Mechanical Damage Detection With High-Resolution MFL Technology

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Due to recent well-publicized pipeline failures and the resulting regulatory focus on pipeline integrity and safety, much more attention is now focused on the subject of mechanical damage in pipelines. The development of inline inspection (ILI) tools capable of detecting the presence of mechanical damage, and ideally, assessing its severity, has become one of the highest priorities for those associated with pipeline integrity.

The many variables of mechanical damage, such as the shape, depth and length of the defect; associated work hardening and pressure cycling effects and proximity to welds, severely complicate the issue of assessment. Consequently, the combination of the risk of failure and the inability of ILI technologies to detect and assess mechanical damage are reflected by today's strict regulatory requirements that govern this area.

Terminology

It is important that the terminology used in this discussion is understood and that it is consistent with that used in the regulations. First, detection is the act of identifying an anomaly or condition in a qualitative fashion, while assessing an anomaly or condition consists of a quantitative measurement of its physical characteristics. Next, the practical and generally accepted definition of mechanical damage is that of an anomaly with a deformation component and a metal loss component, resulting from the impingement on the pipeline by an outside force or object. This typically results from third-party or construction damage.

Dents and deformations are not, however, synonymous. A dent is considered to have resulted from an impingement from an outside force, while a deformation could be a dent, wrinkle, bend, manufacturing variation or any other feature that results in a reduction in the internal diameter of the pipeline. This distinction is drawn because a caliper or MFL tool has great difficulty in distinguishing between the different types of deformations.

Regulations, however, do not refer to the condition as mechanical damage, but rather refer to dents with any indication of metal loss, cracking or a stress riser. Furthermore, regulations do not distinguish among the types of potential metal loss, resulting in any dent, regardless of depth, with associated metal loss being an immediate repair condition. Therefore, for the purposes of this discussion, mechanical damage is defined as an anomaly with deformation and metal loss components.

Orientation

As opposed to defect geometry, one well-understood and important aspect of mechanical damage is the importance of its relative position on the pipeline. A topside dent, defined to be between the positions of 8 o'clock and 4 o'clock, is considered to be potentially most injurious, as this defect is more likely to have been caused by the impingement on the pipeline by an outside force or object. Bottom-side dents are most often caused by rock damage sustained during the construction process.

Bottom-side dents are most often constrained by the object that has caused them, while topside dents are usually unconstrained, allowing pressure cycling effects to act upon the associated stress risers or other defect characteristics, speeding the failure mechanism. Regulations for liquids acknowledge this fact by stipulating that any topside dent that "has any indication of metal loss, cracking or a stress riser," becomes an immediate repair condition.

Detecting Mechanical Damage

Detecting the presence of mechanical damage through ILI techniques becomes more difficult as the deformation component becomes smaller. Historically, caliper pigs have provided the function of "proving up" the pipeline's bore prior to ILI. More recently, high-resolution caliper pigs have been used to detect and assess pipeline deformations. Vendors running caliper tools typically report deformations that are greater than or equal to 2% of the pipeline diameter and can, at best, occasionally distinguish between a sharp and smooth deformation but cannot determine if there is associated metal loss.

Whether by coincidence or by design, pipeline regulations require that any topside dents larger than 2% of pipeline diameter must be excavated and investigated for evidence of metal loss within a prescribed timeframe, depending upon their size.

While caliper tools are capable of detecting and assessing only the deformation component of mechanical damage, properly utilized high-resolution MFL technology is capable of detecting both the deformation component and the metal loss or metallurgic changes from work hardening. With high-resolution MFL technology, one must keep in mind that the geometry of the deformation encountered greatly influences the MFL signal.

While sensor lift-off limits the ability to assess the associated metal loss, the detection of the deformation can easily be achieved. Historically, MFL reporting of mechanical damage has been limited, as the data is complex and the automated analysis techniques used by most ILI vendors are not capable of extracting the information necessary to accurately predict its presence.

