configuration results in the system operating with low differential pressure (DP) along the line and flows that are dependent on the client's demand.

Due to the unique operating conditions, inline inspection (ILI) of the system can be unpredictable and challenging, requiring an engineered approach since standard ILI methods may not be sufficient. This paper describes the collaboration between the operator and ILI vendor, and the ILI vendors approach to successfully inspect the line. An optimized ILI Magnetic Flux Leakage (MFL) TriStream MFL^{TM} tool was utilized, reducing the tool DP requirements by more than 66% and allowing navigation of the pipeline at low DPs, while still providing validated Ultra-High resolution Triaxial sizing specification.

Background

TC Energy Mexico operates the NPS 24 Mazatlán pipeline that connects the Topolobampo pipeline to a client power station in Mazatlán, see Figure 1 orange highlight. The operator requires a baseline ILI to be completed on this system as well as identification of suspected illegal taps. There are two segments within this NPS 24 system, segment one is 220 km El Oro to MLV 107, segment two is 210 km MLV 107 to Mazatlán DMS. This system operates at a line pressure of approximately 700 psi and with coordination with client can have a steady flow between 35 and 70 MMSCFD. The lines flows are dependent on the clients demand and can vary greatly. The nominal wall thickness (NWT) is 0.344 inches, and the heavy wall thickness (HWT) is 0.494 inches in this system, with the tightest bend being 3D.

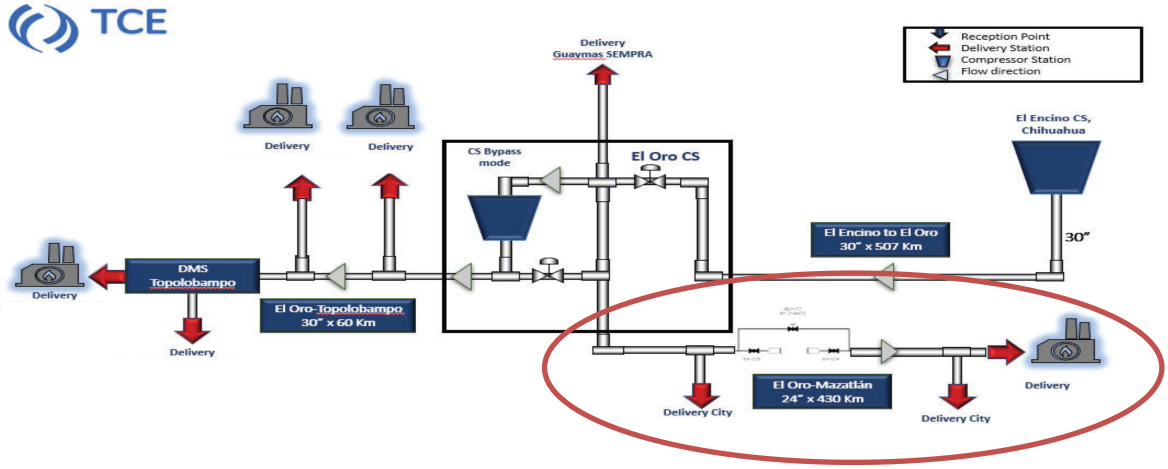

Figure 1. Mazatlán pipeline system map

The system pulls flows to the client plant, by mainly sucking the gas downstream. There is one upstream compressor station within the Topolobampo pipeline segment, 507 km upstream of the El Oro launch location. Given the location of compressor stations and the length of the system, the maximum DP across the line is limited, approximately 20 psi. As a result of the limited DP on the

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system, any ILI tools that will be utilized in this pipeline require that the DP to drive the ILI to be significantly below this number. Furthermore, for any successful ILI, the line must be clean, for this system a tailored progressive cleaning program able to handle the line operating conditions is required.

Collaboration

The operator and ILI vendor worked closely together from the onset of this project. The operator provided details and learnings from all previous cleaning inspections. While past inspection history was limited, the line had been subject to several cleaning pigs of various styles and cleaning aggressiveness and one caliper tool inspection. The run time results and velocities varied greatly pending the style of pig, for example, the run time for a basic cleaning pig was just under 3 days, whereas a dummy MFL pig from another vendor took just over 23 days to navigate one 210 km segment of the line.


