THE MISSING LINK - INSPECTING THE FINAL CRITICAL SECTION OF A LARGE CRUDE TRANSMISSION AND EXPORT SYSTEM

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This paper contains a focussed case history of an in-line inspection (ILI) in a pipeline which is a critical part of an oil export system. The tanker loading line, located off the Caribbean Coast of Colombia can be accessed from land only. Magnetic Flux Leakage (MFL) was chosen as inspection technology and bi-directional tools were applied. Based on a close co-operation between Client and Contractor the project was successfully completed well inside schedule and budget. Several other projects which required a bi-directional inspection capability are summarised.

The operator's perspective

Oleoducto Central S.A. (Ocensa) operates some 850 kilometers of pipeline connecting the Cusiana - Cupiagua oil fields with the tanker terminal at Coveñas on the Caribbean coast. Crossing the entire Colombia and climbing over the Andes, this pipeline is regularly cleaned and inspected by ILI tools. From an integrity standpoint, it is well under control since many years.

Each barrel of export crude then has to pass through the tanker loading pipeline connecting the Coveñas terminal with the tanker loading unit (TLU) only 12 kilometers into the sea. The sub-sea pipeline had never been cleaned or inspected since its commissioning, though crossing a highly sensitive shallow water coastal environment.

This pipeline extends over 0.6km on shore and approx. 11km off shore, ending in a pipeline end manifold (PLEM) on the sea floor at a water depth of 26m beneath a monobuoy system. Diameter is 42" with wall thickness 12.7mm in shallow and 15.9mm in deeper water. Pipe material is API 5LX60. The loading line has been in operation since 1996.

When planning for the inspection of this pipeline, Ocensa decided on Magnetic Flux Leakage (MFL) as the inspection technology to be applied. The main obstacle to employ common MFL inspection tools was the fact that there is no access to the offshore end of the pipeline.

To install a pig trap on the sea floor to make the pipeline piggable for conventional in-line inspection (ILI) tools was not an option. The necessary action for this scenario involves high cost and environmentally sensitive modifications to the existing pipeline system and requires sophisticated diver supported work procedures during the inspection campaign, in particular for recovering ILI tools from a pig receiver under water.

Following an evaluation of the inspection options, 3P Services from Germany was contracted. This contractor had extensive proven experience under comparable inspection circumstances. The critical criteria for Ocensa to choose 3P Services for this project was their ability to do bi-directional high resolution MFL inspections, where the ILI tool is pumped from shore to the offshore end and then, at reversed flow, pumped back to shore.

Further, the inspection project had to be done under a very ambitious time schedule. The first contact between Ocensa and 3P Services was in June 2007, the contract was placed in October, and all inspection work in the pipeline had to be concluded by December 21, 2007.

Pipeline cleaning considerations: In view of the difficult configuration, the pipeline had never been pigged before. Concerns regarding the cleanliness of the pipeline existed for several reasons:

- different crude qualities (from different producing fields) are loaded onto tankers through this system. High asphaltene and paraffin contents are typical for some of those.
- In the land sections of Ocensa's pipeline system sedimentation of those are known, and an appropriate program of regular cleaning pig runs is in place.

- The tanker loading line is operated only from time to time. Between tanker loading operations crude rests in the pipeline, increasing chances for sedimentation of heavy crude components.
- There was absolutely no knowledge about the recent internal condition of the pipeline, since it had never been opened since commissioning in 1996. Modification or repair activities have never been necessary.

These reasons in focus, Ocensa decided to have a complete fleet of cleaning tools prepared and mobilized to site. Though it was not certain whether all these pigs would be required, still the schedule limitations dictated to have them on stand-by. Only this way there the flexibility maintained to react without delay if the pipeline, after the initial pig runs, should turn out to have a serious aspaltene/paraffin problem.

The contractor's perspective

What is different from other pipelines in respect to in-line inspection (ILI)?

