PIPELINE INTEGRITY ANALYSIS BASED ON INTERDISCIPLINARY COOPERATION

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ABSTRACT

For many years, BP Pipelines, North America has used high-resolution Magnetic Flux Leakage (MFL) in-line inspection (ILI) technology to help maintain the integrity of their pipelines. The improvements in this technology that now allow an Operator to make integrity decisions also bring challenges. Reports from ILI can list thousands, or even hundreds of thousands, of individual anomalies or features. When combined with data from NDT field measurements and existing pipe tallies, it can become overwhelming. Methods had to be developed to distill this information for further analysis.

BP Pipelines NA encouraged cooperation between all parties involved in the integrity process to adapt reporting requirements and work procedures to provide the best available information for integrity analysis and to ensure continued improvements. This cooperation is a key part of the integrity equation and essential to a successful program.

This paper presents an overview of the validation process undertaken on a 51 km (32-mile) section of 457 mm (18-inch) pipeline. This pipe section was inspected in 1999 and again in 2003 by the same inspection company. This provided an opportunity to evaluate improvements in inspection technology, assess repeatability of performance and develop an engineering based approach to review, analyze, and validate high-resolution metal loss MFL data. Field verification and data validation included the use of several NDE techniques to acquire field measurements to overlay and compare to the ILI inspection data.

Anomaly classification and distribution is examined and methods of selecting validation locations for future inspection developed. In addition to the primary goal outlined, the 2003 repair program provided an opportunity to evaluate the performance of the composite sleeve reinforcements applied in 1999, after 4 years of service.

INTRODUCTION

In-line inspection (ILI) is used to help manage the integrity of the pipeline system. Improvements in the capability of ILI tools have changed maintenance and repair strategies. In early years, it was not uncommon to investigate all reported indications. Many benign corrosion features were simply recoated and backfilled with only negligible improvement in integrity as compared to the cost of excavation.

As the accuracy of inspection tools improved, maintenance and repair strategies changed to reduce cost while increasing safety. This involved coupling in-line inspection to risk assessments that consider the criticality of reported anomalies and cost effectiveness, with repairs being made only when deemed necessary for risk reduction. In this environment, sizing accuracy is much more important, as are issues that arise when features are misclassified or possibly not detected.

The capabilities of magnetic flux leakage (MFL), the most commonly used inspection technology, are well known. It is also known that these capabilities are dependent upon the pipeline that is being inspected. MFL inspection tools are calibrated for each pipeline prior to the inspection run, setting pipeline specific parameters such as threshold of detection and sensor and magnetizing parameters. The parameters have to be set properly, otherwise errors in either calibration, or analysis, can introduce significant inaccuracies in inspection results. The last remaining element to confirm the adequacy of an inspection is to provide detection threshold and sizing data to confirm and demonstrate tool performance.

API 1163 [1], recently released, will establish a standard for the qualification of in-line inspection systems. This Standard will be performance based and will provide requirements for qualification processes, but will not define exactly how to meet those requirements. A key element to ILI system qualifications is the documentation of the processes used for qualification.

A series of inspections between 1999 and 2003 performed by ROSEN, provided an opportunity to assess the performance characteristics of MFL in-line inspection equipment (Fig. 1 – ROSEN 18-inch, Corrosion Detection Pig (CDP) ILI Tool) in detail, review the current methods of tool validation and develop new procedures to document the processes that will be required by new standards and increasing oversight.

PIPELINE INTEGRITY PROGRAM STRUCTURE

BP Pipelines NA is committed to operate its pipelines safely and to tolerate zero leaks or failures. This single focus often requires that integrity decisions go beyond what might be required from the applicable codes. It also requires that the company acquire, and maintain, a current knowledge-base of ILI and NDE inspection equipment and their capabilities.

The escalating quantity of data available from high-resolution inspection tools necessitates a review of the data management procedures traditionally used and an understanding of how to use the available data in the most effective and efficient manner.

ILI reports typically contain thousands of reported features. This is due to improved sensitivity of the tools, reduced magnetic noise levels through better design, and the ability to discriminate feature signals using automated techniques. Most features will be insignificant and will not put the pipeline at risk, but a certain number may be detrimental to long-term integrity. While the quantity of data can be overwhelming, it is needed if probabilistic integrity methods are used to make integrity decisions.

For the most part, operators do not have the expertise to review the raw inspection data in detail, nor is there time available for this task. They must rely on the detection and sizing performance specifications provided by the ILI Service Provider. Developing the best possible integrity plan demands cooperation between these two parties.

The feature dimensions in the ILI final report serve as the basis for integrity management decisions with regard to the pipeline. For example, they will search the ILI feature database for all metal loss anomalies with a modified B31G [2] "Estimated Repair Factor" (ERF) greater than 0.95; dents or other mechanical imperfections; metal loss features with a depth exceeding 0.50t[1]; and features that may affect a weld zone. These searches will then form the foundation of a field investigation and repair plan.

