What are the real challenges in pipeline inspection?

K. Reber, W. Schmidt, TÜV Rheinland Industrie Services GmbH, Köln, Germany

Abstract

In the following paper we describe the influence of various factors on the reliability of pipeline inspection results. Special attention is paid to in-line inspection of pipelines. If inspection results are not only used for immediate repair programs but also for long-term risk assessment the importance of different input parameters has to be rated. In some cases inspection results yield important information would remain unheeded if no special attention would be directed to it. In the end we discuss the importance of properly archiving inspection data for long-term risk assessment. Available software solutions for properly working with in-line inspection data seem to lack in compatibility with data of different sources. A possible road towards standardization is shown.

1. Introduction

Old pipelines and safe pipelines are not necessarily a contradiction. However, with pipelines growing older the scope of pipeline integrity may shift. In the course of pipeline integrity assessment several methods of inspection are currently being applied. For a risk based inspection approach, the abilities of various inspection methods have to be rated versus the actual inspection requirements. The development of new and the improvement of existing inspection methods should be geared towards meeting these requirements.

Concerning inspection means internal (by intelligent pigs) and external methods are to be distinguished. Many threats are not targeted by inspection. Pipeline integrity threats that are targeted by inspection can be categorized into three classes: Corrosion, or more general operating related metal loss, sharp-edged material flaws with high stress concentration and blunt deformations of the pipeline roundness.

The available means of inspection can be put in context with the assessed risk arising from respective threats. In which of the categories do we have the highest pipeline threat that may remain unrevealed even after inspection is carried out? Various input information has to be used in order to properly assess the risk. This information has often been obtained in the construction time. Many aspects seemed irrelevant at that time, but have become relevant today. The key to obtaining the full picture is found in combining several information sources. Often inspection information is not exploited to its highest possible extend. In many cases slight modifications in the inspection instrument may yield valuable additional information.

2. Importance of material properties

The classic defect assessment triangle distinguishes the different input values in the categories load condition, flaw geometry and material properties. Usually the loading conditions are given by the operational data, that is well known and often even controlled by a SCADA-System. The geometry values are the input to be obtained by the inspection. Concerning the material properties the values have to be obtained from mill certificates and procurement protocols. Obviously this input is at least as uncertain as the geometry input. Whether the actual pipe wall thickness is part of the measured geometry or also has to be taken from existing information depends on the applied inspection method. Indeed, some inspection methods do not measure absolute wall thickness, which means wall thickness may also fall into the third category. For a proper design and integrity verification the values of wall thickness and material strength should be known properly. Especially for the purpose of pressure uprating the distribution of actual yield strength has to be investigated [1]. A standard deviation of up to ± 20 MPa has been observed for a 36”-X70-pipe. In addition the actually observed minimum yield strength was 18 MPa higher than the stated nominal value. How does this distribution compare to the typical size distribution of a flaw due to measurement uncertainties of an in-line inspection tool? Although the material parameter spread is of physical origin and the flaw size is a measurement error, both of these limitation in accuracy represent a limit to the reliability of a risk assessment. We may take the material parameter spread as a measurement error, if we were to measure the parameter at one spot and use these values throughout the pipe.

The actual answer also depends a lot on the chosen pipe and flaw size. As an example we choose a flaw the size of which shall be the minimum detectable size of an ultrasonic crack detection tool. The minimum defect shall thus be a 30 mm long 1 mm deep defect that is found in a 10.6 mm-X70-36”-pipeline. A common approach to assess the severity of defects is the so-called failure assessment diagram initially developed for the assessment of flaws in pressure vessels. A defect is shown by its fracture ratio over its load ratio. The fracture ratio describes how likely the pipe will fail due to brittle failure and is given by the stress intensity factor over the fracture toughness, which is a material constant. The load ratio is given by the ratio of a reference stress, which is a measure for the stress concentration, and the yield strength. The load ratio describes how far from plastic collapse the pipe at the flaw is. The safe range is given by a limit curve taken from various standards. The results are shown in Figure 1. The limit curve is shown for three different models.