Figure 2. NPS 24 TriStream MFL^{TM} configuration

Likewise, the ILI vendor reviewed and presented the current operational parameters of the standard configuration NPS 24 TriStream MFL^{TM}, a brushed and cupped magnetizer (MV) that tows the cupped supported caliper, recorder, IMU module (Figure 2). The ILI vendor reviewed past run history in conventional free swim applications, pull tests and unidirectional wireline tether pulls. The results showed that the DP of the standard tool was approximately 21 psi. The cups and brushes generate the drag and therefore resulting DP to propel the tool down a pipeline. Given the number of cups on the standard configuration and that the brushes are setup to saturate a WT much greater than the WT within the Mazatlán system, in conjunction with the line speeds being slower, there was an opportunity to minimize the drag on the standard configuration, by optimizing the tool subsystems including: magnetic path (brushes) and cups for this line.

The transparency between operator and ILI vendor highlighted the limitations in operating conditions on the pipeline and as well as the tool requirements to successfully inspect the pipeline system. The approach for the project included the ILI vendor complete an engineering study to assess and modify the standard configuration to meet the pipeline requirements, in addition, the operator to set inspection windows where the pipeline operated with consistent flows.

Engineering Study

Essential Variable Review

Essential variables are any components on the tool or part of the process that impacts the overall deliverable of the ILI product (American Petroluem Institute, 2021). In the case of optimizing the tool to minimize drag, changing the brush configuration can have an undesirable impact on the

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magnetic field and saturation of the pipe, ultimately impacting the probability of detection (POD) and sizing performance of the product (Jansesn, van de Camp, & Geerdink, 1994). Furthermore, changing the brush configuration can also reduce the support on the tool and change the dynamics for tool ride and ultimately sensor ride, again impacting the performance. Lastly, optimizing the cup configuration can also impact the ability for the tool to navigate the pipeline as well as maintain a full cup seal during 3D bend passage. A review of the essential variables was completed where the main variables that could be impacted are highlighted in Table 1.

Table 1. Essential variable review summary

Component	Essential Variable
Brush Configuration	Support and drag on the tool
	Magnetic saturation
	Probability of detection
	Sizing specification
Cups	Support and drag on the tool
	Durability

Design and Analysis of Essential Variables

Support on the Tool

Design and analysis were completed focusing on minimizing tool drag while taking into consideration the essential variables. With the cups and brush configuration both impacting the support of the tool, a suspension system was designed and incorporated on all tool modules, see Figure 3. The suspension was optimized to minimize the tool sag and therefore less reliant on support from the sub systems such as the cups and brushes. The addition of the suspension provided the ability to reduce cup interference and optimize the brush configuration to provide the minimum required magnetic saturation to sufficiently inspect the NWT and HWT sections of this pipeline, providing the lowest cup, magnetic and brush drag achievable.

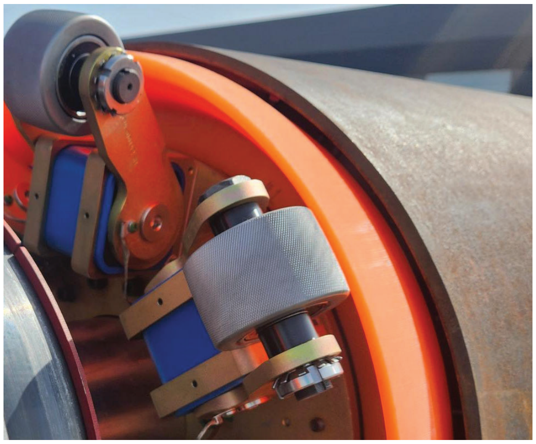

Figure 3. Suspension on caliper module

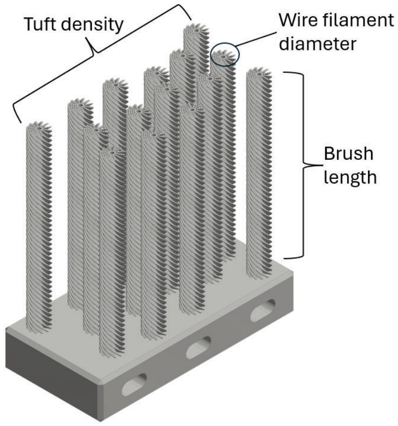

Figure 4. Components of a brush pack

The brush pack, which contacts the pipe wall and completes the magnetic return path to saturate the pipe wall, is one of the primary contributors of tool drag. There are three main components of a brush pack that make up the drag profile of a given pack, brush length (BL), bristle or tuft density (TD), and wire filament diameter, refer to Figure 4.

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The brush length chosen is related to the interference that the brushes will need to bend over inside the pipe as well as provide support to centralize the tool. More interference results in more force to bend over, while less interference means less force. The tuft density or number of tufts in each pack are a linear relationship to the drag of a pack. Wire filament diameters generally used ranges from 0.012 inches to 0.019 inches depending on tool size, level of debris and whether more or less drag is desired.