The main difference is the fact that there is no access to the off shore end of the pipeline. This requires all tools –be it for cleaning, gauging or inspection- to be launched from shore, do its job to the PLEM and then come back to shore. This is called a "bi-directional" operation in contrary to the conventional "uni-directional" pig operation, where a tool is launched at the starting trap of a pipeline, pumped towards the end of the line and finally recovered from the receiving trap.

The bi-directional concept requires to pump back and forth which requires to have tank capacity at the offshore end of the line or, if minimum 2 lines join at the PLEM, product can be circulated. In this case there is only one line going out to the PLEM that has a line fill of approx. 10 000 m³ (approx. 65 000 bbl). This is the minimum storage volume required at the sea end of the line and a tanker was applied to store and pump pigs back to shore. All pigs were propelled by stabilized crude oil.

Ocensa therefore decided that the inspection pigging would take place during a routinely planned normal tanker loading operation.

Is it necessary to do any diver work to prepare such an inspection job? No, not necessarily.

There are loading/unloading pipelines that can be inspected without any work under water. If the design of the PLEM is suitable then a certain volume can be pumped to run our inspection tool and then reduce speed until it hits the end of the pipeline. Reduced speed is a measure to minimize the effect of the "water hammer". This is a safe procedure and has been executed on various other inspection projects.

Ocensa, however, wanted –for several reasons- to avoid pigs to enter the PLEM. The stop and turn-around point was agreed to be the end flange of the pipeline, which is located some 15m in front of the hose connections to the surface. For this purpose three subsea antennae were placed at practical distance from this flange. Via these antennae, the pig passage at these locations was noted and the valves could be closed just in time.

Moreover, Ocensa wished to receive a complete set of geographic co-ordinates for all welds and features along the pipeline, both on- and offshore. This requires to set markers onto the pipeline and to document these marker locations with accurate surface DGPS readings. This is to provide for best possible geographic reference data for the pig's inertial system. This system requires to be calibrated at approx. each 1 km in order to get best possible accuracy. 3P Services' subsea markers were for this purpose placed on the sea bottom prior to the start of the project and only recovered after its conclusion. These markers have long life batteries for several weeks of service.

What kind of tools were applied for the inspection job?

Cleaning: Sequential mechanical cleaning, using series of cleaning pigs that have increasingly harder scraping efficiency, was the method of choice. Different foam and disc supported pigs were prepared and mobilized to site:

Type of pig	***Purpose***
MD (medium density) foam CrissCross	prove piggability
MD foam CrissCross wire brush	remove scale
Bidi soft	soft clean, scrape debris & paraffin
Bidi medium	medium clean, moderate displacing eff.
Bidi hard	hard clean, high displacing efficiency
Bidi accessories:	gauge plates spider nose (controlled bypass to displace big debris volumes) magnets (to carry out magnetic debris, e.g. scale)

The “BiDi” is the classical disc supported cleaning and scraping pig that is commonly used for efficient mechanical pipeline cleaning. For this project, taking into account significant cost of air transport from Germany, it proved very practical to have only two pig bodies with various accessories and attachments. This allowed the optimum cleaning tool to be assembled on site.

Inspection: Two inspection tools were run within the inspection project. While these tools are usually called GEO tool for geometric inspection and MFL for metal loss detection (Magnetic Flux Leakage), such modern and advanced inspection devices measure quite a number of different parameters. The most important are:

Parameter Measured	***on board of tool***	***purpose***	***remarks***
Distance	GEO, MFL	record pipeline length and feature distance	4 odometers each inspection tool
pig speed	GEO, MFL	to confirm pig progress as planned	calculated from odometer data and time
rotation	GEO, MFL	identifies clock position of features	
internal geometry	GEO	identify geometric discon-tinuities	primary GEO sensors, total 24 channels over circumference
paraffin layer thickness	GEO	measures lift off of GEO sensors from pipe wall	24 sensors to measure debris buildup
MFL data	MFL	identify external & internal metal loss	288 primary sensors of the MFL system
DMR	MFL	internal/external Discrimination	100 secondary sensors of the MFL system (Direct Magnetic Response)
XYZ	GEO, MFL	provide geographic co-ordinates to welds, features	inertial system based on gyroscopic sensors
temperature	GEO, MFL	measures product temperature	
pressure	GEO, MFL	measures pressure in front and behind inspection pig	to calculate tool delta P

What is the outcome?