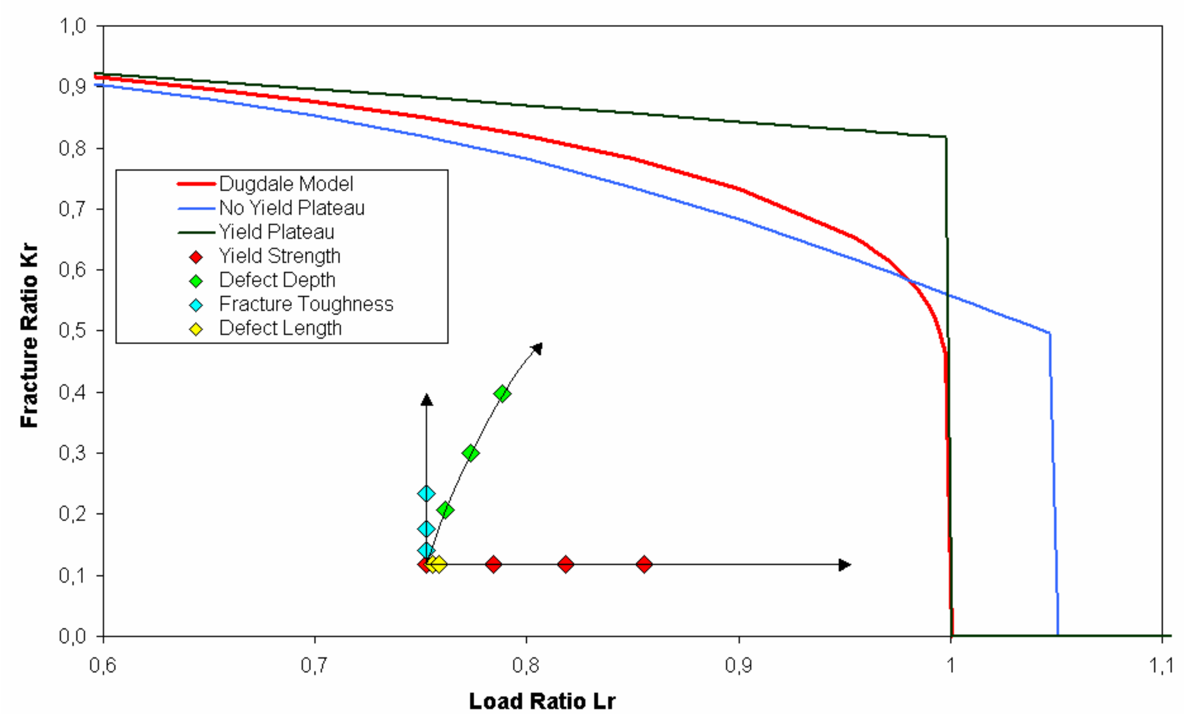

Figure 1: The FAD shows how the assessment point of a defect changes if the various input parameters are changed by one standard deviation per depicted point. The standard deviation is estimated from a probable distribution of these values. It is obvious that the yield strength and the defect depth can have quite an influence.

With this method we can also compare the expected variations in yield strength and flaws size to variations in fracture toughness. Since experimental values for toughness are usually given in Charpy impact energy, most assessment codes give an approximate evaluation method to convert this in the required K_{mat}-fracture toughness term [2]. Various tests have shown that a standard deviation of about ±20 J can be assumed to be present even in base material [3]. In the heat affected zone it can be up to ±40 J [4]. This would translate to roughly ± 500 N/mm$^{3/2}$ in terms of fracture toughness in the case of $\sigma_{CVN} = \pm 20$ J.

What we see in Figure 1 is the starting point of the chosen defect and the point curve for aggravating material and geometry parameters by one standard deviation per depicted point. One standard deviation being 3 mm defect length, 1 mm defect depth, 20 MPa Yield strength and 500 N/mm$^{3/2}$ fracture toughness.