Magnetic Saturation

To ensure adequate magnetic field saturation for the NWT and HWT pipe segments, magnetic modeling was performed prior to any full system testing. Magnetic models were setup to align with current pull test results, using average magnetic hysteresis curves and a parametric study assessing different brush pack options (based on the different brush pack parameters listed above) was completed focusing on the magnetic saturation at up to 2 m/s speed in the HWT (Nestleroth & Crouch, 1998). This data was then used as a starting point for brush pack design to be tested on a full scale. Figure 5 shows the NPS 24 magnetizer return path magnetic model. Table 2 shows the results of the magnetic modelling, where in theory the minimum number of tufts required in a brush pack is approximately 24% of a standard pack to achieve the magnetic minimum threshold externally on the pipe (Bhatia & Westwood, 2004).

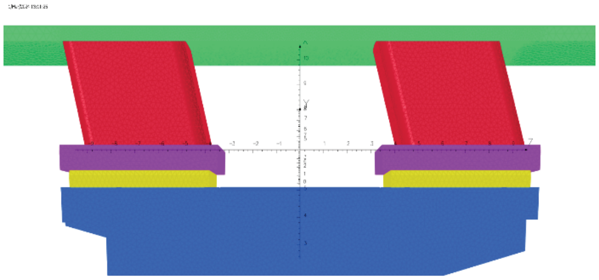

Figure 5. Magnetic FEA model

Table 2. Magnetic modelling results

Tuft Density %	Magnetic field inside pipe (oe)	Magnetic field outside pipe (oe)
100	370	355
90	358	344
74	323	311
57	262	253
38	183	178
24	102	96

Cup Durability

The ILI vendor had recently completed over 1000 kms of large diameter, long transmission line inspection, in hard dry fine debris lines, where high DP to optimize the speed control was the primary goal. Using past experience on NPS 30 and 36 transmission inspections, the ILI vendor planned to use studded cups that have cup diameters optimized for the line. Figure 6 shows a picture of the caliper drive module ready for drag testing.

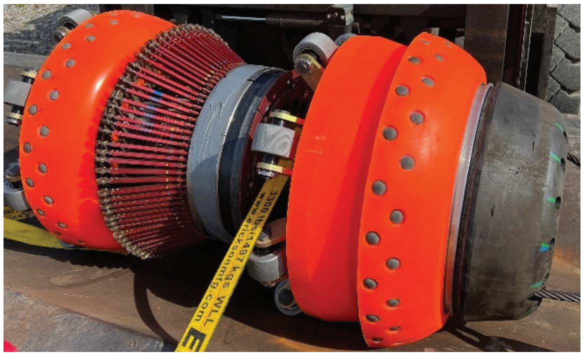

Figure 6. Caliper tow module

Testing Overview

Drag Measurement

To determine the drag of different brush and cup configurations, a series of pull tests were conducted in 0.375 inches and 0.5 inches WT pipes, similar to the pipeline to be inspected, at the ILI vendor's global technology center, based in Calgary, AB, Canada. Figure 7 below shows the pull string used for all pull tests related to this project.

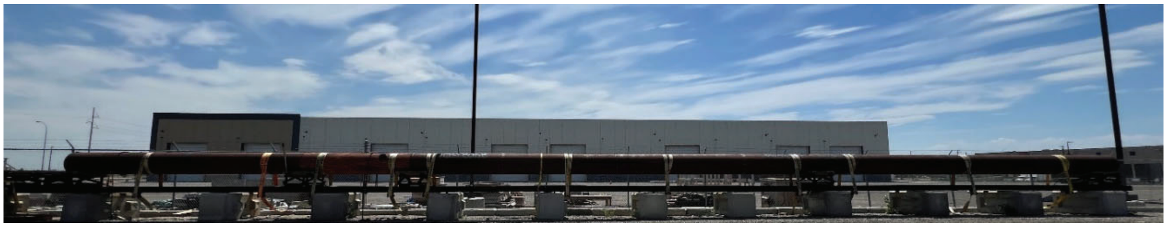

Figure 7. Pull string at Calgary facility

There were 4 different joints in the pull string, ranging from 0.343 inches to 0.5 inches WT, for a total of 101.5 ft (30.9 m) of pipe. Tools were pulled at multiple speeds from 0.5 m/s up to 3 m/s. The drag was measured using live recording through the wireline (WL) truck head attached to the ILI vendors WL pull truck.

