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EVOLUTION OF TRIAX MAGNETIC FLUX LEAKAGE INSPECTION FOR MITIGATION OF SPIRAL WELD ANOMALIES

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ABSTRACT

With an overall objective for broad and confident integrity management of the PetroChina Pipeline Company's pipeline network, we illustrate the impact of a collaborative effort between PetroChina and GE Oil & Gas for the inspection and mitigation of spiral weld anomalies, particularly for new advanced assessments of features oriented along and within the spiral weld.

Tool configuration, sensor types and the role of novel data analysis techniques including magnetic vector component measurements, is presented as a set to address a broader variety of spiral weld threats, while ensuring a high level of operational robustness and reliability.

This paper describes some of the science behind the art, and describes the fundamentals of MFL magnetics and it's evolution as an ILI technology into the 21st century for spiral weld anomaly inspection.

INTRODUCTION

The PetroChina Pipeline Company has a progressive structured integrity program for maintenance and operation of it's pipeline network.

The abilities and challenges of pipeline failure assessment, risk management, mitigation as previously reported have progressed within this strategy including specific mitigation strategies and efforts for primary pipeline threats and a structured integrity management plan and strategy for successful ongoing operations. [1,2,3]

Spirally welded pipe is widely used around the world and in particular, PetroChina has an installed base of over 40,000 km. The key threat identified within the failure history and risk analysis was anomalies related within or near the spiral weld.

As previously disclosed [4], the integrity consideration of spiral weld defects lies in the correct interpretation and consideration of the type of defect and potential failure mode. The need then is a reliable information source for distinguishing inherent cracks and "crack-like" features (toe, lack of fusion) apart from corrosion features (HAZ area body or weld dressing) as related to the weld integrity itself.

In 2008, PetroChina approached GE to collaborate on inspection capabilities and performance specifically towards the spiral welded pipe concerns raised in the failure history and PetroChina's risk assessment.

PIPELINE CONSIDERATIONS AND COLLABORATION

The particular pipeline network of interest has the following characteristics:

- Pipeline Diameter 28”
- Nominal Wall thickness 8mm ,
- Pipe Grade X52 spiral-welded
- Design pressure 43 bar (53% SMYS),
- MAOP 36 bar (45% SMYS)
- Pipe Age: 1974 construction

In 2007, PetroChina and GE performed a trial inspection run to determine field experience in the capabilities of MFL and triax sensing for corrosion and particularly for spiral weld anomaly assessment.

Subsequently in 2008, PetroChina approached GE with the challenge to advance the capabilities regarding quantifying and interpreting spiral features. These included

- Lack of fill/under-cut,
- Weld porosity, Incomplete penetration,
- Lack of fusion,
- Roof topping, Weld misalignment & "Hi-Low"
- Corrosion

GE accepted the challenge and the PetroChina-GE collaboration evolved over the next 18 months to include manufactured defect sets, multiple pulltest studies. and field evaluation work. The studies have focused and been applied to inspections and efforts for the NEOGF network of PetroChina, providing crude oil transportation in Northeast China

With conventional MFL inspection, detectable features such as on typical long seam-welded pipe, we classify and describe crack or metal loss defects in terms of it's length (down the pipe) and it's width (around the pipe). Pipeline inspection tools for crack detection rely on a given defect's orientation to be axial (parallel) or circumferentially (perpendicular) to the main pipe axis.

In the case of spiral welds, the nature of the defects and their related signals now changes relative to the angle and to the weld itself. MFL, and in particular multi-axis magnetic sensing (known as Triax), was determined to be the best option to progress.

PetroChina and GE have been working together to advance the interpretation and analysis of spiral weld anomaly signals as seen by MFL technology of which we provide an overview. Overall, a common objective was shared to increase inspection confidence to provide for increased pipeline operation and throughput.