Cleaning: After the recovery of the first cleaning pigs it became clear that the pipeline did not have a significant volume of debris to be removed. Therefore, the actual cleaning program could be shortened to one foam pig run and two Bidi runs. The second Bidi was equipped with gauge plates and served as “profile pig” to prove sufficient internal bore for the inspection tools.

From the inspection data a highly detailed data base of the pipeline in its present condition is achieved. 100% of the pipe surface, including in the weld areas, is fully inspected. All indications of metal loss are reported by length, width and depth, both external and internal, together with the exact axial and circumferential position on the pipeline. Meanwhile, Ocensa has already concluded a first campaign of investigating and verifying information included in the inspection report. The results have been analyzed in much detail and have served for fine tuning of the data interpretation for those findings that have not been verified. A closer analysis of the metal loss findings is not subject of this paper.

A multitude of further valuable information has become available. This is e.g. minor ovalities in millimeter-size (from GEO data) that are present in the land section, and a more detailed vertical profile of the pipeline than known before (from XYZ data, see Fig. 6).

Moreover, tool operational data help to understand performance of the inspection tool. The pressure data recorded by the MFL tool e.g. indicate that the differential pressure necessary to move the tool is only approx. 0.1 to 0.5 bar (Fig. 7).

Fig. 8 shows the speed performance of the MFL tool on its way from the launcher at the Ocensa terminal out to the PLEM and back again. On the way out, an almost perfectly constant pig speed of 1 m/sec can be found. This was exactly the agreed pig speed and it was kept accurately constant, since here Ocensa’s export pumps could be used that have a highly sensitive flow control. After the first antenna indicated the pig passage, pumping was slowed to 0.1 m/sec. Following the second antenna just a few meters in front of the PLEM, valves were closed completely. The third antenna, positioned right behind the pipeline end flange, confirmed the pig’s final position just at the right place.

At approx. the middle of the offshore section, there is a transition in pipe wall thickness. The flow control on the way out was that accurate, that this transition can even be found in the speed profile: While the pumps take care for a constant flow rate, the pig accelerates to a marginally higher speed when the ID is slightly reduced because of higher wall thickness. On the way back the tanker pump was simply set to a certain capacity level and not changed throughout the run. The decline of the resulting pig speed is due to the changing static tank levels: with progressing emptying of the tanker, its oil level falls while the onshore tank level rises.