Magnetic Field Measurement

The magnetic fields generated by the tool were measured during pull tests both internally and externally on the HWT pipe segment. Internally, the field was measured using the Triaxial sensors equipped on the TriStream MFL^{TM} tool, also known as the axial bias level (ABL). The external magnetic field (EML) was measured using a proprietary system, measuring the field at 3, 6, 9 and 12 clock positions around the pipe. These magnetic field readings provide a comparison to the magnetic modelling predictions, as well as confirm the pipe saturation during different pull test speeds ensuring adequate saturation for full POD for both internal and external features.

Test Configurations

Four different brush pack configurations were pull tested and compared against the standard brush pack. These brush packs varied in tuft density fill, wire fiber diameter and brush length. Each of these packs were mounted onto the tool body in different patterns. All packs were tested fully mounted to the tool body (100% population), while some tests were completed with a checkered board alternating brush pattern (50% population), as shown in Figure 8. Table 3 summarises the brush packs and tool mounting configurations tested.

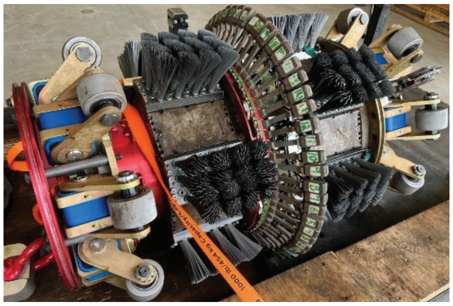

Figure 8. Checkered brush setup

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Table 3. Pull tested brush configurations

Test ID	Test Configuration Description	Brush Pack Configuration	Front Pack Assembly	Rear Pack Assembly
1	240307_Standard_full_asy	Standard pack	100%	100%
2	240610_57TD_full_asy	57% TD, 100% BL	100%	100%
3	240617_57TD_50_asy	57% TD, 100% BL	50%	50%
4	240619_38TD_50_asy	38% TD, 90% BL	50%	50%
5	240620_38TD_full_asy	38% TD, 90% BL	100%	100%
6	240624_38TD_full-50_asy	38% TD, 90% BL	100%	50%
7	240710_29TD_full_asy	29% TD, 90% BL	100%	100%

The drive module highlighted in the section above was pull tested at the same 4 speeds, with drag being measured to determine the equivalent DP.

Results and Discussion

The EML, ABL and equivalent DP for each of the test configurations listed in the above section are summarized below in Figure 9. The magnetic modelling results aligned well with the 100% brush assembled configuration. The initial magnetic modelling and actual magnetic results from the first two tests aligned well enough to give confidence in the finalized brush configuration used in test 7. The DP results from the first two tests were not as expected, as the DP for the standard tool and for the 57% TD brush pack resulted being the same. In theory the 57% TD brush pack should have resulted in lower DP. This unexpected result is likely the magnetic drag force being much greater than the brush drag induced by the brush configuration.