APPLICATION OF MAGNETIC FLUX LEAKAGE TECHNOLOGY

As noted, magnetic flux leakage (MFL) techniques have evolved in the pipeline inspection industry since the 1960s. Since 1978, GE has provided high resolution MFL inspection to the global industry. Since the 1990s, GE has offered and advanced the technology with the use of magnetic vector sensing or "Triax". In conventional MFL, only the main magnetic (axial) field component is measured and has been proven as robust over the decades. However, magnetic fields are vectors consisting of 3 field components. In "Triax" sensing, we capture all three field components which offers further resolution, insight and ultimately confidence in the interpretation of the feature.

As illustrated in Figure 1, the three components are known as "Axial", "Radial" and "Transverse" to match the natural cylindrical coordinates of the pipe. The axial field is commonly measured by all MFL tools and is representative of the volume of the defect and disruption of magnetic field through the pipe wall. "Radial" and "Transverse" fields similarly occur when a defect is present and tend to characterize the profile of the feature.

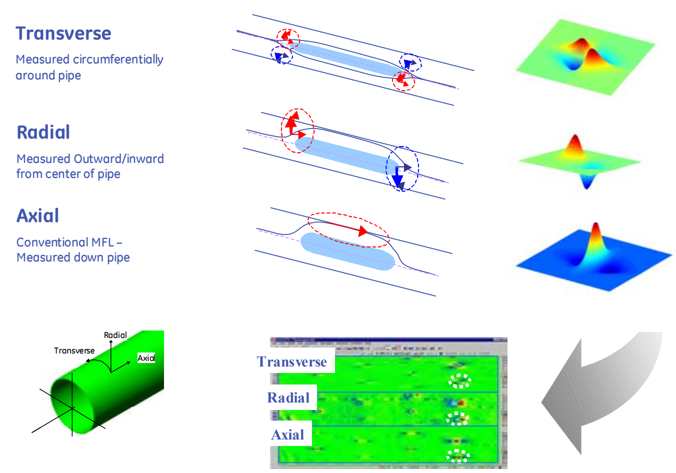


Figure. 1 Overview of Signal Responses from multi-axis sensor MFL inspection

It was found in previous testing on spiral welds that Triax vector sensing allows very good detection abilities for spiral weld features. [5] Data may be displayed as amplitude based color plots as shown in Figure 2 (an actual dataset) and Figure 3 as seen for an artificial feature that was manufactured for test program purposes.

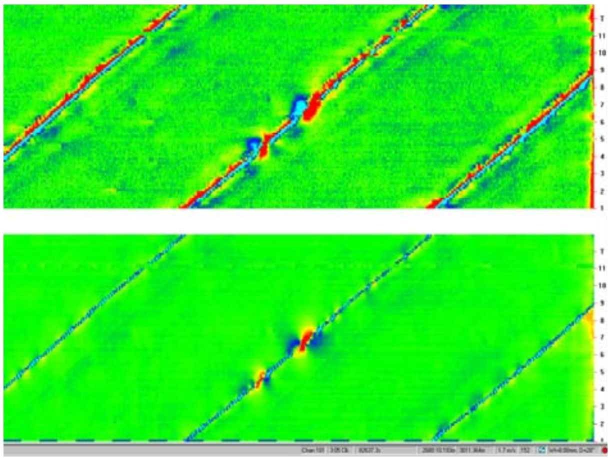


Figure 2 Example of Triax MFL Signal Data with spiral weld distinctly visible Top is "Radial", Bottom "Axial"

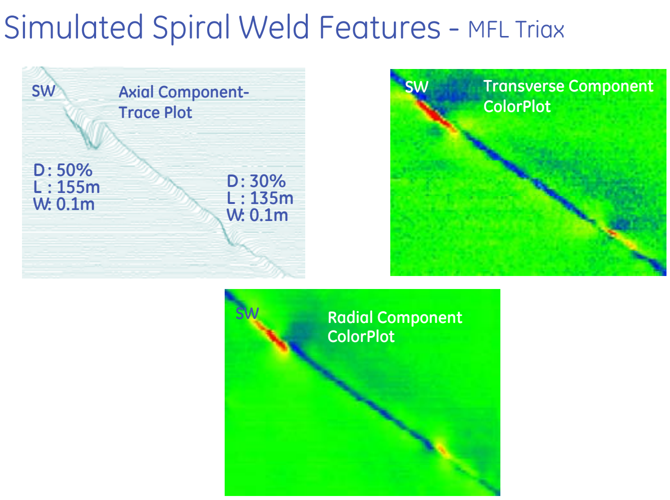


Figure 3. Simulated initial Spiral Weld features via grinding and thin shim plates

