Feeler Pig – A New Tool for Multi-Size Pipeline Inspection

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Abstract. The PPG-1/PGP-1 crude pipeline connects platforms Pargo and Garoupa in the Campos Basin. Crude is processed at Garoupa by removing water and transferring it to the coast. For 10 years this pipeline had operated with more than 20% of water. In 2001, the pipeline was surveyed with a Magnetic Flux Leakage (MFL) pig. The results showed internal corrosion in almost the entire 22 inch-pipeline concentrated on its bottom part (channeling corrosion). This type of indication is very difficult to size using MFL tools. The logistic arrangements were made to replace the damaged pipeline, but before the beginning of the work the pipeline was surveyed again using an Ultrasonic (US) pig this time, in order to enhance the sizing of all defects. The results of the US pig confirmed the MFL pig report, so all previous arrangements were maintained with the purpose of replacing the corroded segment.
At that time, a new inspection pig was under development at PETROBRAS Research Centre in cooperation with the Catholic University of Rio de Janeiro (*Pontífica Universidade Católica* - PUC-RJ). This new pig, the feeler pig, ran on that pipeline and the results were compared to the two most common methods used in pipeline inspections.

Introduction

The Feeler Pig developed by CENPES and PUC-Rio was specifically designed to detect and quantify internal corrosion. In the case of the Pargo-Garoupa pipeline inspection, the pig was made-up of only one module, which made logistics - transportation, launching and receiving operations - easier. It is very similar to a Geometrical Pig. Other advantages could be also be mentioned, such as its capacity to work with multiphasic fluid and at speeds above 1 m/s, initially prescribed for the Ultrasonic Pig.

1. Cleaning

The pipes were cleaned before the instrumented pig inspections took place and a large volume of waste was dragged as pigs ran through them. This eventually caused disturbances to the process at the destiny platform. A pressure vessel was requested for the segment downstream to the pig receiver in order to buffer the slug and to store the debris carried by the flow. This request was critical in view of the significant water percentage and the big amount of waste inside the pipe. Figure 1 shows Cleaning Pigs used in this operation.

Figure 1 – Cleaning Pigs used in the cleaning operation

2. Final Stages of Preparation for the Inspection with MFL Pig

In April 2003 an inspection was performed using a Magnetic Flux Leakage (MFL) Pig. In spite of the large number of cleaning pig runs, there were expectations and doubts regarding the quality achieved by the cleaning process. After the geometrical inspection, performed by a Geometrical Pig, and the magnetic cleaning process, the MFL pig was launched and reached the end of the pipe without major problems, thus validating the cleaning process used.

3. Inspection Results Using MFL Pig

The results of the MFL pig inspection indicated extensive corrosion at the lower generatrix, with a large accumulation of defects. The company in charge of the inspection reported difficulty to size discontinuities due to the large number of defects clustered at the lower generatrix and the presence of metal debris inside the pipe is suspected.
Tims et al [1] presented a case in which the presence of metal debris caused false impressions on the magnetic inspection tool. This was the case of a submarine gasline that ended up being unnecessarily replaced due to the presence of such debris.
After the initial discussion, a preliminary list of the more significant metal losses was delivered. There were severe defects along the whole pipe, mainly concentrated at the lower generatrix. Although the pipe was operating under low pressures and made of API 5L X60 steel, a technical analysis performed considering the high corrosion rates as well as the remaining strength of the tubes recommended that 16 km of the pipe were replaced.

4. Final Stages of the Preparation for Ultrasonic Pig Inspection

In order to guarantee the success of the US Pig run operation the following measures were taken: oil temperature was reduced to 60º C at the most, oil homogeneity without a water phase was assured, Cleaning Pigs ran three times, a study of the logistics of the pig run at the launcher and receiver was carried out, the speed of the pig was controlled based on the export flow rate of about 1m/s. The procedures mentioned above were followed and everything took place as expected.