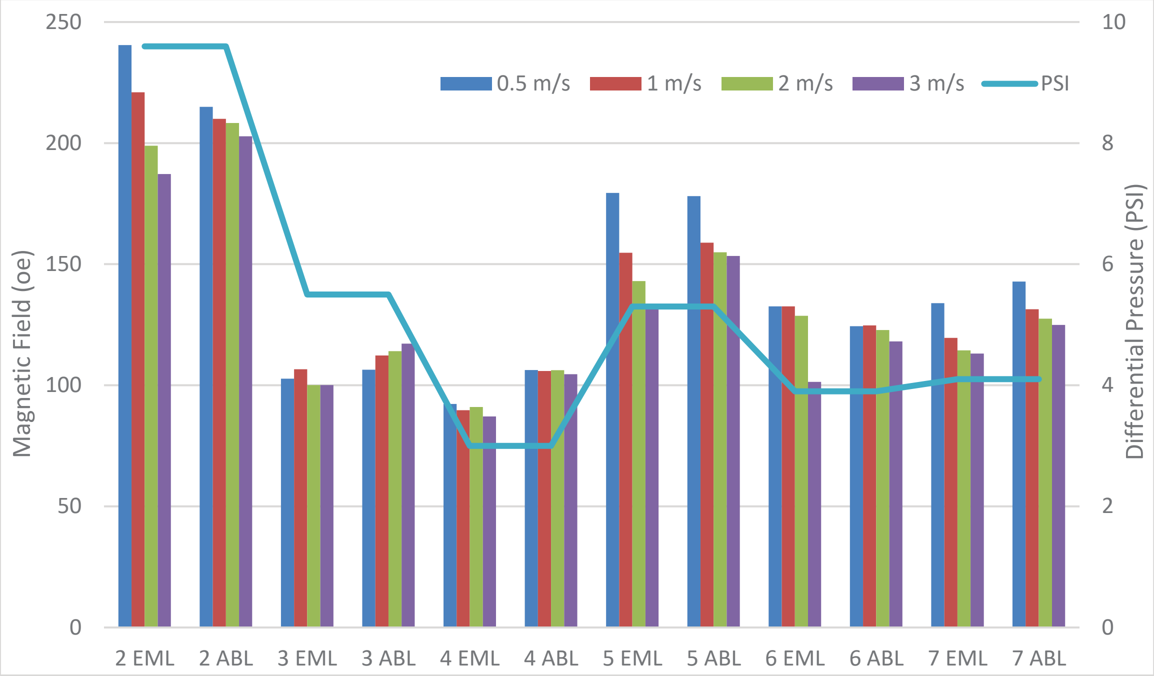

Figure 9. EML/ABL and DP plot for each brush configuration in HWT

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For the 100% brush assembled tool configurations, the EML and ABL results are as expected, where the EML/ABL decreased as tool speed increased. As brush packs were removed, the DP requirement dropped in a proportional increment as expected. In all 100% brush configurations, the EML/ABL levels by the tool were above the ideal minimum field level for meeting POD.

The drag of the cups on the caliper module were measured to be 1250 lbs or 3.0 psi equivalent. This was approximately a 70% reduction in cup drag forces as compared to the standard tool configuration. The primary drivers for this significant reduction were due to the optimized cup sizing on the middle and rear cups on the drive module.

Outcome

Validation

The final configuration, named low differential pressure (LDP), (Figure 10) selected for the inspection was based on minimizing the brush and cup drag while achieving acceptable and repeatable magnetic saturation in the HWT section at speed. The drive section included studded and size specific cups. The 29% brush configuration was used. The caliper section was used as the tow module while the MFL was positioned as the trailing module. Changing the order of technology modules from the standard configuration provided the ability to add in suspension, ensure adequate cup sealing in bends and provide the ability to add in additional battery life in the event an inspection ended up taking longer than expected.

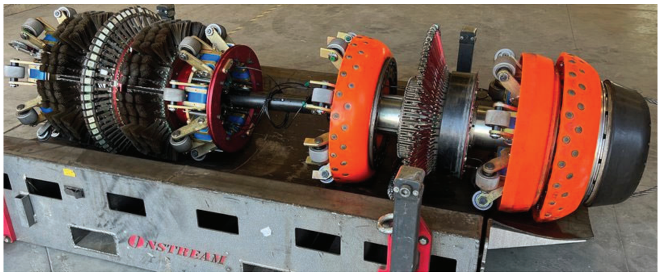

Figure 10. Final configuration at validation and commissioning

The final configuration was pull tested with the drag measured to be 2950 lbs, DP equivalent of 7.1 psi, in the HWT. The EML/ABL was above the ideal minimum threshold, the minimum level measured during the highest speed of ~3.1 m/s (Figure 9, Test 7). However, there was nearly a 60% decrease in EML/ABL for this final configuration as compared to the standard tool build due to the brush configuration.

The EML and ABL data provide an indication on potential impact to the POD. For MFL based technology, the POD will be most impacted in the HWT at the highest

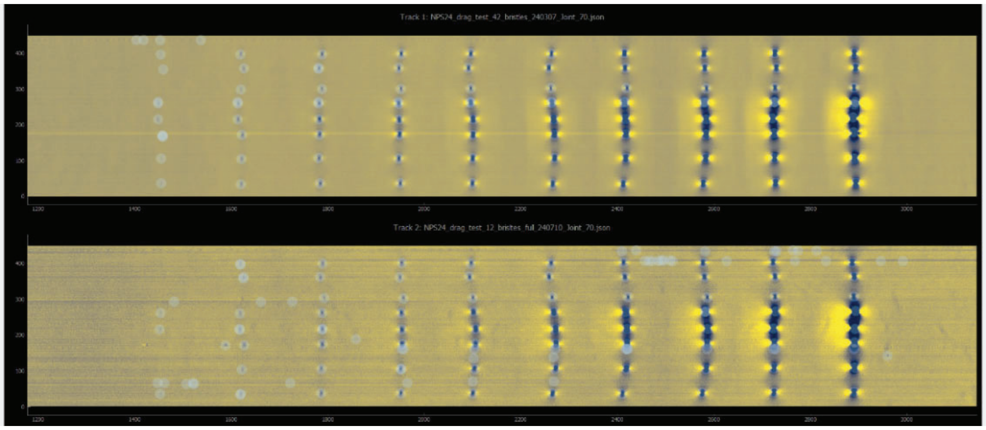

Figure 11. POD comparison using automated analysis in the HWT at speed **missioning**

