Demonstration of Pipe and Pipeline Integrity by Means of Intelligent Pigging Systems

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Summary

Pipelines are the veins of the world’s economy. The integrity of the systems is of utmost importance to secure availability and operational safety at a very high level. With these specially developed pigs, damages can be determined well ahead of time to prevent unplanned shut-downs. These pigs are well established tools in the day-to-day operation of pipeline systems. Which system is the most suitable one to determine the integrity of a pipeline system? How can the results be interpreted to achieve the most efficient maintenance schedule? This article will, initially, give an overview of all pig systems existing on the market. Then it will use practical examples to demonstrate how to prove the integrity of pipeline systems and what actions need to be put in place in order to regain the full operational safety of the pipeline system as quickly as possible as every downtime costs considerable amounts of money.

The service life of all man-made “technical products” is limited. Piping and pipelines are no exception. For technical installations such as pipelines, availability of which is critical for global economy, strength analyses and service life calculations must be prepared to furnish evidence of pipeline integrity and strength. The aim of these analyses and calculations is, despite ongoing operational loads, to prevent impermissible stresses from acting on pressurized parts and possibly resulting in critical conditions.

The increasing use of thin-walled pipes made of high-strength steel further adds to the necessity of inspecting pipe walls for direct and indirect defects. Direct defects are those which impact on pipeline safety and integrity and are generally detected by inspection pigs (pipeline inspection gauges). Indirect defects such as damage to insulation of a buried pipeline do not involve any direct hazards but may evolve into direct defects over time.

Inspection pigs have been used in pipeline testing for over 20 years. In these tests, the diagnostic devices are carried along passively through the pipeline, propelled by the flow of the respective medium. The following groups of direct defects can be detected by inspection pigs.

- **Geometry pig**: Indication of deviations from the ideal circular shape (dents, ovalization, wrinkles, changes in internal diameter, angular distortions)
- **Wall-thickness pigs**: Measuring of wall thickness (wall thinning, manufacturing-related anomalies, internal and external corrosion, scabs, laminations)
- **Crack detection pig**: Inspection for cracks, undercut, notches, grooves, weld imperfections in longitudinal direction
- **Leak detection pig**: Used in defect search

All defects that can be detected by inspection
pigs affect pipeline service life. Strength analyses are prepared to furnish evidence that there will not be any impermissible stresses resulting in critical conditions in spite of ongoing operational loads acting on pressurized components. Stress analysis is based on the assumption that a defect's actual load rating and fatigue strength can be determined by means of strength analyses and that dynamic consideration of fatigue curves allows conclusions as to service life to be drawn.

**Geometry pig**

This type of inspection pig was developed to identify and measure deformations such as dents and bulges, ovalizations, ripples and wrinkles, as these may increase stress.

Deformations:
Deformations are deviations from the ideal circular shape of the pipe cross section. Under internal pressure, additional deformations (elastic, plastic) occur, which are not considered in pipeline design. The following criteria may be used to assess deformations:

- extent of diameter deviation
- deformation geometry
- extent of cold forming
- surface defect in the vicinity of the deformation

Deformations can be subdivided into the following types:

- Dents or bulges
- Ovalizations
- Ripples or wrinkles in bends

To detect these deformations, three different types of pigging systems have prevailed in practice:

- mechanical scanning by means of wheels
- mechanical scanning by means of cups
- contact-free scanning using the eddy current principle

Geometry inspection pigs consist of two conical cups. An array of lever-type sensors is distributed evenly around the circumference of the rear cup, similar to an umbrella, and scan the pipe wall. In another version of this pig, the lever-type sensors do not touch the pipe wall but are moved by the deflection of the pig's cup. The deflection of the lever-type sensors is transmitted via joints to a swashplate and, via an arrangement of articulated joints, transformed into pulses which are recorded and registered by a data carrier. The distance travelled in the pipeline is recorded by odometer wheels, whose pulses are also recorded on the data logger. A special software allows exact localization of bulges and dents, circumferential welds, pipe components, ovalizations and changes in wall thickness after the inspection run. Pig velocity which influences recording accuracy also can be determined.

