PRESSURE ASSESSMENT OF CRACK DEFECTS EMPLOYING ULTRASOUND IN-LINE INSPECTION

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ABSTRACT

The in-line inspection industry for the grading and assessment of corrosion and cracking has taken a step forward due to the development of new ultrasonic tools using the most up-to-date technology available. Free swimming ultrasonic inspection tools have been employed successfully for 15 years for the measurement of corrosion and 9 years for cracking in pipelines. Through the efforts of the original creators of this technology and well established expert partners, a new generation of UT ILI has been created. This technology upgrade not only applies to the mechanics and electronics of the UT tool but to a complete rebuild of the processing and front-end software. An example of the efficiencies gained from the new system is that it allows for analysis to begin in hours after the receipt of the tool as opposed to other UT ILI technologies that require weeks of pre-processing. The new system allows for the most accurate representation of the defects in both location and sizing. Pressure based analysis is a primary requirement for prioritizing crack and crack-like defects in pipeline integrity management programs. Applying growth rates to the failure analysis of the crack defects allows for a more efficient and detailed maintenance schedule to be developed.

1 INTRODUCTION

The main focus of ultrasonic crack inspection is of course to locate and size cracks. An integrity engineer relies on this information to ensure the pipeline is safe and secure. The results of an ultrasonic inspection directly affect the present and future management of the pipeline. Through the use of the most up-to-date technology a more realistic pipeline integrity management programs can be developed.

In the case of cracking there are a number of recognized defect acceptance methods available for assessing these defects, for example ASME B31G[1], and API 579[2]. Through experience it is realized that there are issues related to the input data used in these calculations. The engineer assessing such cracks must be aware of the tolerances of the IN-LINE inspection vehicle data, the type of defect being examined, the variance in the pipeline material being examined, and the variability in the pipeline operational data.

Historical information and knowledge of the pipeline manufacturer and vintage cannot be overlooked. This information provides details on the type of cracks or crack-like defects that will be found in the pipeline. There are certainly quite a range of cracks and crack-like the facts some even innocuous to the integrity of the pipeline. A few examples may be seen in Figure 1.

This paper will provide some insight into the new generation of ultrasonic ILI tools as well as some discussion on the analysis of crack defects. In an effort to provide more comfort to the integrity engineer examining crack-like defects a method encompassing the variations in material properties as well as sizing estimates will be examined.

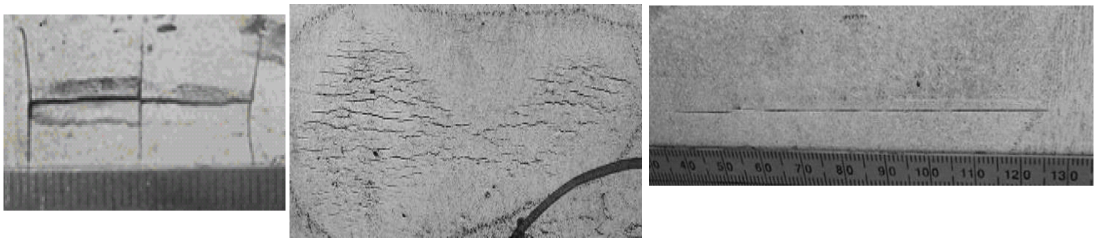


Figure 1: Examples of various crack configurations and geometries.

2 NEW GENERATION OF ULTRASONIC ILI TOOLS

Modular design of the tools allows for a wide range of pipeline diameters to be inspected using one core units, keeping the same circumferential resolution (senor density). Crack detection technology is available from 10” up to 42” with only the sensor carrier and the cups having to be fitted to the exact size of the pipe. Figure 2 shows a 10” crack detection tool.

In addition, retrofitting the tool from crack detection to wall thickness (corrosion) measurement, and vice versa, can be done easily and within an hour. For most of the diameters, even a simultaneous corrosion and crack detection run could be performed.