INSPECTION PERFORMANCE CRITERIA

The performance of any form of inspection is typically characterized in three main metrics: Detection, Identification and Quantification (Sizing). The recognized definitions from API 1163 [6] were the framing points for the programs' success criteria and evaluation of improvement. These in summary were:

Detection

The ability to correctly find and detect a feature is expressed as the Probability of Detection (POD) and directly based on the number of features detected and the overall number of anomalies.

$$PoD = \left[\frac{\#\,\text{times detected}}{\text{total}\,\#\,\text{anomalies}} \times 100\right] \text{per anomaly/feature type \& size}$$

Classification

The ability to correctly classify the type of feature – is expressed as Probability of Identification (POI) which more practically can be defined in terms of a dig success rate as experienced by an operator. This expression evaluates the # correct classifications within the overall dataset. Correct responses are known as True Positives or "TP"s, while incorrect responses are known as False Positives or "FP"s.

TP+FP = All Responses

$$\text{POI Dig Success Rate} = \frac{TPs}{(TPs + FPs)}$$

Sizing & Quantification

Sizing refers to the ability to predict the dimensions and extent of the defect that can be expressed statistically as a sizing tolerance and certainty. The tolerance is usually expressed as a plus/minus range of values while the certainty is a statistical assessment that the feature will be within the tolerance as shown in Figure 4.

As an example, typical specifications for MFL for common pitting defects is accuracy of +/-10% of Wall thickness with 80% certainty, meaning > 80% of time, the defect size prediction will be correct to +/- 10% of the local wall thickness of that defect. An improvement in both accuracy and certainty demonstrates overall improvement.

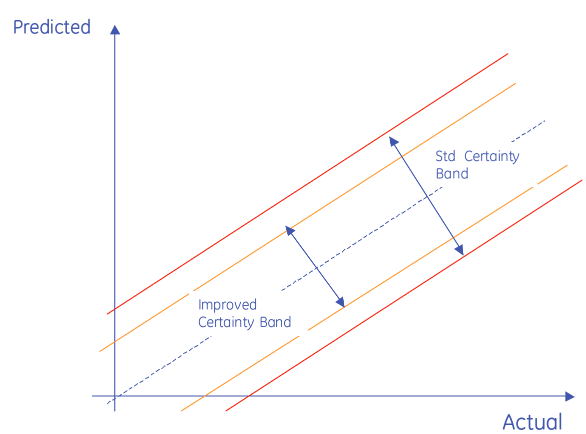


Figure 4. Unity Plot Assessment Example Sizing

DEFECT TESTING AND ASSESSMENT PHASES

Stage 1: March 2008

PetroChina provided spools for an initial pulltest containing lack of fusion and porosity features. Small porosity features were marginally detected but the main assessment considered the lack of fusion feature detected. by PetroChina's radiographic data as shown in Figure 5.

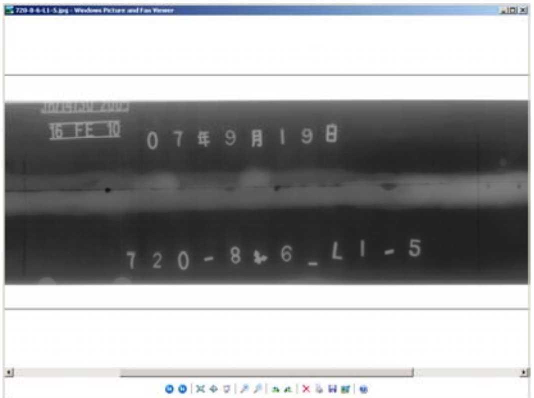


Figure 5 Radiographic Image - Example of Lack of Fusion spiral weld defect

Rooftopping and High/Low behaviour was not distinctly observed in the signal data and such could not be assessed in detail (Figure 6). However, the main objective of the program remained, regarding the distinction of "crack-like" and missing metal . As such, the classification prediction for crack and non-crack-like spirally aligned features became the primary focus of the teams in the next stage.