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speed. A review was completed to see if the POD was impacted due to the significant change in EML/ABL levels because of the brush configuration. Using automated analysis, all features that are currently within the TriStream MFL™ specification were identified. Therefore, the POD was not impacted by the brush configuration change. The features within the HWT pipe segment that were identified using automated analysis are shown in Figure 11, comparing the standard tool brushes against the pack selected for this project

A detailed feature signal analysis was completed to understand the impact of the lower magnetic saturation due to the final brush configuration. As expected, for the same feature, the peak amplitude (PA) measured by the final configuration tool was lower as compared to the standard tool, this change was constant, predictable and as expected. Figure 12 shows the PA of the axial component for the same features of the standard tool as compared to the final configuration for WT 9.6 mm, 10.5 mm and 12.7 mm. Unity of the PA for the same feature would be preferred, given the difference in magnetic strength, the PA on the final configuration was lower. While the PA was a tight fit to the line, the slope is different, which indicates the need to tune the feature sizing model to adjust for this difference.

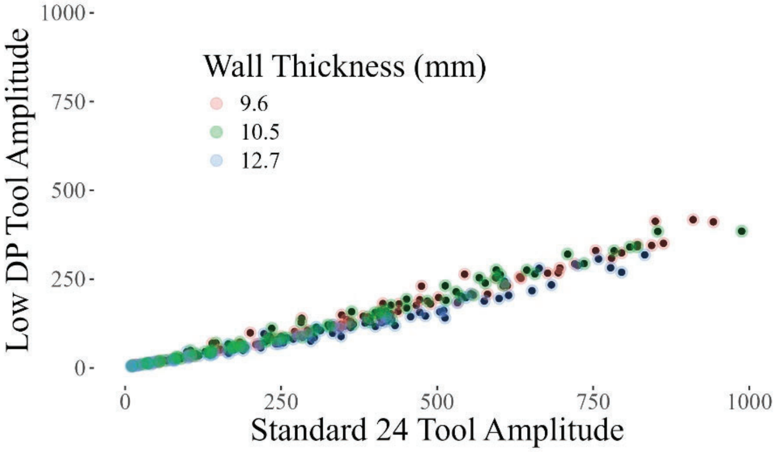

Figure 12. PA unity plot for NWT and HWT

The axial PA analysis demonstrated the need for sizing algorithm adjustment to meet specification. Since the essential variable change surrounded magnetic strength, the current algorithm was able to be tuned for this difference. The unity plot below, Figure 13, shows the blind sizing performance after tweaking the current algorithm specifically for this final NPS 24 LDP tool configuration. This algorithm was a tool specific model required for this configuration.

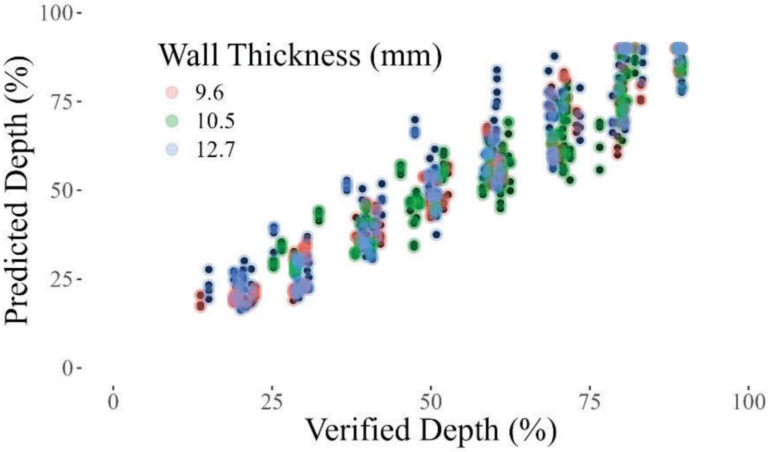

Figure 13. Unity plot for ALG 125, adjusted model specific for this tool configuration

Inline results

Tool Performance

The two segments were inspected within a two-week window, the first segment inspected on Aug 5, 2024, the second segment inspected on Aug 19, 2024, with a tool refurbishment and transport time in between. Both inspections were successful, the tool navigated the line smoothly, in a predictable time, collecting 100% data. Table 4 summarizes the run statistics for each segment.