While it has been emphasized how the accuracy in obtaining material parameter also influences the result, the need to acquire this data in a simple manner is another issue. Traditionally large scale destructive tests are being conducted. Statistics on mill certificates yield very reliable information on the typical distribution of material parameter. The absolute values at a specific spot, however, are still undetermined. In-line inspection tool to measure material hardness have been developed [5]. Hardness and material strength can often be directly converted. However, there is no clear relation between ultimate strength and yield strength. We see from this result that in-line material parameter measurement is only reasonable if a certain accuracy is achievable.

3. Geometries

There are several types of imperfections in the perfectly round shape of a pipeline that pose a potential risk. In most cases the risk stems from a reduced fatigue resistance due to stress concentrations. Many of these imperfections are detected and measured using in-line inspection tools. Although these tools are designed for a different purpose, the data is often exploited for assessing other types of flaws.

3.1 Unintended expansion

Recently some cases of unintended expansion have been reported, which are likely to have been caused by high pressure hydrotests (stress test). Although the stress test has the intention to load the material beyond the elastic limit, only a minor deformation is accepted. Reported expansion levels are in the range of 5% strain. With this cold expansion a strain hardening with a material embrittlement is observed. Obviously the closer the Y/T-ratio is to 1 the more problematic is any unintended strain hardening. While the effect of hardening is easily understood by looking at stress-strain curves, the effect on the material toughness is not obvious. Conducted tests [6] have shown that toughness measured as the J-Integral or CTOD-values is reduced with increasing prestrain. It is also known that the transition temperature increases in work hardened material [7]. Figure 2 shows how transition temperature and brittleness change with increasing prestrain.

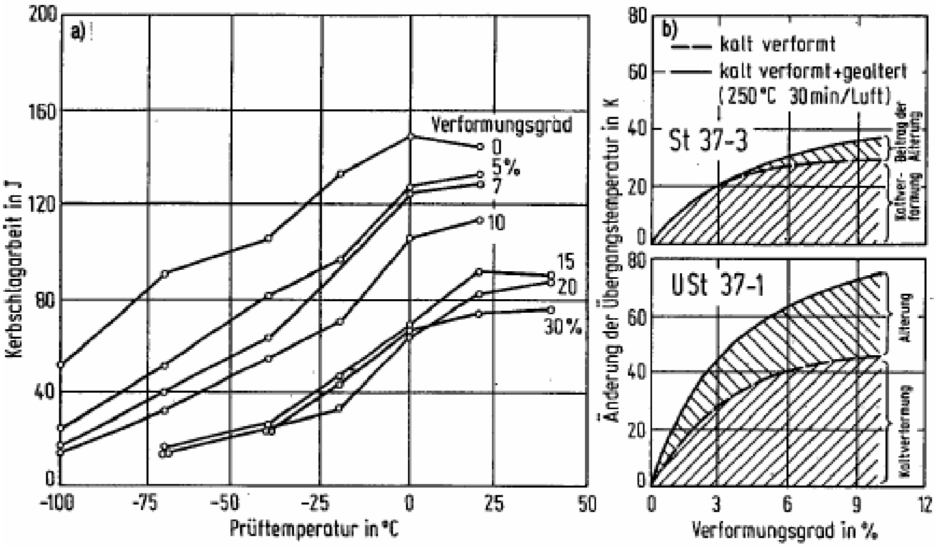

Figure 2: Charpy impact energy versus prestrain taken from [7]

Although these two effects are usually not detrimental for the considered strains of 5%, both of these effects should be considered. In combination with other effects especially cyclic loading the expected lifetime of these pipes is reduced.

For all pipelines that have been subject to high pressure tests an evaluation of in-line inspection data with respect to expanded joints is advisable. Expanded joints can be found in regular (one or multi-channel) caliper data. These tools are usually able to record diameter data with an accuracy of 1%, which should reveal the worst expansion[1]. However, for regular caliper surveys little or no attention is paid to this effect. Only indentations are of a concern.