Namely to distinguish crack-like features within the weld from undercut or missing metal (corrosion) features. This emphasis was specifically motivated by the known difference in methods of engineering assessment of the integrity of the pipe, depending on the feature type. [7,8]

<u>Stage 2: April - December 2008</u>

An initial manufactured defect set was determined via a GE 6-Sigma technique known as a "Design of Experiments" or "DoE". [9] The defects varied in length, width opening, depth, position in weld and internal/external surface location as shown in Figure 6. PetroChina accepted the challenge to manufacture the defects with a photograph illustrating such examples as shown in Figure 7.

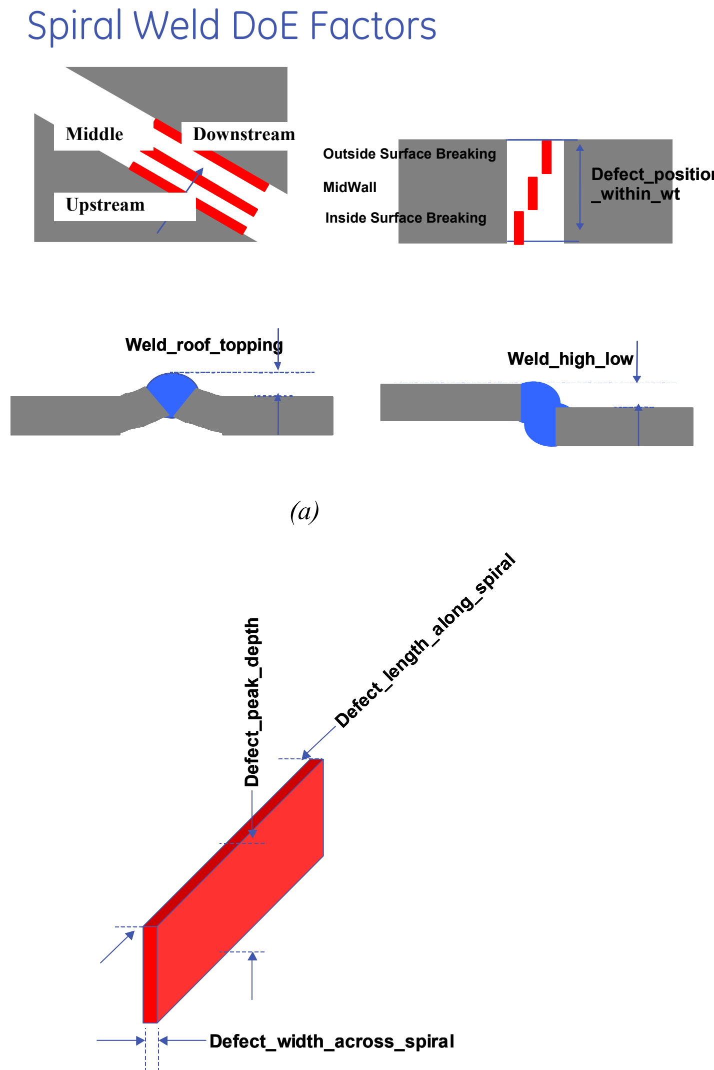


Figure 6. Spiral weld feature parameter definitions (a) Defect Location, b) Defect Dimensions

Figure 7 .Test Spools containing manufactured spiral weld defects.

Stage 2 was the largest testing stage that included over 120 defects, with multiple repeated pulltests at 4 different speeds. This provided a significant dataset of 100s of signal samples to establish the performance trends and capabilities. Crack-like features were defined as having a width across spiral < 1mm opening, while missing metal features have a width across spiral > 1mm opening.