Depending on the pipe diameter, the following measuring accuracies were determined:
### Bulge

<table>
<thead>
<tr>
<th>Range of diameter</th>
<th>Trigger threshold</th>
<th>Measuring accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ID_{red} &lt; 10 %</td>
<td>ID_{red} &gt; 10 %</td>
</tr>
<tr>
<td>6&quot;-12&quot;</td>
<td>1.2 % ± 0.8 %</td>
<td>± 1.0 %</td>
</tr>
<tr>
<td>14&quot;-22&quot;</td>
<td>0.8 % ± 0.6 %</td>
<td>± 0.8 %</td>
</tr>
<tr>
<td>24&quot;-38&quot;</td>
<td>0.6 % ± 0.5 %</td>
<td>± 0.7 %</td>
</tr>
<tr>
<td>40&quot;-56&quot;</td>
<td>0.5 % ± 0.4 %</td>
<td>± 0.6 %</td>
</tr>
</tbody>
</table>

### Ovalization

<table>
<thead>
<tr>
<th>Range of diameter</th>
<th>Trigger threshold</th>
<th>Measuring accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ID_{red} &lt; 5 %</td>
<td>ID_{red} &lt; 5 %-10 %</td>
</tr>
<tr>
<td>6&quot;-12&quot;</td>
<td>1.0 % ± 0.9 %</td>
<td>± 1.4 %</td>
</tr>
<tr>
<td>14&quot;-22&quot;</td>
<td>0.8 % ± 0.6 %</td>
<td>± 1.2 %</td>
</tr>
<tr>
<td>24&quot;-38&quot;</td>
<td>0.6 % ± 0.5 %</td>
<td>± 1.0 %</td>
</tr>
<tr>
<td>40&quot;-58&quot;</td>
<td>0.5 % ± 0.4 %</td>
<td>± 0.8 %</td>
</tr>
</tbody>
</table>

### Wall thickness pig

Wall thinning results in impermissible stress increases which may limit pipeline service life or result in leakage caused by pitting. Wall thinning is defined as a reduction in wall thickness on the inner or outer wall surface of the pipe which may have been caused during metal sheet manufacturing or during pipeline operation.

Categories of wall thinning:
- Defect caused by milling (arose while material was hot)
- Surface defect (arose when material was cold)
- Mechanical reworking

We distinguish between diagnostic tools using the ultrasonic principle and those using the magnetic flux leakage method.

#### Ultrasonic wall-thickness pigs

These pigs use the pulse-echo principle, in which an ultrasonic pulse generated by a transducer runs through a standoff medium (e.g. oil), is partly reflected from the inner wall surface, passes through the pipe wall, is fully reflected from the outer wall surface and returns either as frontwall or backwall echo to the transducer. The transmission times of the echoes and the differences between frontwall and backwall echo are recorded. The transmission times of the echoes and sound velocity in the standoff medium and in the pipe wall allow exact statements to be made on wall thickness. With this procedure, the theoretical accuracy of measured wall thickness is +/- 0.2 mm. Using an appropriate number of ultrasonic transducers, sampling frequency and pig velocity, 100 per cent measurement of pipe wall thickness can be performed. Defects with a diameter of 10 mm and larger are detected. The depth of anomalies, however, can only be determined from a diameter of 20 mm upwards. As the ultrasonic method requires a coupling medium to overcome the distance between transducer and pipe wall, this system can only be applied in pipelines transporting fluids. In gas pipelines, the diagnostic system must be used in a fluid batch.

Ultrasonic inspection pigs consist of several interconnected units (battery, data recording and US unit plus transducer carrier). They can manage pipes with a bend radius of up to 1.5 x D. Currently, ultrasonic pigs with a size of between 6" and 56" for service pressures of up to 100 bar are available which, depending on their equipment, can inspect pipelines over a length of up to 500 km.
**MFL (Magnetic Flux Leakage) pig**

In this pigging procedure, a saturated magnetic field is produced by a permanent magnet and transmitted via magnetic brushes into the steel of the pipe wall. The magnetic flux which is deflected by defects (wall thinning, volume defects) and forced outside the pipe wall is recorded by sensors. The extent of flux leakage is in relation to the extent of the defect in the pipe wall. The magnetic sensors are evenly distributed at 8 mm intervals around the circumference. Due to the sampling frequency, wall anomalies are identified every 3 mm and indicated as percentages. MFL pigging enables only qualitative recording of wall thinning, i.e. it only identifies changes in wall thickness but does not supply any actual values.