It is clear, that if the reported feature details are to be used in this manner, that the tool results must be verified. Did the tool perform as specified by the ILI Service Provider? This was the first step in the program being described.

Pipeline Integrity programs involve many phases, including; selecting appropriate inspection technology, line preparation, running ILI tools, assessing reported features and managing field assessments and repair. This is the responsibility of the Operator and effective project management is critical. Experience with ILI technologies and field assessment processes will ensure an effective program.

An integrity program should not only result in a safer pipeline but should also produce continuous improvements. The program will involve multiple technical disciplines; the ILI Service Provider, NDE Service Provider, and the Operator at a minimum. These groups must work cooperatively and have confident in each other if the goals of the program are to be met.

CASE STUDY

In 1999, a 51 km (32-mile) section of the 457 mm (18inch) pipeline running from Texas City to Pasadena, Texas was inspected. The ILI report listed approximately 1,600 features. A detailed analysis indicated that none of the features required immediate response and only one location required investigation.

A repair plan was developed and the required maintenance scheduled. A corrosion anomaly, approximately 1.5 m (5-feet) in length, was repaired using five Clock Spring composite sleeves. At the same time, as a result of a railroad right-of-way expansion, a 16 km (10-mile) section of pipe was re-located and replaced with new pipe.

The same section of pipe was re-inspected in March, 2003 with the results being used to learn more about the tool performance and to begin developing methods to assess the data from future inspections and validate tool performance.

TOOL VALIDATION

With improvements in ILI data allowing more comprehensive integrity assessments, and with developing regulations like API 1163 [1] and the IMP rule [3], BP Pipelines NA determined that it was necessary to confirm inspection tool accuracies and develop processes to distill the large amounts of data to a usable form. An extensive investigation program, based on the results of the 2003 inspection, was therefore implemented. The goal was to learn more about tool accuracy, develop procedures to validate performance and develop methods to enhance future integrity decisions.

The findings from this program were enlightening and worth sharing with the industry.

Feature Categories and Tool Specifications

It is now common, and industry accepted, for ILI Service Providers to define tool performance specifications based on the feature classifications developed by the Pipeline Operators Forum (POF) document "Specifications and Requirements for Intelligent Pig Inspection of Pipelines" [4], in the late 1990's.

The POF document defines seven feature categories based on the axial and circumferential extent of the feature, and encourages ILI Service Providers to specify tool performance based on these categories. Anomalies detected by an ILI tool will fall into one of the seven possible categories illustrated in Fig. 2, "Feature Classification Graph".

The performance specifications for each category can have a different tolerance specified. For example, pitting may be ± 0.15t, while axial grooving is ± 0.20t with 80% confidence. There may be different specifications for automatic grading versus manual grading. In addition, there may be different tolerances assigned to different pipe types. Seamless pipe, for example, tends to be magnetically 'noisy', making defect detection and sizing less accurate than would be the case in seam-welded pipe. Performance specification may also change for anomalies located in the heat-affected zone of welds.

When validating the performance of a tool, it is important to know how to interpret the performance specification to be used. The ILI Service Provider will share this information with the operator. The performance specification include Probability of Detection (POD) and accuracy specifications for feature categories. It is important to note that most ILI Service Providers (MFL) will not declare a threshold of detection or accuracy for pinholes, axial slotting, or circumferential slotting as depicted in the POF document. Each ILI Service Provider may have different specifications based on the specific tool or technology applied.

Location of features along the pipeline is typically specified as ± 0.5% of the measured distance. Location of features from the upstream girth weld is typically ± 10 cm (3.94-inches) and circumferential position typically ± 10 degrees. In the field investigation performed, feature location specifications were met over 95% of the time.

Feature Selection for Tool Validation

Many of the features reported in the ILI report fall into the three categories for which no specification is given (pinholes, axial slotting, and circumferential slotting) and therefore cannot be used to validate performance. Features with dimensions below the Probability of Detection can not be used to validate performance.

Table 1, "Feature Distribution by Category", illustrates the distribution of feature categories from the 2003 inspection for this pipe section. Of the 1,297 reported external features, only 158 can be considered for tool validation purposes (36 pitting, 46 general, 13 axial, 46 clusters, and 17 circumferential grooving). Of these features, 123 were investigated.

Clusters are not one of the categories previously mentioned and must be carefully reviewed to determine if they can actually be used to validate performance. Clusters are formed by smaller features that interact according to the interaction rules used by the company. If features interact, they are grouped to form a cluster. The Cluster is given a length equivalent to the overall length of the clustered features, and a depth based on the deepest feature within the cluster. If the deepest feature within the cluster is from a category for which no accuracy is specified, then this cluster cannot be used as a validation feature. This happened often in this particular inspection.