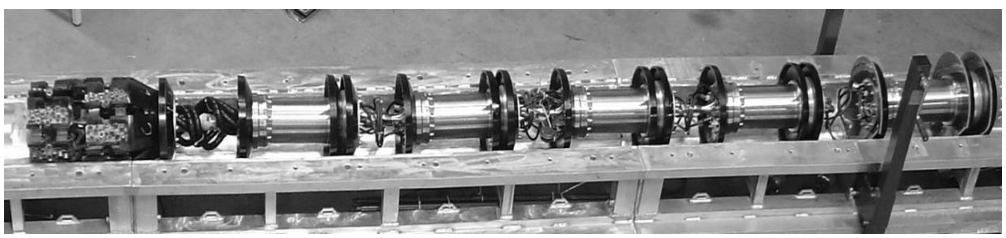


Figure 2: Ultrasonic 10” Crack Detection Tool.

Some of the advantages of the new design and tool construction include a shorter overall length by up to 40%, an increased inspection range up to 300km, inspection speed increased to 1.5 m/s and very quick data turnaround and visualization of data.

2.1 SCC found from In-Line Inspection

As an example, 242 km of seamless 324mm pipe was recently inspected. The pipeline has a history of SCC and has been inspected using circumferential magnetization tools twice in the last 6 years with very little success.

Fifteen defects detected as SCC colonies were dug up and were verified. All were confirmed to be SCC and locations and lengths and widths of colonies were confirmed. All depths measured in-the-ditch were found to be within 0.5 to 1 mm of the depths predicted by the ILI. All colony lengths measured in-the-ditch were found to be within 10 to 20 mm of the lengths predicted by the ILI. An example of which may be seen in Figure 3.

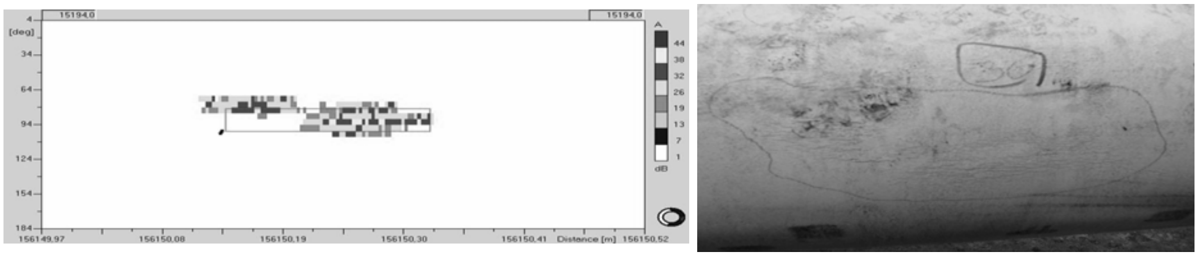


Figure 3: SCC as found by UT ILI and actual.

3 CRACK EVALUATION WITH SAFETY IN MIND

To evaluate the severity of a crack defect more than just its length and depth must be known. To more accurately judge the safety of the defect a general knowledge of the material as well as the operating conditions must be known. These parameters are then employed in accepted fracture mechanics principles to derive a justifiable conclusion of defect safety.

3.1 Input Data

No single method can cover all varieties of defects, pipelines, defect assessment methodologies or deliverables. With a final assessment outcome in mind the type and level of detail of information that should typically be considered include:

1. Pipeline parameters such as diameter, wall thickness, grade, long-seam type and specific material properties such as yield and tensile strength and toughness.

2. Operational characteristics such as historical operating pressure, temperature, pressure cycles, pipeline products and environments. Future operating conditions must be taken into account as well.

3. Pipeline history that includes manufacturing techniques, construction techniques as well as past failures, repairs, inspection results and/or hydro-tests.

4. The loading conditions on the pipeline must be considered immediate to the defect such as hoop stress, axial loading, over pressures, cyclic loads and future changes to pressure requirements.

5. The defect type is of particular importance as it must be known for an appropriate assessment to be made (if the type is not known then the worst case scenario should be used). The types of cracking they can be encountered range from Colonies of SCC, (that may be transgranular or intergranular, running axially or at angles to the applied loads) lack of fusion that has grown by fatigue or environmentally, within mechanically damaged areas, or even crack-like defects such as surface breaking stringers or laminations. The above is certainly not an exhaustive list.