Experts reviewed the datasets over several months. Common conclusions were progressed so that multiple categories of classification were determined for spiral weld signals, as illustrated in colorplots of Figure 8. The signal behavior was independently confirmed via Finite Element Modeling for magnetic defect signal responses as shown in Figure 9. Example of signal responses of an actual crack-like defect is shown in Fig 10.

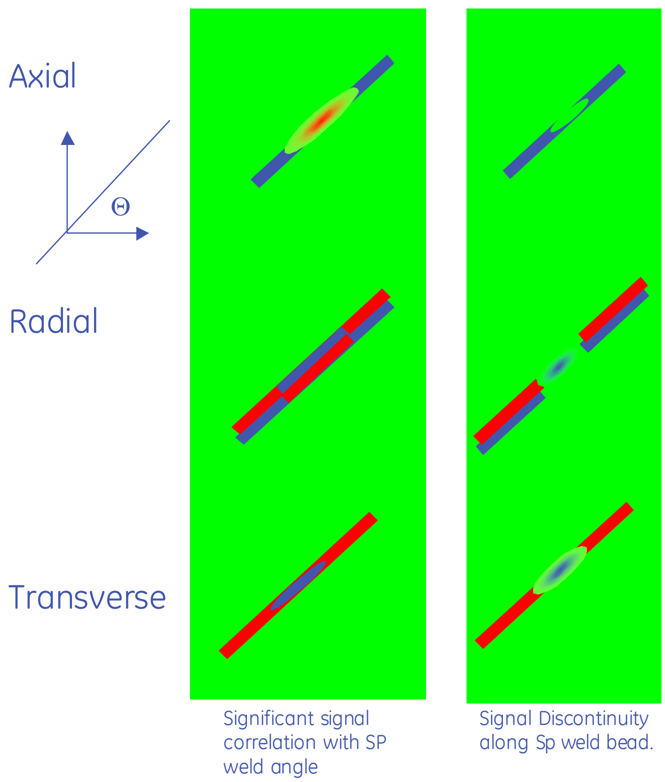


Figure. 8 Spirally aligned features of interest
Left :A strong signal aligned with the spiral and
Right: A weaker signal as a form of discontinuity of the weld bead signal.

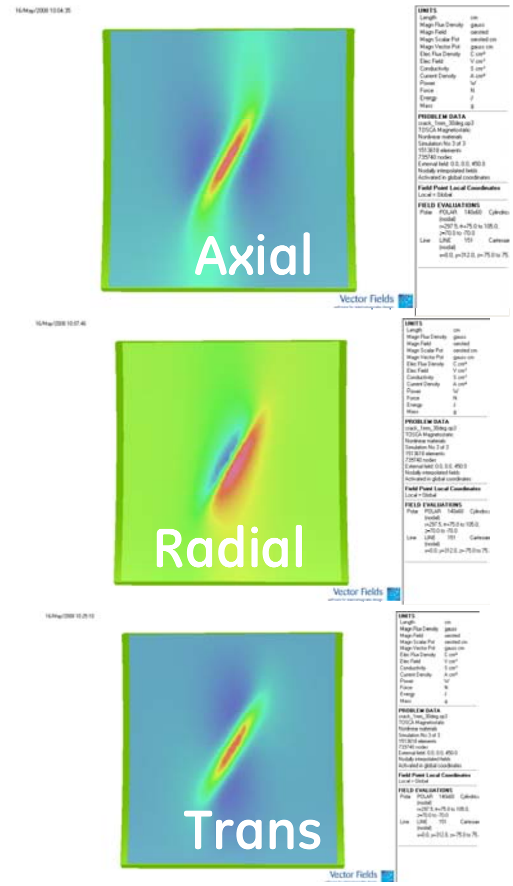
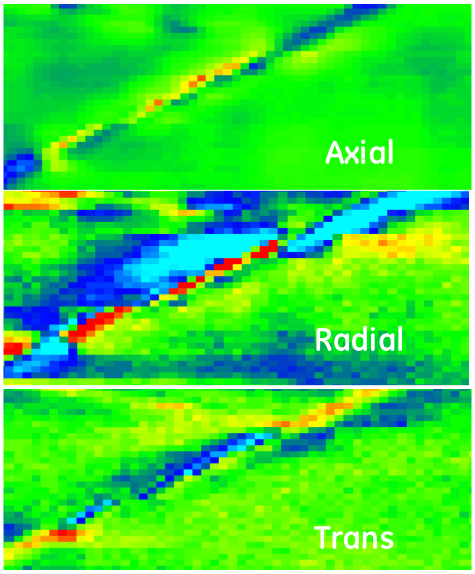
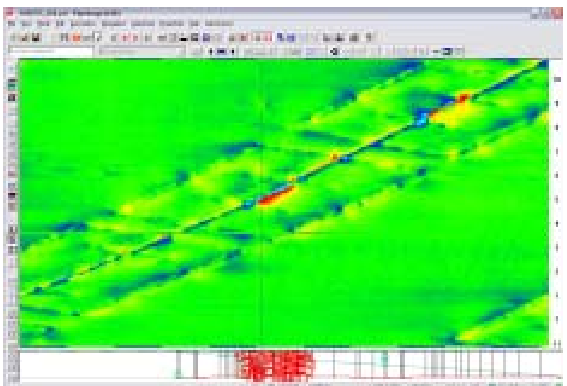