Field Investigation

Industry standards, such as ASME B31.8S, 2001, [5] and API 1163, recognize the need to verify integrity assessment performance. The ability to track the methods and instruments used to acquire the verification data, and the accuracy of the data itself, are critical to the overall validation process. RTD Quality Service was contracted to perform the necessary field examination. he following provides some discussion regarding important variables in a specification for verification inspections.

The goals of the verification inspection process must be clearly defined to ensure that it returns consistent, detailed measurements, to qualify the detection and reporting performance of the ILI tool (false positives, false negatives, true positives and true negatives).

The verification inspection method must provide greater measurement resolution of anomalies than was available from the ILI tool, and do it in a manner that tests inherent limitations and qualifies the risk associated with the integrity level established using the inspection report. Applying technologies with the same or lesser resolution may not allow the statistical review of reported features needed to develop an efficient, economical and safe integrity program. The required resolution for verification inspection is an order of magnitude greater than the resolution of the original inspection.

Correlating data-sets from different technologies inherently requires a comparison at many levels. Procedures detailing each step of the process are essential for repeatability, scrutiny by others, and to qualify and describe performance. Feature definitions and nomenclatures must be consistent between the verification inspections and the ILI report. Accuracy of the measurement equipment must be considered together with the accuracy of the ILI tool used. Indexing of features to the reference girth weld and feature measurement scales must be consistent. Location of features in the field must be done using detailed, clearly defined processes and feature location must be confirmed unambiguously.

Comparison of ILI and verification inspection is a tedious process; however, if the results qualify the ILI reported feature measurements, the benefits can be significant. Through a systematic, consistent process, the ILI report can be used more effectively as a management tool, allowing an Operator to develop more effective maintenance programs that ensures integrity and minimizes cost.

Field personnel performing verification measurements must be qualified for each specific measurement task. Efficiency demands multi-skilled personnel, knowledgeable in ILI, the verification inspection methods, different reporting systems and nomenclature, and the inherent vulnerabilities of each. Qualifications for these personnel are not currently described by the industry. The Operator must ensure that the individuals acquiring validation data have the skills and experience necessary for this task. Attempts are underway to develop minimum performance requirements for these individuals and the associated knowledge requirement and training.

There are several technologies capable of measuring corrosion and wall loss anomaly dimensions an order of magnitude more precisely than the original inspection. Technologies for verification of other pipeline threats such as gouges, scrapes and Stress Corrosion Cracking (SCC) have not yet been developed or are in development.

Correlating data sets from different technology types (different physics) to quantify variance ranges of multiple parameters (depth, length, width, shape, detection, false calls…etc.) requires clearly defined processes. This is exacerbated where corrosion patches involve hundreds or thousands of pits, when complex continuous damage is present, or where damage is on the inside surface of the pipe.

Verification Inspections should include an assessment of the soil properties and operating environment of the pipeline. This information is essential in determining susceptibility to time dependent, condition dependent, features such as SCC. Each verification inspection should also include examination for these feature types.

Secondary benefits which can be realized during the Verification process;

- Inherent calibration pieces to judge performance of subsequent assessments
- Mechanical assessment of qualified anomalies
- QA records

BP Pipelines NA is currently working with RTD Quality Services to develop reporting structures and processes that will streamline the verification process on future inspections. The goal is to have a fully automated system for acquiring field data that allows downloading data directly to other Integrity Management applications.

RESULTS OF FIELD INVESTIGATIONS Feature Categories

The first task of the evaluation process was to determine if features were correctly categorized by the inspection tool. Although difficult to see, Fig. 3 – "Feature Prediction", shows the feature categories predicted by the ILI tool for the "General" and "Pitting" categories are typically good but the tool give only a gross prediction for "Circumferential Slotting", "Axial Slotting", "Circumferential Grooving", and "Axial Grooving" categories.

This is to be expected. The depth and length measurements that define feature categories in the POF document cannot be duplicated in the field. Length and width measurements are obscured by the fact that the tool will report dimensions based on the threshold-of-detection profile-line, (refer to Fig. 4 "Metal Loss Profile"), typically 0.05t, while the field measurement will be from the zero depth profile line. This can lead to significant differences as can be seen in Fig. 4 and reflected in the Feature Prediction graph.

In addition, the length and width tolerance of the tool is typically ± 15 mm (0.6-inches). When this tolerance is applied, it is very easy for a feature to fall into a neighboring category.

For MFL tools, it is best to limit the number of categories into which features are classified. From the experience gained in this case, circumferential grooving and slotting categories should be grouped as a single category as should the axial slotting and grooving categories. This still allows an Operator to make integrity decisions on based on feature geometry but does not overly complicate the process.