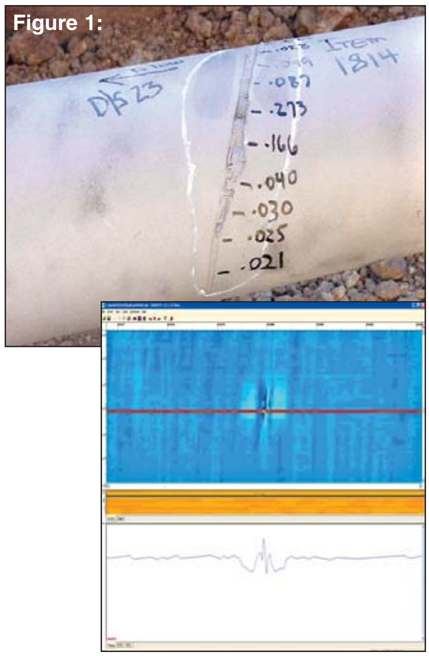
Combine the known limitations of MFL and the caliper tool's ability to detect mechanical damage with the evaluation and repair conditions of the regulations and it becomes obvious why there is an apprehension to call a deformation with metal loss and why even plain deformations less than 2% of pipeline diameter go largely unreported. This frames the issue of detecting and predicting mechanical damage with inline inspection techniques. It is difficult to detect and impossible to assess with current ILI technology, and if predicted, it carries onerous regulatory implications.

Extracting Information

Baker Hughes Pipeline Management Group (PMG) has recognized that high-resolution MFL datasets may yield information indicative of the presence of mechanical damage if specialized analysis techniques are used. Experience has shown that a manual interpretation of the data by a highly trained and qualified analyst provides the only means for extracting the information necessary to predict deformations with metal loss with a high probability of success.

There are many features that alert an analyst to the presence of mechanical damage. The most obvious is the tell-tale signature of the deformation component caused by sensor lift off. High-resolution MFL technology is quite effective in detecting deformations but cannot assess or size them. As a consequence, MFL reporting has historically called them a deformation. Other indications that analysts key on are metal loss or gain signals and/or the signatures of metallurgical changes in the parent metal that occur due to work hardening or other similar mechanisms.

Figure 1:



Validation Digs

In order to validate the Baker Hughes PMG's ability to predict mechanical damage, an ambitious program that analyzed a statistically significant number of validation digs was undertaken. To accomplish this project, feedback was solicited from clients and to date, data from 44 different ILI runs in natural gas, liquids and chemical lines ranging in size from 4-24 inches in diameter has been analyzed (see Figure 2 for a distribution of the pipeline sizes inspected).

The dig data consists of 322 predicted mechanical damage anomalies. There were in excess of 1,400 plain deformations (i.e., without associated metal loss) that were predicted, 59 of which were dug by the clients for reasons such as being greater than 2% of pipeline diameter, within close proximity to another called defect, a girth weld, or a long seam weld.

The majority of the deformations that were predicted in this study were first sized through the use of Baker Hughes PMG's MFLCal

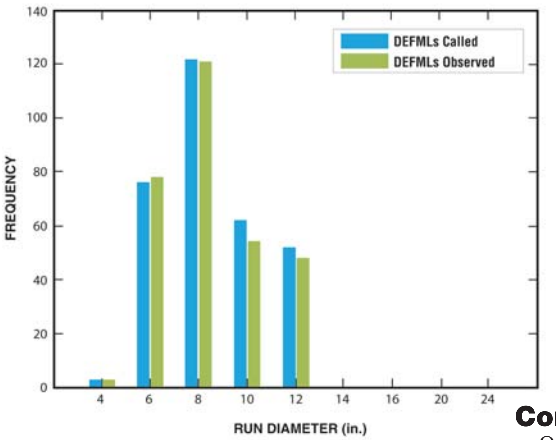


Figure 2: Mechanical damage calls by diameter.

Combo Tool, which combines high-resolution MFL and caliper technology. Other deformations were sized through the use of a standalone caliper tool, with the data being manually integrated with the MFL dataset. "In the ditch" validation of the size of each of these deformations, along with the validation of the presence or absence of metal loss, was performed by Baker Hughes PMG's clients or their contractors.

The orientation of the defects examined in this study was also consistent with that of mechanical damage and reinforce the regulatory focus on topside dents (see Figure 4 for defect orientations). There were, however, bottom-side defects that were predicted and found to have contained a metal-loss component. There was no information received to ascertain if these bottom-side deformations were constrained or unconstrained.