6. The capabilities of the inspection methods employed its sizing tolerances and accuracies should be known.

3.2 Failure assessment

As mentioned previously there is more than one method used to determine the acceptability of a crack with respect to the safety of the pipeline. Two methods commonly used today are the NG-18 "ln-secant" method (Kiefner [1])and the failure assessment diagram (FAD) approach used in API 579 (API [2]), BS 7910, and R6 procedures. To examine each method an example will be used based on a 406mm diameter pipe, 6.35mm wall thickness, Grade 358.5 MPa, toughness of CVN 34J with a crack depth of 1.59mm and length of 200mm

3.2.1 NG-18 Procedure

It has been determined that the critical crack size depends on the nominal stress, the material strength, and the fracture toughness. For a longitudinally oriented defect in a pressurized cylinder the relationship between these parameters is expressed by the NG-18 "ln-secant" equation that follows. To conserve room we will not explain the variables.

$$\frac{C_V \pi E}{4 A_C L_e \sigma_f^2} = \ln\left[\sec\left(\frac{\pi M_S \sigma_H}{2\sigma_f}\right)\right] \tag{1}$$

To assess crack-like flaws the user must supply representative values of Charpy energy as well as the yield strength of material and detailed dimensions of the defects. Figure 5 illustrates an example of the use of the NG-18 equation with the above noted pipe properties and crack dimensions. The use of this equation is generally for prioritization of crack-like defects. This equation should not be used in steels exhibiting very low toughness.

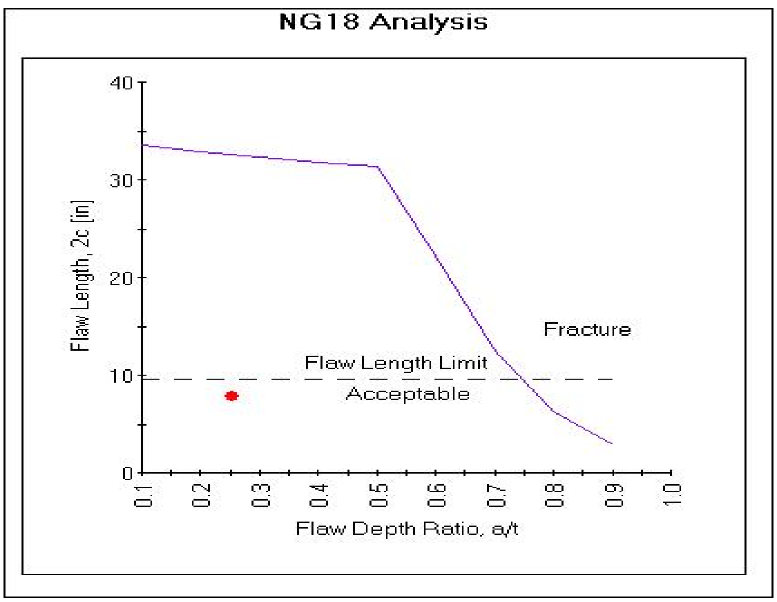


Figure 5. Example NG-18 Failure Pressure Estimates for specific pipe properties, CVN value and crack size.

The application of these curves is quite intuitive and therefore easily understood by technical employees and executives alike. Given that appropriate pipe properties are used during such an assessment the values provided allow for easy justification for program management.

A further important topic that will not be covered in this paper which would then be assessed after such an examination is that of crack growth. There are well documented guidelines as to the procedures and applications of crack growth that are highly dependent upon the mode of growth and could in turn become quite complex should there be more than one mode in action.

The application of such a technique as given in figure five is quite discreet and has not applied any of the tolerances as mentioned prior. The estimated tolerances can be applied similarly to the following discussion on the failure assessment diagrams.

3.2.2 Failure Assessment Diagram Procedure

The failure assessment diagrams or FAD, are becoming a desired method for the analysis of a structural integrity assessment. This method is generally a graphical representation of stress or stress intensity versus the load applied. The resulting graphical representation (Figure 6) delineates a critical failure line thus establishing a safe or acceptable zone versus a region of fracture failure or plastic collapse. When working with such a representation the failure pressure is not readily defined. This application is quite easy and useful for a technical employee and the technical group but much less explainable to managers or executive personnel.

The illustration and figure 6 denotes the calculated stress intensity ratio versus load ratio for a the given defectabove. The critical failure curve represents a brittle material when Kr is equal to one at Lr equal to zero. Conversely, a totally ductile material would be represented when Kr is equal to zero and Lr is equal to one. In between these points the steel is a combination of brittleness and ductility.