Length Prediction

Fig. 5 "Feature Length Accuracy", shows the reported length vs. actual field measured length of 123 features. In this case, the tolerance for all reportable feature categories is ± 15 mm (± 0.60-inches). Features with a measured length greater than the predicted length are likely a result of the reporting threshold and threshold-of-detection of the tool and do not necessarily represent an error in tool accuracy (refer to Fig. 4 "Metal Loss Profile"). It is very difficult to validate length predictions, but in general terms, the feature lengths predicted by the tool are reasonable. In this case, taking just the raw data without correcting for the reporting threshold or threshold of detection, the tool was within tolerance 86% of the time.

Feature Depth

Each reportable feature category has unique specifications which must be considered in tool validation procedures. All features in each category were systematically reviewed and the depth error determined. This was a complicated and time consuming exercise that added little real value to the overall process. The feature categories and reported length and width specification, in the lower left quadrant of the "Feature Classification Graph", Fig. 2, are so commingled that this type of assessment just complicates the process.

The results of an inspection can be validated on a global features basis. In this case, there were 123 features from various categories that could be used for tool validation. On a global basis, they can provide confirmation that the tool met the depth sizing specification and that the feature dimensions in the report can be used with confidence.

In this particular inspection, the feature depth accuracy for the 123 features was ± 0.15t, 84% of the time. Using a simple trend line correction, the accuracy increases to 0.15t, 93% of the time. The trend line equation shows a tendency to under call features by 8%. This was then used in subsequent integrity decisions to ensure that all significant features were addressed. This corrected depth data is shown in Fig. 6 –

"Corrected Feature Depth Accuracy".

This graph shows predicted feature depth versus the feature depth measured in the field. The field measurements will contain a measurement tolerance which must be understood if this data is to be used for integrity assessment decisions. RTD Quality Services used qualified personnel and written, qualified procedures, to acquire the field data so that the effects of measurement tolerance would be minimized. In addition, the ILI Service Provider reviewed the field procedures and accepted the acquired field data with confidence in its accuracy. This is the key issue in the overall integrity program; it must be a cooperative effort of all involved parties.

Based on the results of this validation process, it was determined that the reported feature dimensions could be used with confidence.

A detailed correlation of the ILI data to pipeline survey and design information resulted in a very accurate as-built pipe tally that will be of value for the remainder of the service life of this pipeline. Future inspections in this pipe section will be much easier to validate because pipeline as-built condition was confirmed, feature details were well documented an indexed to the pipeline inventory footage, and all acquired information documented and filed for future reference.

Investing time in this initial validation process resulted in a safer pipeline and will save time and money on future inspections.

GENERAL OBSERVATION ON THE PROCESS

Some very valuable lessons were learned during this process that may be useful to other operators.

- ILI tools are an integral part of the integrity management program. These tools inspect the entire pipeline, which allows a full assessment of the condition of the pipe and the integrity of the system. It is important to select appropriate inspection technology based on the concerns and operating history of the pipe section being evaluated. It is important to know the capabilities and limitation of the various ILI technologies.
- There can be issues with the methods used to locate features on the pipe. The ILI Service Provider will enclose the signal from a feature in a rectangular box with dimensions equal to the length and width of the feature. The location of feature from the upstream girth, and its circumferential position on the pipe, will be referenced to the upper left corner of this box (S). This is the method recognized in the POF document (Fig. 7, "Metal Loss Orientation") and used as a standard by most ILI Service Providers.
- In the field, the NDE specialist will generally enclose the anomaly or feature in a similar rectangular box but will generally reference the centerline of the box in both the axial and circumferential direction. This is a recognized practice in the NDE industry. This inconsistency can add to the complexity of the validation process.
- How anomalies or features are located / referenced on the pipe must be consistent. An industry standard should be adopted.
- The inspection report contains valuable information on the as-built condition of the pipe section. The report must be reviewed very carefully to confirm the accuracy of the pipe material properties and operating characteristics provided by the Operator and input into the report by the ILI Service Provider. Errors can affect the accuracy of any calculation used to determine the integrity of the pipeline. Correlating ILI inspection data to all available pipe design data results in an accurate pipe tally that can be used in all future inspections and integrity decisions. This will save money and improve safety. It is important for the Operator and the ILI Service Provider to work closely with one another during this stage.
- Estimated Repair Factors, or any other calculation used to help determine the integrity of the pipeline, must be confirmed. Material properties and operating characteristics at the feature location must be verified. Errors can be the result of incorrect material specifications provided by the Operator or incorrect calculation by the ILI Service Provider.
- Inspection tools are very sensitive to wall-loss features and can routinely detect and report

features less than 0.05t wall in depth. Depending on the reporting threshold (ex. ≥ 0.10t), this can lead to instances where a feature may be present in the data but not listed in the report. Each time the pipeline is exposed; the area should be inspected and