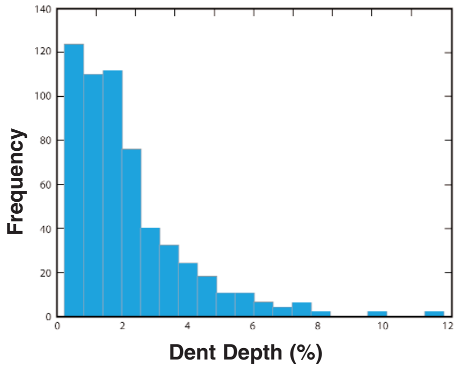


Figure 3: Mechanical Damage Call and Associated Dent Depth.

An interesting trend in the data showed that (see Figure 3), the vast majority of deformations were less than or equal to 2% of pipeline diameter. Considering:

- Regulatory focus on deformations that are 2% of pipe diameter or greater.
- Caliper tools typically have a reporting threshold of 2% of pipeline diameter.
- Most MFL analyses are not reporting small deformations as previously discussed.

It should then come as no surprise that there is a large population of small, unreported deformations.

Correct Calls

Of the 322 mechanical damage calls made, 289 were correct. This represents a 90% success rate for correctly predicting mechanical damage in this data population. Conversely, only 10% of Baker Hughes PMG's calls resulted in operators digging deformations that did not contain a metal loss component (false alarm rate). In this study alone, 289 potentially injurious defects were identified and remediated that would have otherwise have gone unreported.

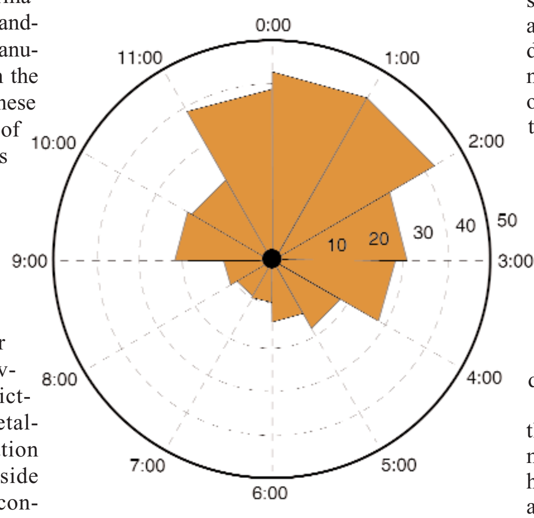


Figure 4: Mechanical Damage Orientations

Missed Calls

It is also instructive to review the false negative or missed calls to better understand the limitations of using high-resolution MFL for the detection of mechanical damage. Of the 22 missed calls:

- Eight misses were attributable to damaged sensors, excessive debris in the line, excessive wall thickness variations, association with the long seam or girth weld;
- Eight contained shallow, narrow axially oriented defects which are very difficult to identify with axial MFL;
- Five contained very large deformation components; and
- One resulted from misinterpreted data.

These mitigating factors influence the statistical relevance of the 22 false negative or missed calls out of the total population of 59 predicted plain deformations that were excavated in this study. In order to definitively assess the ratio of missed calls to predicted plain deformations, a much larger percentage of the approximately 1,400 predicted plain deformations would need to be examined at a much higher dig program cost. This was not an objective of this study, as all digs were funded by clients as part of their rehabilitation programs.

Summary

Considering all ILI runs where Baker Hughes PMG has made mechanical damage predictions — most of which fell outside the scope of this study — approximately 95% of all pipelines contained at least one mechanical damage prediction that would have otherwise not been predicted by stand-alone caliper or other ILI technologies. This indicates that there are a significant number of unreported mechanical damage anomalies remaining in pipeline systems.

While this method of detecting mechanical damage is not the panacea that many may hope for, it has proven to be extremely effective in detecting potentially injurious defects that would otherwise go unreported. In this study alone, 289 such mechanical damage defects were identified and remediated.

Much more work remains to be done on the subject of detection and assessment of mechanical damage. This study shows that high-resolution MFL data can yield valuable information if the proper analysis techniques are applied. ***P&GJ***