Also ultrasonic wall thickness inspection tools are capable of detecting this kind of flaw. An increased pipe diameter could be detected in the so-called stand-off data (see below). Again the regular data analysis, which is more concerned with the detection of corrosion, does not pay attention to this effect. Ultrasonic inspection tools with a flexible sensor carrier would only see an expansion at the taper joint. The sensor carrier will adapt to the expanded diameter without any trace in the data. Stiff sensor carriers would reveal this effect in a clearer manner. The resolution of the stand-off measurement is in the range of 0.4 mm for older tools, but can be set to below 0.1 mm for newer tools. This is well within the requirements to detect unintended pipe expansion of 5%.

During third party inspection of pipeline construction a stress test and a caliper run is usually carried out. The possible connection between the two test methods is not always taken into account, although a gauging of the new pipe is common [8]. A properly conducted stress test will never lead to an unintended expansion of pipe joints, nevertheless it should be considered to use the caliper survey to check for any effects.

3.2 Roofing

The problem of roofing, also known as peaking, exists in longitudinally welded pipe. Due to incorrect bending of the steel sheet in the mill, the sheet ends are joined with a certain angle at the longitudinal weld. The problem is a poor fatigue behavior in the longitudinal weld. Problems of this kind have repeatedly been reported, but the detection and quantification was not easy. In a previous project the degree of roofing i.e. the angle and thus the deviation from

[1] The intended expansion according to VdTÜV1060 is lower than 0.1% which is not within the detection capabilities.

the perfect round shape has been measured by an ultrasonic inspection tool [9]. The data were used to carry out fatigue life-time prediction.

What is the most suitable method to detect and measure this kind of shell distortion? Traditional inspection tools intend to find corrosion-type defects. In order to do so in pipe sections with a change in diameter or out-of-roundness a typical inspection tool sensor carrier will adapt its shape to the inner pipeline surface. This usually is beneficial for the detection of corrosion, but will render the tool blind for the detection of ovalities or roofing. For ultrasonic inspection tools the option is to stiffen the sensor carrier in such a manner that no adaptation to the pipe shell will occur. In this case the so-called stand-off measurement of the ultrasonic transducer can be used for the determination of the geometry deviations. The stand-off is the time-of-flight from pulse emission to surface entry echo. The value is thus a measure for the interior shape of the pipe. A sample screenshot is shown in Figure 3.

The data in the upper part of the screenshot shows the stand-off values. The reddish color indicates an increased stand-off due to the roofing effect. There is a slight upwards trend in this band, because the tool is rotating. The lower part of the screenshot shows the wall thickness data. The seam weld part is enhanced with the dotted line. The roofing represents a tilting of the surface which leads to a loss of the rear wall echo. This is depicted in the green color.

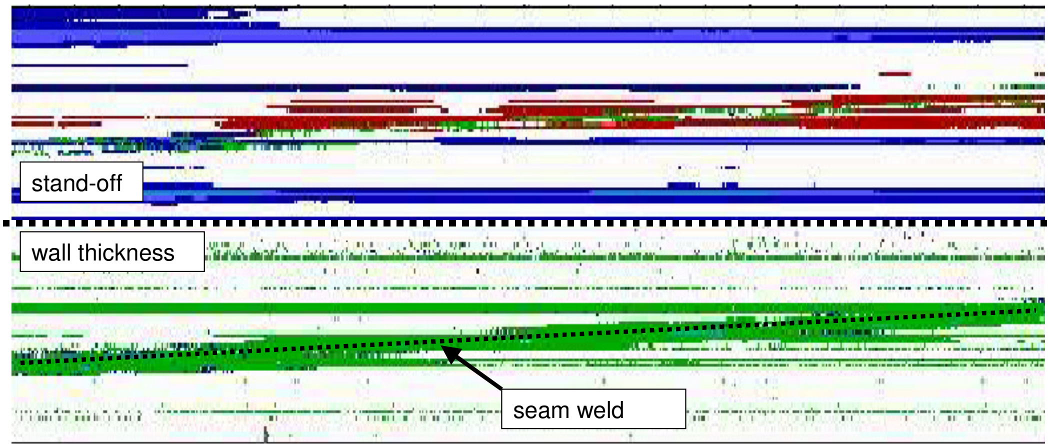

Figure 3: C-Scan of the Inspection data of an ultrasonic wall thickness measurement.