- compared to the inspection data to confirm that all features reported have been confirmed and that significant features were not missed by the tool. More importantly, the results of these investigations must be documented and shared with the ILI Service Provider to ensure continuous improvement.
- Manual grading can be used to enhance the accuracy of the reported feature dimensions. In this case, manual grading did not produce significantly better results than the automatic grading, however it did provide better ID / OD discrimination. This may be peculiar to this pipe section and will be re-tested on subsequent inspections.
- Field investigation must be methodical and well documented. The data being collected is not only used for the immediate purpose of validating the current inspection, but also becomes the tool by which future inspections in this pipe section will be validated. Having accurate, well documented data will allow better integrity decisions and save time and money in subsequent inspections by minimizing the number of calibration digs required.
- Field investigations must be carried out by qualified personnel and measurement techniques must be appropriate to the task. If complex features are being investigated it may be necessary to use sophisticated measurement systems such as LASER scans to get as precise information as is needed to validate tool performance and assess the operating capabilities of the pipeline. The tolerance of field measurement techniques must be considered and all parties must be able to accept the accuracy of the acquired field data with confidence.
- Features that are ‘clustered’ require careful review. Clusters are dimensioned by the deepest feature within the cluster and the overall length of the clustered features. If the deepest feature within a cluster is from a feature category that is unspecified by the ILI Service Provider, then additional attention is required.
- It is crucial that the ILI Service Provider be involved in each step of the validation process. The ILI Service Provider must understand the processes being used to collect feature information to validate the inspection and the Operator must understand the capabilities and limitation of the inspection tool. Discrepancies must be addressed quickly and thoroughly. Changes to procedures must be documented and implemented. This is the key issue to making the process work. Both the Operator and the ILI Service Provider must work together. There is little value in collecting verification information if it does not result in improved performance. Each incremental improvement in the inspection and integrity process will result in better, more accurate inspections and improved integrity decisions.
- The length and width of features measured in the field does not necessarily relate exactly to the dimensions predicted by the tool. The tool will report length and width based on the reporting threshold and the threshold of detection profile-line, while field measurements will be from the zero depth profile. (refer to Fig. 4, “Metal Loss Profile”)
- Feature interaction rules can lead to some controversy. The inspection tool may report several features in close proximity that do not meet the interaction rules specified by the Operator. Upon investigation, the field technician will see the features as one continuous patch of corrosion and measure it as such. The light surface corrosion that interconnects the deeper individual features can not be rationalized in the field. By keeping track of these events, the Operator can determine if the interaction rules being applied are appropriate.
- Field investigation details will be used to validate all future inspections in this pipe section. It is important that the field procedures be documented, and followed, each time the pipe is examined.

INTEGRITY PROCESS

When the results of an inspection are confirmed, an Operator can use the reported feature information to make long term integrity decisions. Statistical methods can be used to confirm the number of features to investigate. Features can be ranked based on criticality and repair decisions made with confidence. The effort needed to correlate ILI data to design detail, confirm tool accuracy, and manage inspection information is an investment in the pipeline that pays back through improved safety and long-term efficiencies.

Calibration Locations

Based on the results of the 1999 inspection, an anomaly located at 43+95 feet, consisting of multiple isolated pits and general corrosion and covering 142 cm (56-inches) of pipe was investigated and repaired with Clock Spring. These sleeves do not affect the performance of an MFL inspection tool and, when properly installed, will prevent further corrosion growth. If detailed defect measurements are acquired at the time of the repair, then the repaired defect can be used to validate subsequent MFL inspections.

To confirm that the Clock Spring sleeves had protected the pipe from further corrosion, this section was removed from the pipeline after the 2003 inspection. When the pipe was repaired in 1999, the surface was sand blasted to a clean, bare finish. Five Clock Springs were installed, side-by-side. The repair was then over wrapped with a CANUSA heat shrink sleeve to protect the repair location and pipe from corrosion. Fig. 8 shows the pipe surface after the Clock Springs were removed.

After four years of service, the Clock Spring repairs were effective in all respects. Defects repaired with Clock Spring can be used to validate subsequent inspections.

CONCLUSIONS

Running ILI tools is an integral part of BP Pipelines NA integrity management program. When the results of an inspection are used to develop an integrity plan, it is critical to confirm the accuracy and completeness of the ILI data. The process for tool validation must be documented and calibration done cooperatively with the Operator and the ILI and NDE Service Providers.

Field investigation of features must be done using appropriate NDE measurement techniques by qualified personnel. The ILI Service Provider must have confidence in the acquired data and the data must be shared openly and often between all parties involved in the program.

ILI data provides an excellent ‘as-built’ record of the pipeline, but some time must be expended to confirm the accuracy of the design information. This investment will improve all integrity decisions throughout the service life of the pipeline.

All features investigated and allowed to remain in the pipeline must be accurately measured in a consistent manner and recorded for future use. These features will become calibration locations on subsequent inspections.

Improvements in pipeline integrity, based on in-line-inspections, will not come from a single quantum leap, but rather through incremental improvements. This requires cooperation between the ILI Service Providers and the Operators.