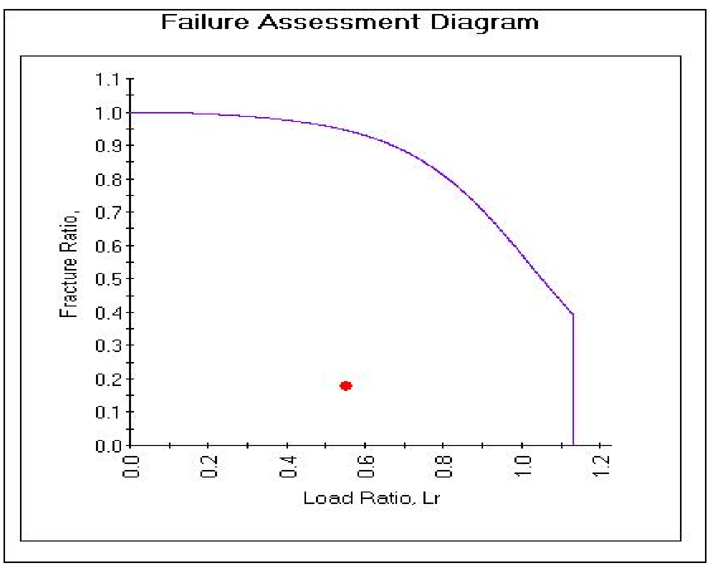
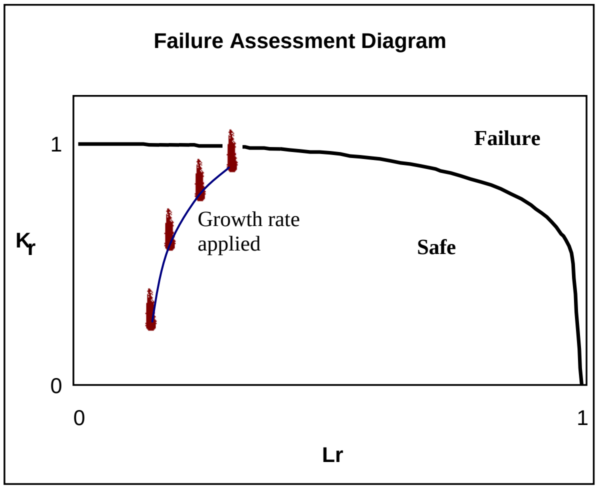


Figure 6. Traditional Deterministic Failure Assessment Diagram

When considering variances of variables such as suggested minimum yield strength, ultimate tensile strength, wall thickness and the crack dimensions such as length and depth a statistical distribution is best suited. The general methods using standard deviations with normal distributions are the more accepted approaches. Using such statistical distributions, generally accepted methods such as Monte Carlo simulations are quite useful. Ranges can be set for such uncertainties as toughness, yield strength and ultimate tensile strength as well as the expected errors in crack sizing (by ILI or NDT). Such interpretations have been shown as appropriate[3] and a representation of such can be found in Figure 7. For the given example, it can be seen that the probabilistic method gives a measure of how the uncertainties may shift the representation in FAD and that this example is well within the non-failure domain. Employing a growth rate and applying it to the probabilistic assessment would yield an assessment curve such as can be seen in Figure 7.

Figure 7: Probabilistic Failure Assessment Diagram



4 CONCLUSIONS

With these methods an engineer can feel assured that the “cloud” of uncertainties surrounding defect integrity assessment has been considered. Also, developing repair management strategies into the future requires some knowledge of defect growth whether it be environmental or operationally related. The use of UT ILI tools is an ever expanding field and certainly the most efficacious means to which to explore for crack and crack-like defects. One last conclusion, I required more than the six page limit to do an adequate job for this paper.

5 REFERENCES

1. Kiefner, J.F., Maxey, W.A., Eiber, R.J., and Duffy, A.R., “Failure Stress Levels of Flaws in Pressurized Cylinders”, Progress in Flaw Growth and Toughness Testing, ASTM STP 536, American Society for Testing and Materials, pp461-481, 1973.

2. Fitness-For-Service, API Recommended Practice 579, First Edition, American Petroleum Institute,Washington, D.C., January 2000.