5. Inspection Results Using Ultrasonic Pig

The report presented general internal discontinuities such as mass losses located at the lower generatrix, between 4 o'clock and 8 o'clock positions. Corrosion was not severe in

the initial segment of the pipeline and it got worse as the distance from point zero of the pipeline [2] increased.
In general the results were qualitatively similar to those provided by the MFL Pig, yet less defects were mapped and they were not so deep. An analysis of the remaining useful life of the pipe – which took into account the parameters that rule the corrosive process as well as the remaining pipe strength – pointed out that the damaged segment could still operate for a few years. Considering that pipeline replacement always requires a significant amount of time, the initial recommendation to replace 16 km of the pipeline was followed at an approximate cost of US$ 15 million.
The global results of MFL Pig and US Pig inspections are shown on figures 2 and 3, where the similarity of longitudinal and circumferential distribution of discontinuities can be seen. Both of them are concentrated between the 4 o'clock and the 8 o'clock positions and approximately between kilometers 2 and 16.

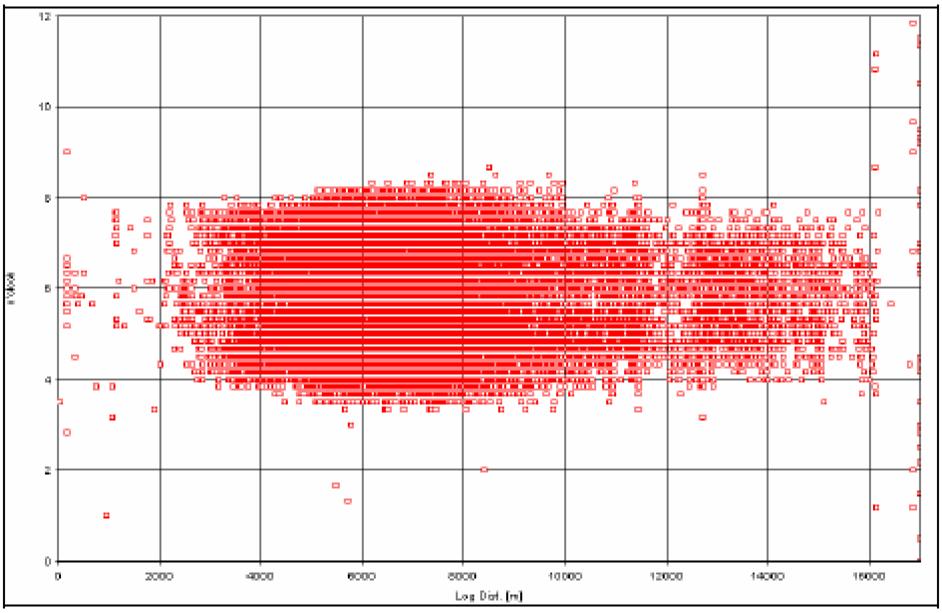


Figure 2 – Distribution of all discontinuities recorded by MFL pigs (planned pipelined). The hourly position of the occurrences is on the vertical axis. The position along the pipeline in meters is represented on the horizontal axis.

6. Corrosive Process

The pipeline corrosive process was caused by a combination of mechanisms associated to marine growth deposition and separation of the water phase produced. The first process can be confirmed by the large amount of Barium sulfate debris removed during the pipeline cleaning operation. The second process becomes evident by the number of years that the pipeline has operated producing large amounts of water at low flow rate speeds of about 0.5 m/s. Figure 4 shows a schematic drawing of the preferential location of the defects between 4 o'clock and 8 o'clock positions.