ACKNOWLEDGMENTS

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REFERENCES

1. API 1163 – Draft “In-Line-Inspection System Qualification Standard”
2. B31G “Manual for Determining the Remaining Strength of Corroded Pipelines”
3. Integrity Management Program rule, (IMP) 49 CFR Parts 192 and 195
4. Pipeline Operators Forum (POF) document “Specifications and Requirements for Intelligent

Pig Inspection of Pipelines"

5. B31.8S 2001, "Supplement to B31.8 on Managing System Integrity of Gas Pipelines"

Feature Category	Number	% of Total	# Above POD Threshold	Investigated
Pinholes	33	2.5	4	3
Axial Slotting	14	1	14	2
Cir. Slotting	346	27	22	15
Pitting	384	29	36	54
General	142	11	46	26
Axial Grooving	125	10	13	7
Cir. Grooving	85	6.5	17	13
Clusters	168	13	46	3
Total	1,297	100%	198	123

Table 1 - Feature Distribution by Category

Figure 1 – ROSEN 18" CDP ILI Tool

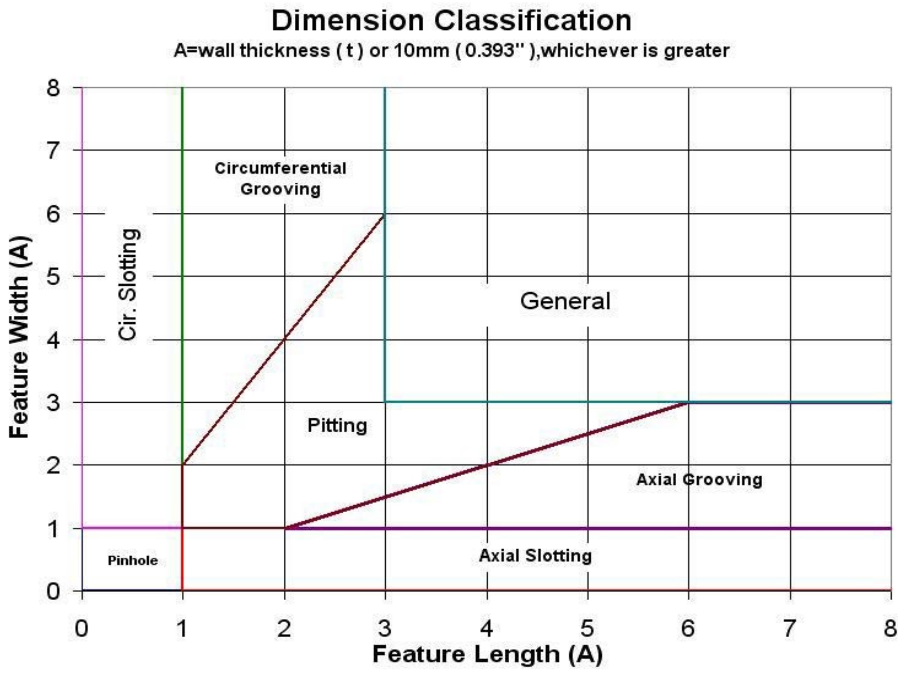