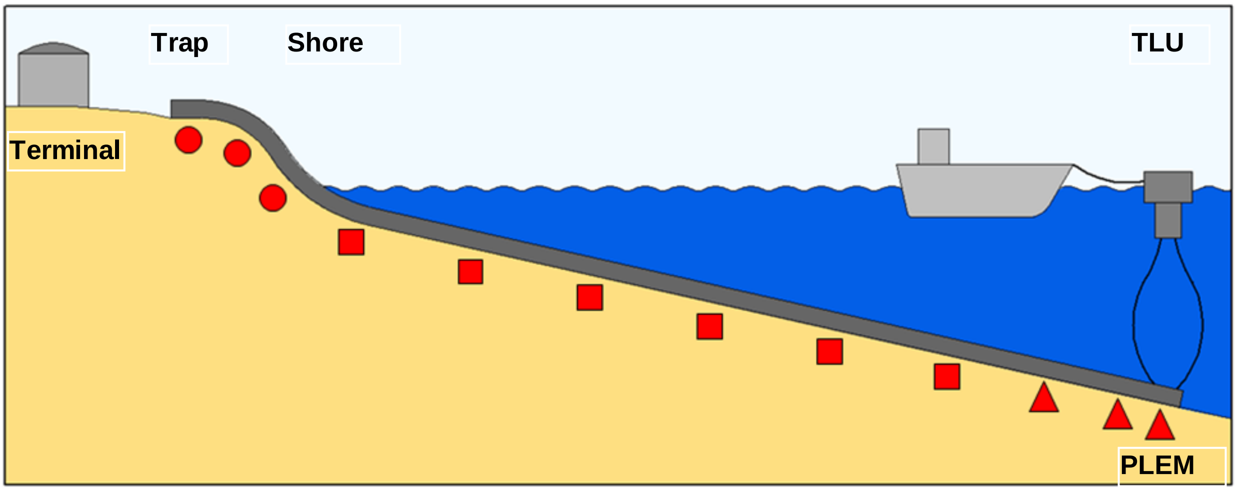

Fig. 1: General layout of the Ocensa tanker loading system and 3P Services' antennae and markers

Fig. 2: Pig trap at Ocensa's terminal, Covenas, Colombia

Fig. 3: Cleaning pig equipped with gauge plates, transmitter, magnets and inertial system after the run