Figure 9. Modeled Crack Magnetic Responses using Finite Element Methods

The features are aligned with the spiral weld angle and their signals are observed as strong and weak signal amplitudes. And notably a crack-like feature may be long and significantly deep but may also generate either a large or small amplitude signal, so confident classification prediction was required to allow further assessment.



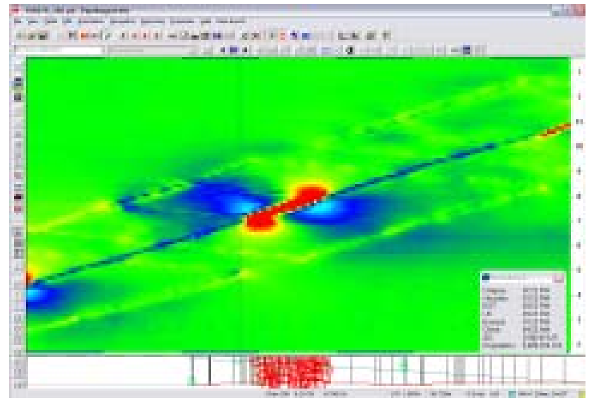
(a)



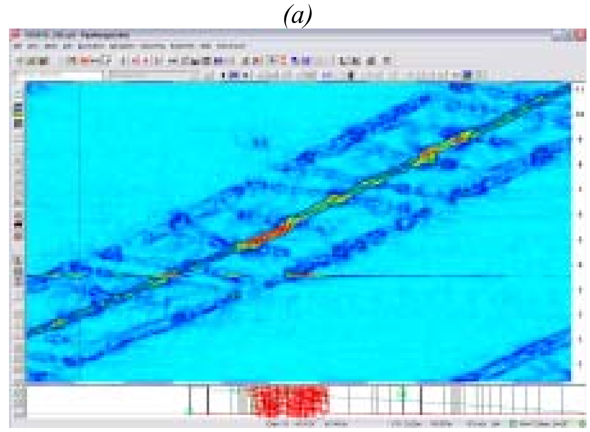
(b)

Figure 10 (a) and (b).
Signal Responses from a "small" crack-like feature

Initially distinguishing crack-like features from missing metal was deemed to not be a straightforward relationship or even possible. In subsequent efforts a classification scheme for spiral crack-like vs. missing metal features was created using advanced image processing techniques. The image processing technique generated and compared the spatial distribution of a filtered and processed signal amplitude against the original dataset as shown in Figure 11.