Some ultrasonic inspection tools use a sensor carrier that consists of a rigid body. These tools can readily be employed for an internal roundness measurement. In fact the measurement is more or less a high-resolution multi-channel caliper measurement. Regular caliper tools are either one channel, i.e. only the overall bore reduction is recorded, or they record several channels. However, even multi-channel caliper tools do usually not have the necessary lateral resolution to reliably detect and measure roofing.

4. Archiving

It has been shown that inspection data can be used in circumstances that have not been anticipated. It is thus important to be able to access this data a long time after acquisition. Also it should be possible to make the data available to others for further evaluation. Proper archiving and dissemination of the data is of paramount importance. Pipeline Integrity Management Systems (PIMS) have been devised for this issue. When it comes to in-line inspection these systems often fall short of the desired compatibility and accessibility of inspection data. Most in-line inspection tools vary with respect to the measurement principle, the data storage format and the need to interpret this data. Especially for the need to interpret the data, the result of inspection is often reported in a concise inspection report format. Any further assessment is based on this condensed information. This is desirable for fast and effective responses to in-line inspection. However, there are cases, where the long-term usage of the actual inspection data is desirable. For this reason most inspection vendors supply some kind of viewing software, that allows to navigate through the data and visualize the data at any inspected spot. Since the inspection data is always bound to the hardware it was acquired with, none of these pieces of software is compatible with any other inspection data. In simple words, the "Microsoft windows for pipeline inspection data" does not exist. The organizations that view the inspection data for further evaluation are thus obliged to handle the data with a multitude of different systems. In some cases they may not even be allowed to do so. Vice-versa even small inspection companies are obliged to offer a viewing software to their clients, even though they see their field of expertise in the improvement of the inspection method itself. A standardization would be the solution. If a standardized inspection data format could be set up, any software engineering group with a background in pipeline management could introduce a product that could be used for all inspection data. Operators as well as consultants that would want to use the data for further evaluation, would only need this one piece of software, and inspection companies would only need to put their data in a certain format and could integrate it seamlessly into a local database.

While some larger inspection companies may also have a certain ambition in building complete software packages, it would be in the interest of an open, transparent and competitive inspection market to standardize the inspection data format. The notion that inspection data is only to be used by the inspection company itself is untypical in areas, where inspection plays an important role.

As far as a standardization of the data base model of pipeline data is concerned, several models have already been introduced [10]. These database models describe a common structure for storing and exchanging pipeline related data. In-line inspection data are one data source. However, only data are considered that can be described as an item along the pipeline. A continuous stream of inspection data is not part of a database model.

Some software packages that allow to navigate through inspection data and that are open to various sources of inspection data are also available. Most of these software packages are, however, not especially tailored to pipeline inspection but rather to a certain inspection method like UT.

For an inspection data standardization model the requirements shall be briefly described for in-line inspection data.

4.1 Data Matrix

For inspection technologies where the inspection data merely consist of a scanning of the surface, the readings can easily be put into a matrix representing a section of pipe. The abscissa would be related to a distance along the pipeline, the ordinate would cover a section or usually the full circumference of the pipe. The data readings could be stored in a matrix type data object. As an example, for MFL-inspection the matrix would consist of readings of the magnetic field values, for ultrasonic pulse echo methods the matrix could be time-of flight of wall thickness readings in a rectangular matrix. Eddy current methods would show for instance amplitude levels.