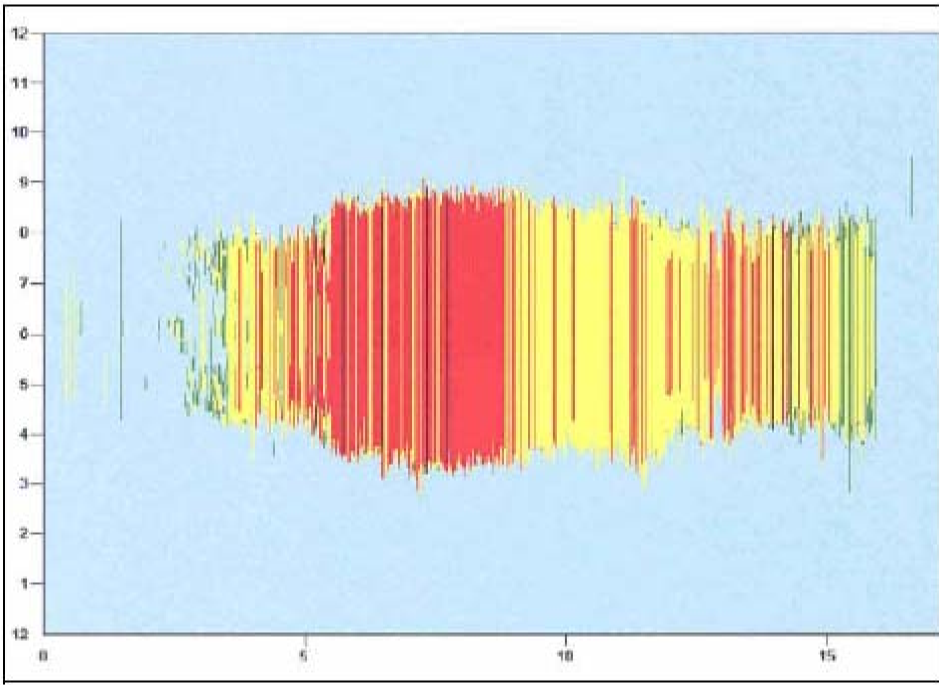


Figure 3 – Distribution of all discontinuities recorded by the US pig (planned pipelined). The hourly position of the occurrences is on the vertical axis. The position along the pipeline in kilometers is represented on the horizontal axis.

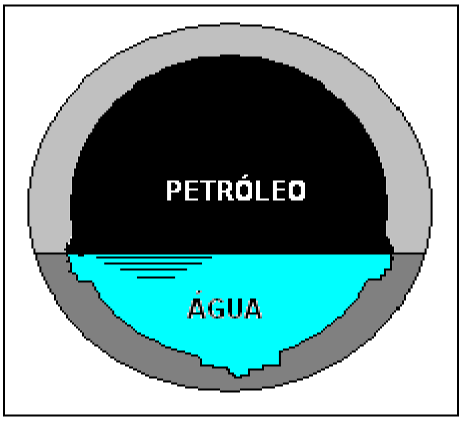


Figure 4 – Water-oil interface and corrosion-prone areas in laminar flow with emulsion break.

7. Inspection Using the Feeler Pig

7.1.Characteristics of the prototype

Figure 5 shows the Feeler Pig during the final assembly phase, before pipeline inspection.

The main characteristics of the tool are presented below:
Cross-sectional resolution: It is given by the ratio between the pipe inner perimeter and the total number of thickness gauges. In this case, the prototype was provided with 250 sensors uniformly distributed along the perimeter, thus rendering a 22”/250 = 7mm cross-sectional resolution. The lowest observable defect is given by the thickness gauge diameter

(probe), because it must penetrate the defect. In the case of the prototype, the value was 2 mm;
The largest defect that can be missed depends on the probability of it passing in between two thickness gauges. Considering the gap between thickness gauges and their diameter, this value in the prototype was 5 mm; which can be reduced by increasing the number of sensors.
Cross-sectional resolution: It is defined by the sampling rate and by the tool speed. Taking a speed of 1 m/s as an example, the 512Hz rate used on the prototype provided a cross-sectional resolution of 2 mm.
Gauging: Each sensor was individually gauged in order to insert the true response curve of each sensor into the data acquisition software, thus correlating the angle of the thickness gauge to the tension generated by the angular sensor.
Validation: The tool was lab tested using defects simulated in a 20 m long pipeline.

Figure 5 – Feeler Pig assembled for inspection, provided with 250 sensors, two hodometers. The electronic unit and the batteries are housed inside the pig.