(a)



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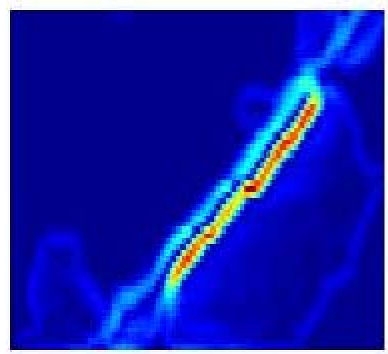

(c)

Figure 11. Example of Image Processing data sets
(a) Original MFL Defect Signal and
(b) it's image-filtered equivalent
(c) it's image-processed equivalent

In particular, it was noted that the signal size and extent for crack-like behavior varied distinctly enough to allow a classification rule. In subsequent pull-testing and analysis it was then shown to significantly improve the Probability of Identification.

Robust models for sizing and interpretation of MFL are complex. For the spiral weld defects, the behavior of the signal and defect parameters (eg amplitude, length, width) showed decent correlation but was determined to require further work and assessment as of Q4 2009.

Stage 3: July 2009

A subsequent defect set was manufactured by PetroChina to further validate and distinguish minor changes in the spiral weld features, with a focus on defects with very narrow openings (crack-like). The pulltests were completed in Q3 of 2009 with detailed analysis currently in progress.

RESULTS & SUMMARY

Collaboration between PetroChina and GE has allowed the advancement of pipeline inspection data analysis spiral weld anomalies. Improvements to detection, identification and sizing have been observed and demonstrated.

Over 1000 kms have been inspected to date with continued collaboration into 2010 and beyond to refine the capabilities and models.

Spiral weld feature detection was demonstrated as > 90% POD, exceeding expectations & comparable industry specifications.

Classification and differentiation of crack-like and missing metal features was improved to 70% POI for pulltest results to date.

Sizing accuracy and confidence was recently assessed as a preliminary model for spiral weld non-crack-like features and included data from all pull-testing and data analysis stages as shown in Figure 12. These preliminary results demonstrate such a model is achievable and even this initial version has a respectable sizing performance in comparison to industry standards for general metal loss.

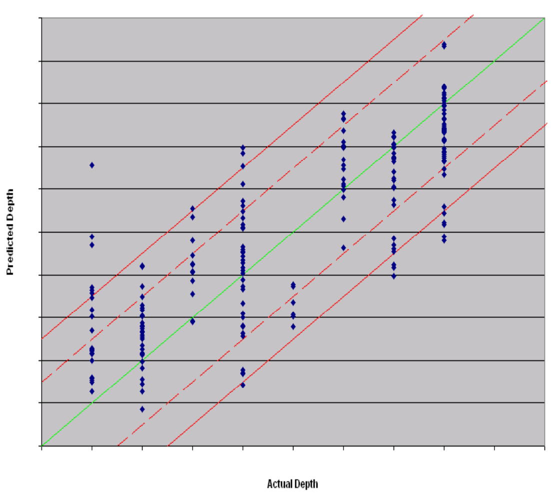

Figure 12. Initial Sizing Performance of Spiral Weld Anomaly Model.

FUTURE DEVELOPMENTS

PetroChina and GE PII Pipeline Solutions continue their collaboration to progress and refine the spiral weld analysis models. Together we are also currently investigating similar interpretation methods that could be applied for Girth Weld anomalies as illustrated in Figure 13.

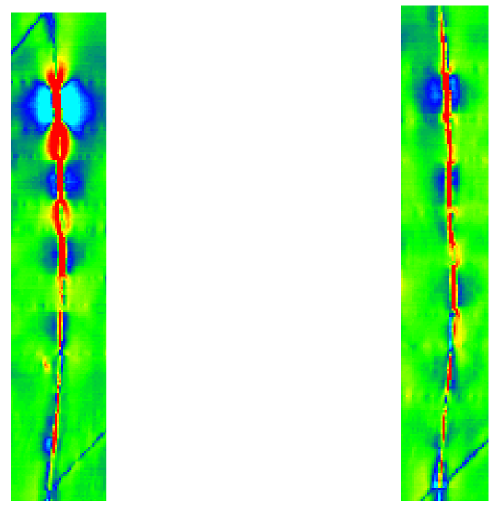

Figure 13. Plots of MFL data for various girth weld anomalies of interest

ACKNOWLEDGMENTS

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