More difficult is the situation for inspection methods, which do not simply scan a surface but that employ an interaction of a flaw with a wave traveling in a lateral direction, i.e. in the plane of the pipe. Examples would be guided wave types of inspection, pulse-echo ultrasonic waves with oblique incidence or TOFD. In this case the information needs to be projected onto a plane, if it is to represent a scanned matrix of the pipe surface. This projection could be displayed like the above mentioned scanned surfaces. An interpretation of the data would of course always require to view the readings of a single sensor.

4.2 Data layers and views

All inspection methods yield different layers of data. The echo of a UT wall thickness inspection could be represented in stand-off and wall thickness data. To every single point on the surface two pixels could be assigned. In a similar manner for MFL inspection a field level value and a reading of a secondary sensor (type2, IDOD, etc.) are obtained. For eddy current measurement an amplitude and a phase information has to be displayed. For all of these examples the relation of the two (or possibly more) values is clearly defined. A common software package would need to be able to display various layers of this data. The special relation between the two layers often depends on the employed inspection tool and needs to be known exactly.

4.3 Distance and orientation tagging

In most cases a matrix of inspection readings would represent a section of pipe of a certain distance and orientation. While the start and the end is a clearly defined distance, the circumferential limits may be given by orientation or by sensor number. There is not necessarily a direct relation between orientation and sensor number, as any internal inspection tool may rotate. A normalization of the orientation, i.e. a compensation of the rotation of the tool, is usually not useful, because inspection data is naturally best described by a moving sensor. Every sensor will yield a trace of data. For some inspection technologies a normalized view may be advantageous. However, it would be difficult to correlate this view to other data.

4.4 Relation to a PIMS

The proposed software for inspection data display could in principle be extended to a full scale PIMS, by integrating many other functionalities. This is an approach that many inspection vendors follow. The other solution is to establish a direct link between the inspection data viewing software and the PIMS. A distance value would be exchanged between the two programs relating the PIMS data to a certain portion of inspection data. This may become quite demanding, if several inspection data sources are to be linked.

5. Conclusions

The assessment of in-line inspection data needs to be done carefully for various reasons. Limitations of its accuracy are to be heeded for a proper defect assessment. There is an interrelation between tool accuracies and reliability of material properties. On the other hand the full information is not always exploited. For some unusual types of flaws regular tools or tools with minor modifications may yield important information. Since the interpretation of in-line inspection data is a long term process a proper archiving is important to make use of the full value of the information.

References

[1] A. Wisskirchen, Druckerhöhung von Gashochdruckleitungen der öffentlichen Gasversorgung, 3R international (43) Heft 3/2004

[2] BS 7910:1999Guide on Methods for assessing the acceptability of flaws in metallic structures. Appendix J

[3] Tests carried out at TÜV Rheinland for various clients Data not published

[4]Bai, Knauf, Hillenbrand, Materials and design of high strength pipelines, Conference Proceedings ISOPE 2000 YB-001

[5] Belanger A. "Managing HIC-Affected Pipelines Using Multiple-Technology Hard-Spot Tools." Conference Proceedings Pipeline Pigging, Integrity assessment & Repair 2004.

[6] A. Cosham, P.Hopkins, A.Palmer An experimental and numerical study of the effect of pre-strain on the fracture toughness of linepipe steel, Proceedings of the 4th international Conference on Pipeline Technology, 2004, Ostend

[7] Dahl, Kopp, Pawelski, Umformtechnik, Plastomechanik und Werkstoffe, Verlag Stahleisen, 1993

[8] DVGW Arbeitsblatt G 463, Gasleitungen aus Stahlrohren für einen Betriebsdruck > 16 bar- Errichtung

[9] Rehabilitation of a Crude Oil Pipeline – Methods and Assessment criteria, H.J. Schmidt, W. Schmidt, Proceedings to the 5th international Pipeline Symposium, Köln 2002.

[10] Pipeline Open Data Standard see http://www.pods.org/ or APDM ArcGis Pipeline Data Model see http://www.apdm.net/