Figure 2 - Feature Classification Graph

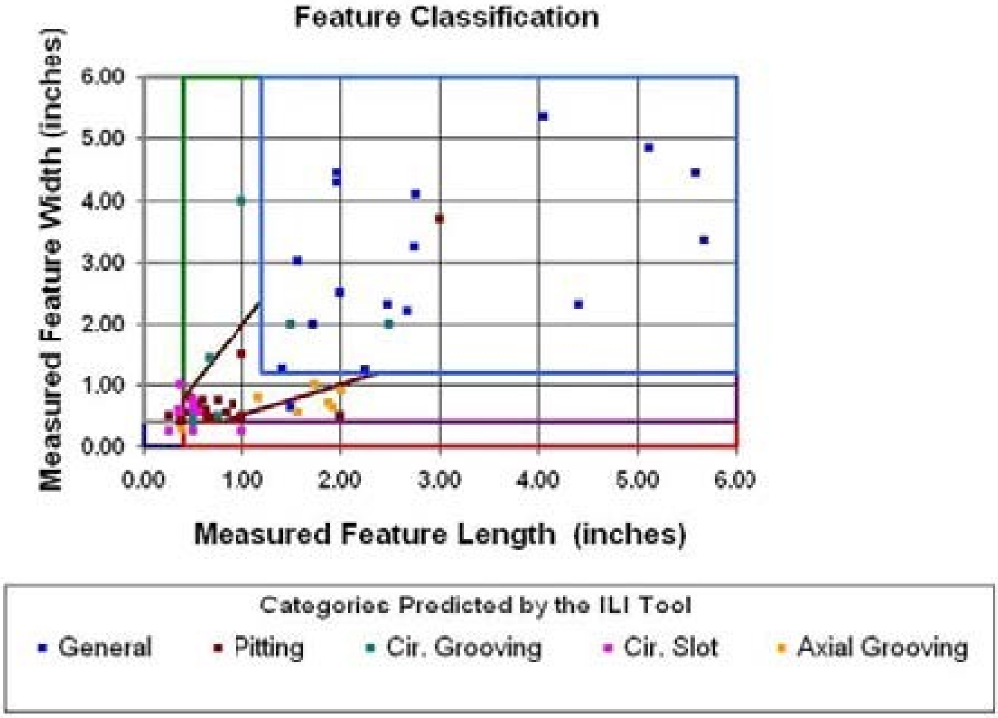

Figure 3 – Feature Prediction

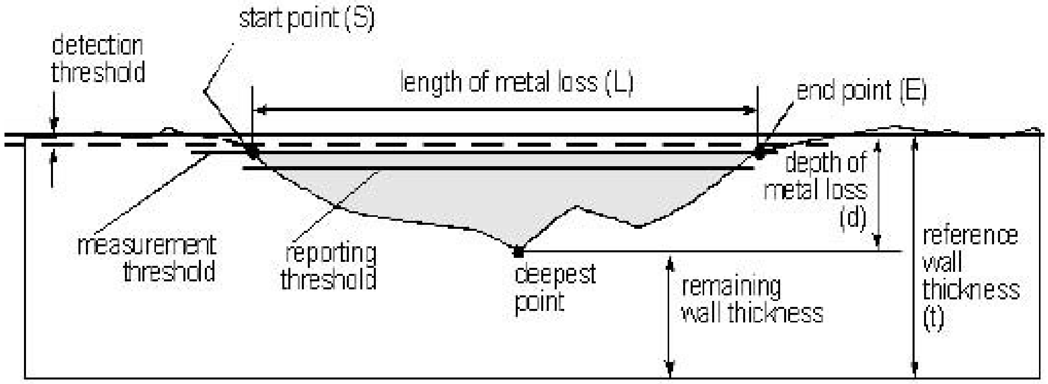

Figure 4 – Metal Loss Profile

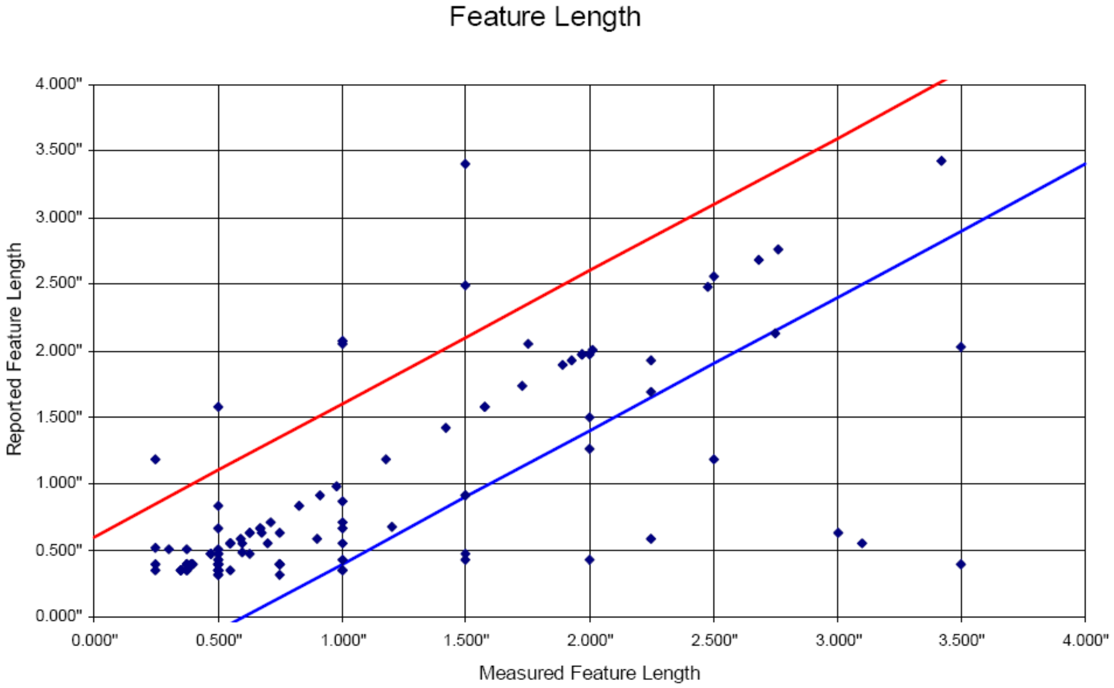

Figure 5 – Feature Length Accuracy

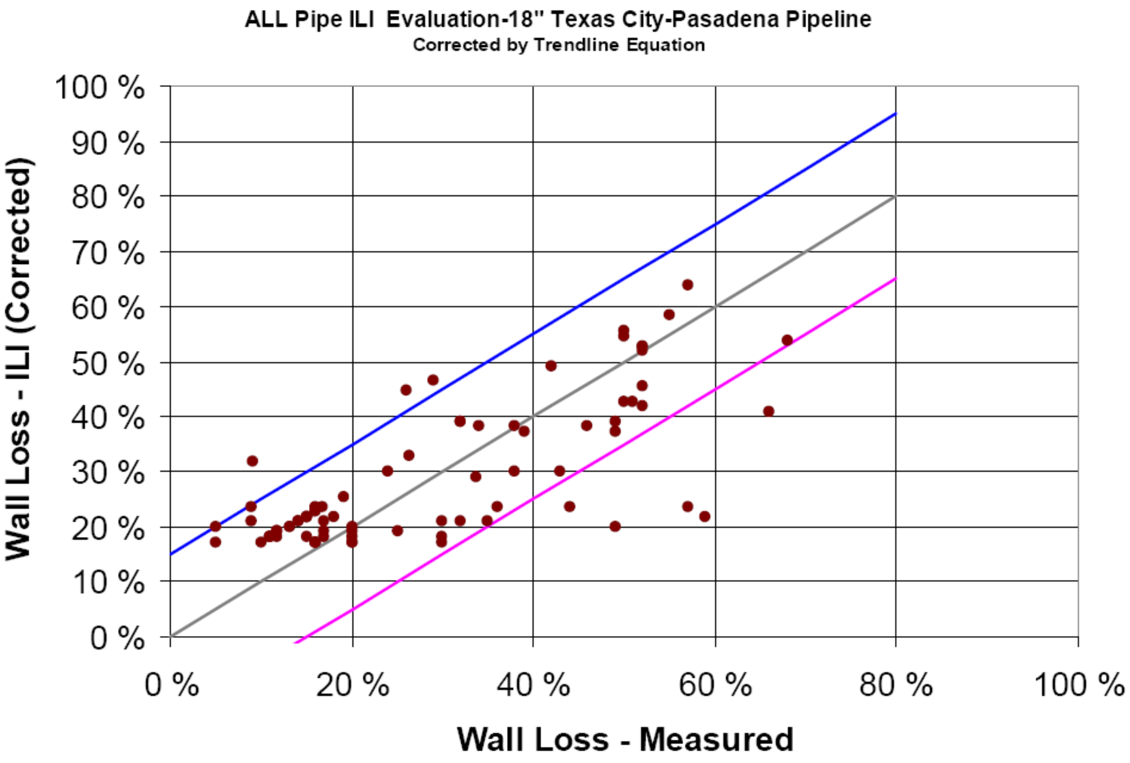

Figure 6 – Feature Depth Accuracy

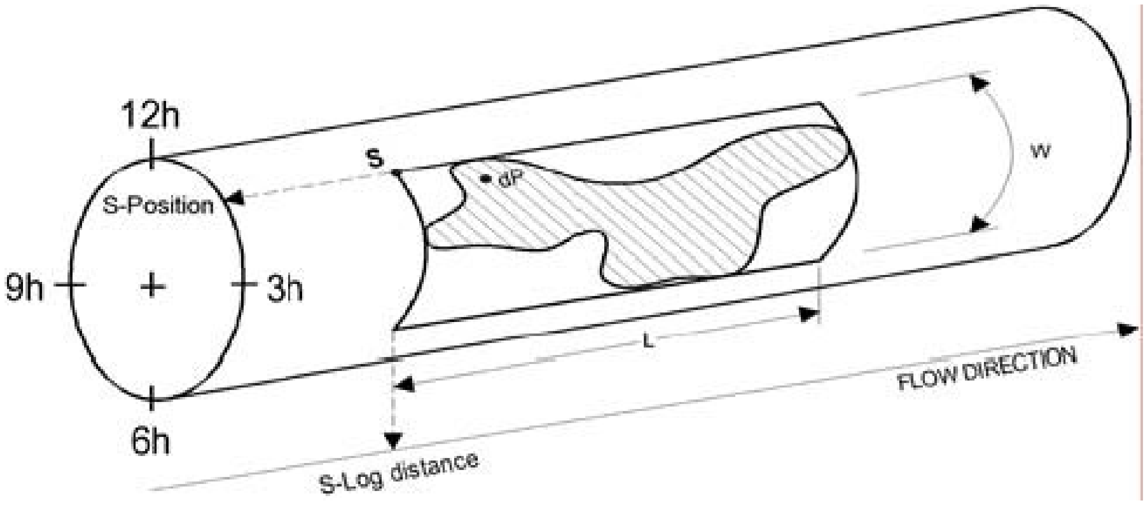

Figure 7 – Metal Loss Orientation (POF)

Figure 8 - Section of Clock Spring Removed by Sandblast