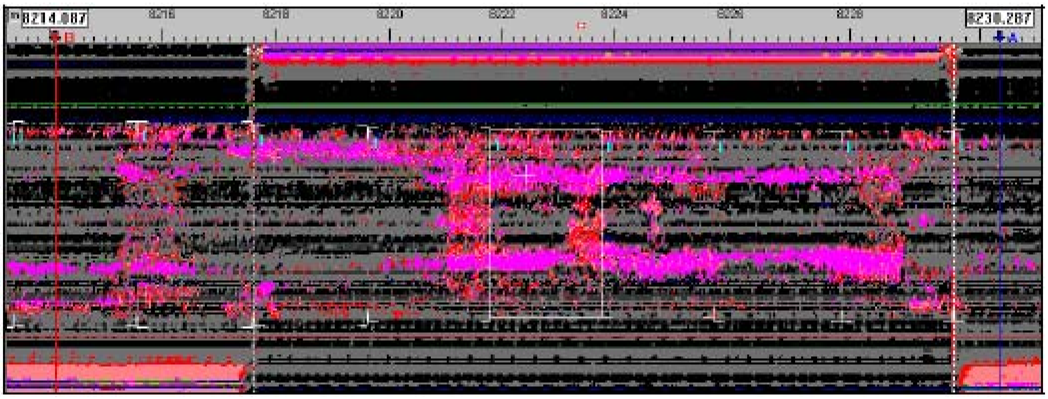
7.2.Comparison between MFL Pig and Feeler Pig

The results obtained with the Feeler Pig were compared with the previous inspections performed by the MFL Pig and the Ultrasonic Pig. The comparison with the MFL Pig was difficult because the magnetic leakage of the defects, that are too close to each other, interacts with one another, thus making it difficult to define the spatial resolution of each individual defect. “Magnetic spots” generated in the MFL Pig report can only be interpreted by the equipment operator, that is, by the company responsible for rendering the service. In any case, a gross comparison between both systems was carried out and a good correlation was obtained, however depths could not be compared.

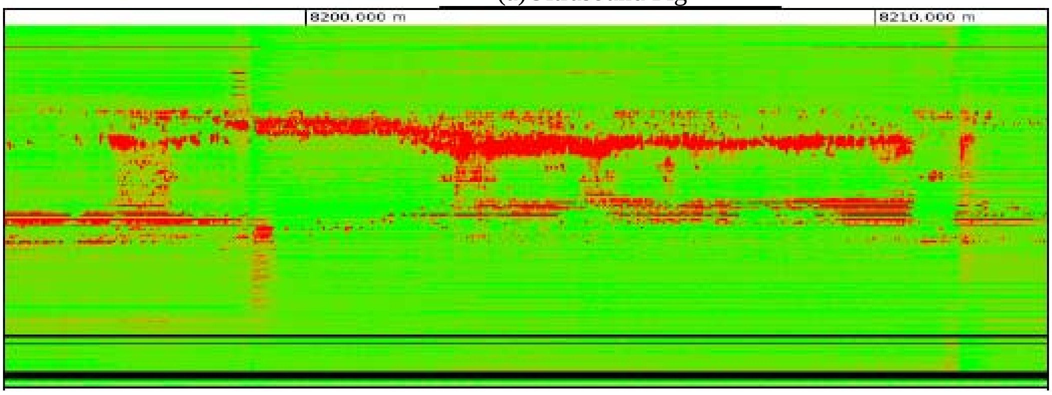
7.3.Comparison between Ultrasonic Pig and Feeler Pig

The comparison between the results obtained by the Ultrasonic Pig and the Feeler Pig was much more feasible because both systems intend to provide the defect measures directly.

As both inspections contain an excessively large number of data, results were presented by selecting the main defects found, yet we must emphasize the general consistency of the results provided by both inspection tools.
Since hodometers point out slightly different distances (16.840 km – Feeler Pig and 16.739 km – US Pig) girth welds correlation was performed in order to identify and correlate both inspections more precisely. Corrosion images rendered by both tools were compared considering corrosion shape, extension and depth and the process was easier because both - the US Pig's and the Feeler Pig's - visualization software provide a C-scan format signal.
In general terms, the global analysis of the run revealed that both corrosion surface mappings were similar, which means that the cross-sectional and the longitudinal sizings provided by both tools was the same and that the resolution characteristics of each one of the techniques were equivalent.
Figure 6 shows a typical result of this comparison where the geometrical similarity of corrosion provided by both techniques can be clearly observed.