Table 4. Run summary statistics for each segment

Segment	El Oro to MLV 107	MLV 107 to Mazatlán
Distance (km)	220	211
Average Tool Speed (m/s)	1.36	1.45
Speed Excursions	2	0
Run Time (hours)	45	41

The velocity plot for segment El Oro to MLV 107 is below in Figure 14. The plot shows a smooth velocity profile throughout the line, except for 2 speed excursions. The first speed excursion occurred at the launch of the tool and was due to following the same launch procedure as previous cleaning runs. The tool was provided excess DP (equivalent to previous cleaning runs), resulting in the speed excursion. The second speed excursion occurred at a location in the pipeline where all pigs (cleaning pigs, etc) were becoming stopped in a bend and releasing with speed. A review of the ILI data suggested the bend was tighter than expected, not 3D, which was causing the pigs to become stopped. The tool navigated WT transitions and bends with minimal change in velocity. Adjustments were made to the launch procedure for the second segment, resulting in no speed excursion at launch or throughout the inspection.

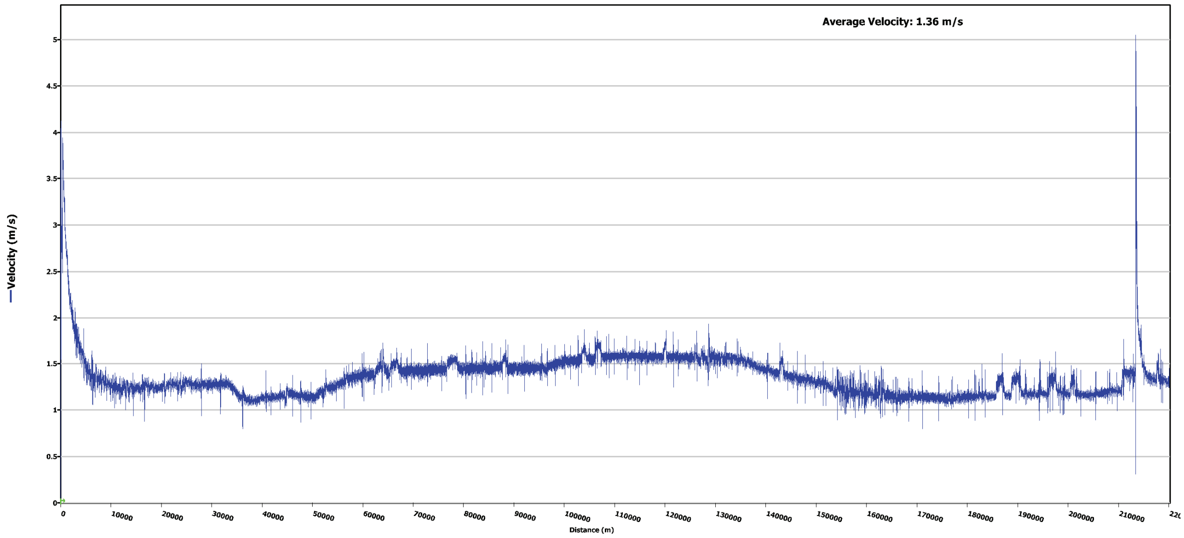

Figure 14. El Oro to MLV 107 ILI speed plot

A review was conducted comparing the performance of this LDP configuration against the standard HWT fully brushed 1.5D configuration within natural gas pipelines operating at similar line pressure of 750 psi and comparable WT transitions. In all cases of navigating bends, valving, and WT transitions, the LDP outperformed the standard configuration. Changes in velocity due to fittings or bends were measured to be approximately 30% higher for the standard configuration as compared to LDP. This result is as expected, as the standard tool is configured to inspect much heavier WT at higher tool speeds and as a result will not be as compliant through tighter fittings or bends.

Data Analysis

Upon successful completion of the ILI's, the Analysis process for each segment started providing data quality assessment within 7 days of completed inspection, preliminary reporting in 21 days and final report at 60 days. At the preliminary reporting stage, the ILI vendor identified four features that did not appear to be metal loss, nor traditional Tees or offtakes and were suspected as potentially illegal taps. Figure 17 shows the radial component of the MFL signal and 3D view of the radial response, the internal/external (IDOD) signal and caliper data of one of the unusual features. A signal response was seen in the MFL and IDOD, however, no response was visible in the calipers data. The non-reporting by the caliper sensors is not typical, as generally with a Tee or offtake there would be a response from the caliper sensors. There was no notable caliper response for all four sites of interest. Furthermore, the 3D MFL radial signature does not match the typical response of a metal loss, where usually there is a peak, trough, peak shape.