Fig. 4: GEO inspection tool being installed into the trap

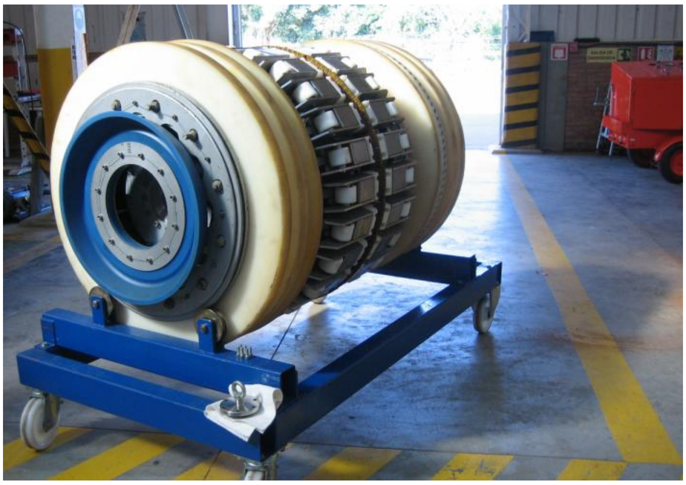

Fig. 5: Single module 42” MFL inspection tool

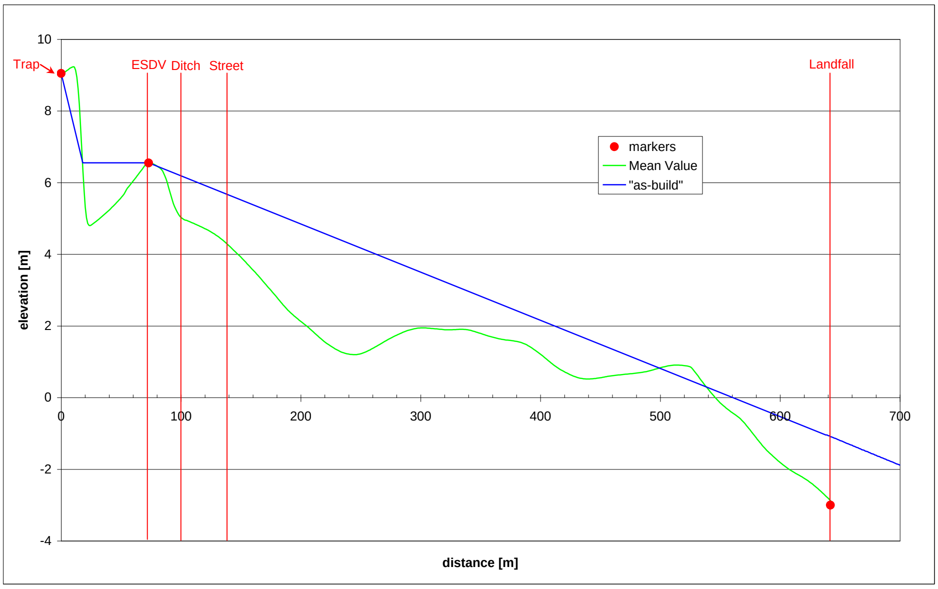

Fig. 6: Vertical pipeline profile onshore section

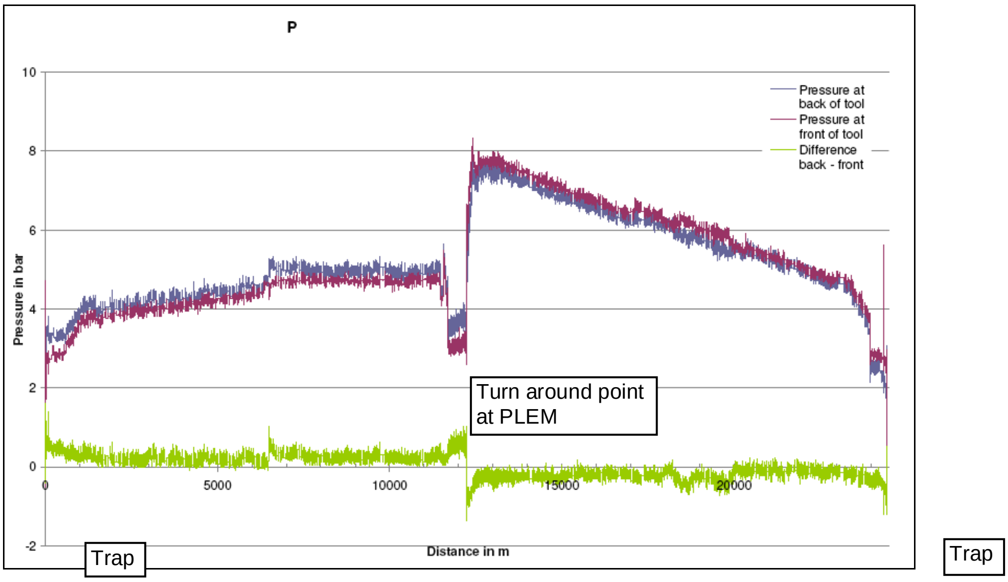

Fig. 7: Pressure recording during MFL run by the inspection pig

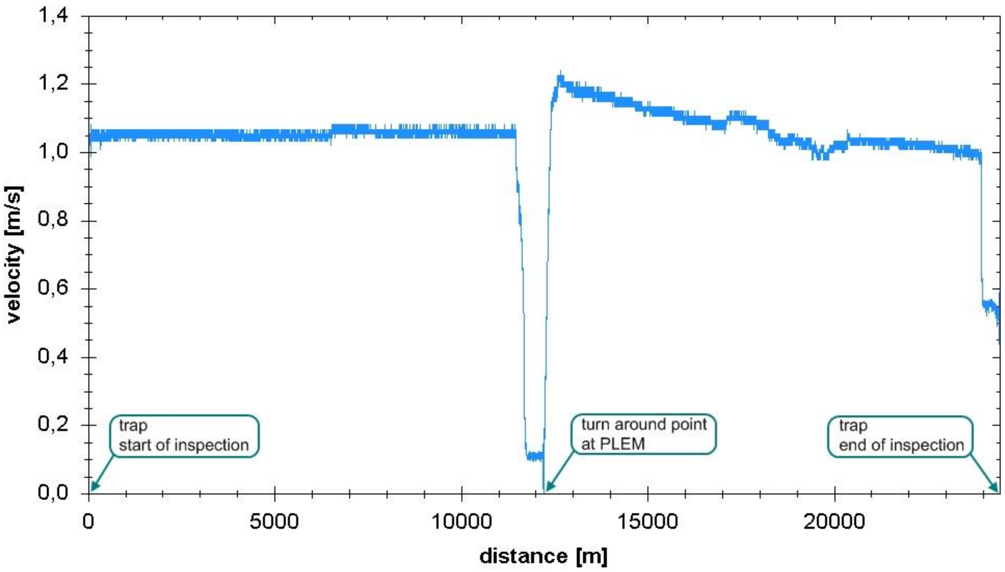

Fig. 8: Speed profile MFL run, top shore to PLEM, bottom PLEM to shore