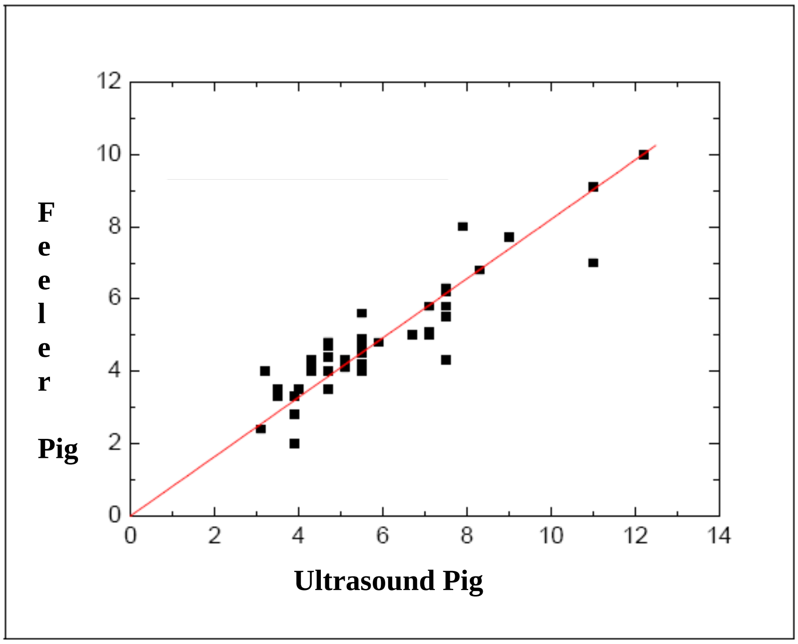
(a)Ultrasound Pig



(b)Feeler Pig

Figure 6 – Images obtained by both pigs in the same defective area. There is “visual” similarity between the two images.

Figure 7 shows the depths correlation measured by both techniques for a given set of corrosion defects. An excellent correlation is observed, in spite of noise interference. The correlation factor measured in this graph is 0.82, which indicates that the geometrical technology – Feeler Pig – tended to provide lower values than the ultrasound technique.



8. Repair

The damaged segment of the pipeline was fully replaced and reconditioned for safe operation. Currently it is already operating normally. While the connection to the new segment was underway, oil was transferred to a single buoy.

9. Conclusions

Having run three types of pigs in this pipeline allowed us to arrive to the following relevant conclusions:

a) It is still very difficult to quantitatively size the depth of defects concentrated at the lower generatrix of a pipe because of the accumulation of alveoli – due to the presence of debris – is often found in this area;

b) Special attention should be given to cleaning procedures in these cases;

c) It was more difficult for he MFL Pig to size defects in comparison to the Ultrasonic Pig and the Feeler Pig;

d) Feeler Pig technology can be used with great success to access pipeline internal corrosion. New calibration systems are already being implemented, which will bring about a significantly more precise depth sizing;

e) The comparison between the defect depth measures provided by the Ultrasonic Pig and the Feeler Pig has shown a good approximation because both are direct reading techniques;

f) The cost of the Feeler Pit is probably higher than the geometrical pig and lower than the MFL and the Ultrasonic pigs;

g) These results are still limited to a single inspection performed with the Feeler Pig. Further tests and field inspections will have to be carried out in which defects are expected to have different geometries and flow conditions in order to analyze the advantages and limitations of this tool in a more broader sense.

10. Acknowledgments

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References

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[2] - FRANZOI, A. R., MELO, F. S. V., MORAIS, P. R., BUENO, S.I.O., Inspeção com Pig Ultra-Sônico em oleodutos de águas profundas. IBP 1386 05, Rio Pipeline Conference, Rio de Janeiro, Instituto Brasileiro de Petróleo e Gás: Out., 2005.