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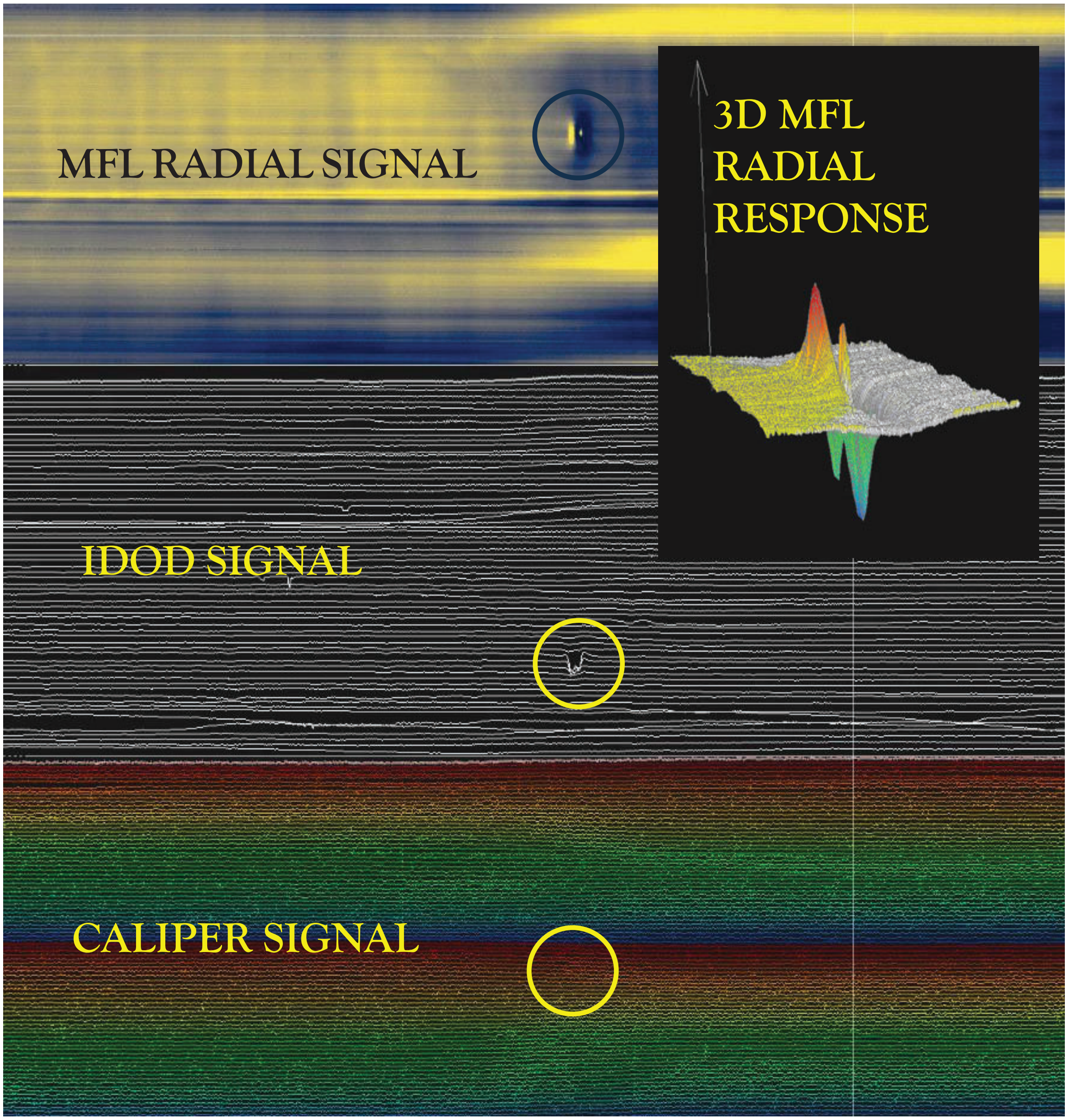

Figure 15. MFL, IDOD, Caliper response of suspected illegal tap

The operator chose to investigate the potential illegal tap features of interest. Daylighting the first one confirmed it to be an illegal tap. Figure 16 shows the illegal tap that correlated to the MFL and IDOD signatures in Figure 15.

Figure 16. Illegal tap

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Summary

The collaboration between operator and ILI vendor was key to the success of this project. Transparent, timely communication and sharing of technical information resulted in determining the minimum operating requirements the ILI vendor would need to meet. This aided in defining the pipeline operating conditions required to successfully navigate the pipeline. In a 5-month period the ILI vendor was able complete an engineering study and develop an ILI tool which reduced the DP requirements of the standard NPS 24 TriStream MFL™ by 66% in the HWT segment of pipe. While this was achieved by changing the magnetic return path through optimization of the brushes, the ILI vendor was able to maintain acceptable magnetic saturation levels within the HWT segment at speeds up to 3 m/s providing standard TriStream MFL™ POD and sizing specification. A successful baseline inspection was achieved on both segments of the Mazatlán system, the ILI identified four potential illegal taps on the pipeline, where one of the taps was daylighted and confirmed.

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