The following defects can be identified:

- Material loss
- Laminations open towards one surface
- Larger-sized inclusions
- Sharp dents and bulges

Pitting (3 x s) is identified from a depth amounting to 20% of wall thickness. More extensive defects (> 30 x 30 mm) are identified as of a depth of 10% of wall thickness.

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**Online inspection pigs**

This type of inspection pig transmits the measured data via a cable out of the pipeline during the inspection process thus allowing immediate online evaluation. A UT (ultrasonic testing) pigging system in which an ultrasonic transducer scans the pipe wall through helical movements merits special mention. The forward movement can be controlled by a pump line. This system is applied to pipelines with diameters as small as 3” and small bend radii and is able to cover a distance of up to 30 km.

**Crack detection pig**

Cracks are defined as material separation mainly in perpendicular or diagonal direction to the pipe wall. Cracks represent lack of bonding or fusion which can be attributed to various root causes:

- fatigue cracks
- stress corrosion cracking
- hydrogen induced cracks
- laminations visible on wall surface.

Pipeline inspection for cracks is based on two familiar principles.
- Ultrasonic testing (UT) with oblique incidence technique
- MFL method

### UT crack detection pig

The pulse-echo UT method with a 45° incidence is applied. Depending on the pipeline diameter, a total of 480-896 transducers are installed on a transducer carrier in such a manner that half of them send their ultrasonic pulses clockwise and the other half counter-clockwise. This ensures that each volume element of the pipe wall is tested by several transducers. Cracks detected by the pig may either be external or internal cracks. The diagnostic system reliably detects defects with a length of 30 mm or longer and a depth of at least 1 mm. The system is designed in particular for the detection of longitudinal cracks as these -- due to stress conditions in pipes -- involve the largest hazards. This procedure has proved its worth in practice for a long time and, in the meantime, has become one of the standard test procedures. This type of inspection pig guarantees high accuracy, but, due to the ultrasound method, requires fluid as a coupling medium.

### MFL crack detection pig

This type of pig can be used to detect longitudinal cracks in particular in the vicinity of longitudinal welds in pipes. In contrast to conventional MFL pigs, pipe circumference is not magnetised by brushes but by four arms each equipped with separate magnets and brushes. The magnetic field is thus not oriented in longitudinal direction but is rotated by 90°, i.e. at right angles to the pipe axis. This facilitates detection of narrow, longitudinally oriented cracks. Cracks need to have a minimum length of 25 mm and a minimum depth of 50 % of the wall thickness and/or a minimum length of > 50 mm and a minimum depth of 25 % of the wall thickness to be detected. This type of inspection pig can be applied to pipelines made of ferritic materials transporting both gas and fluids as it does not require any coupling medium.

### Evaluation of test results:

#### Geometry pig

The following criteria are used to assess identified deformations:

- Static/dynamic stress
- Size or deviation from diameter
- Deformation geometry
- Extent of cold forming
- Surface defects
- Special features e.g. location in relation to weld

Each of the above aspects must be separately evaluated with a particular focus on fatigue stress acting on bulges exposed to dynamic loads, which can be evaluated in line with the AD Codes of the S series.

#### Wall thinning

Criteria for wall thinning are:

- Defects caused by manufacturing
- Defects caused by operation
- Localized small wall thinning
- Extensive wall thinning

In line with national standards, these defects can be assessed for acceptability by means of the comparison of surfaces or, in cases
involving extensive defects with little curvature, by means of the calculation procedure for plane areas. When applying the approach outlined in ANSI B 31 G or the RSTRENG method, a limiting curve, where the failure criterion is yield stress, is determined, and defects are classified and assessed on the basis of this curve. As a general rule, assessment of defect acceptability and pipeline design should always be based on the same standard.

Cracks

Depending on boundary conditions (component, geometry of anomalies, material performance, stress) crack propagation may result in localized failure leading to subsequent leakage or global pipe failure. As most pipelines have relatively thin walls, the reliability of the results provided by the pigging system is of utmost importance. In case of doubt, the probability of crack propagation must be determined through conservative calculations, and further action initiated. Direct comparison of the defect indicated by the pigging system and the exposed defect is a must to allow conclusions to be drawn with respect to other defects. When exposing a defect, it should be examined by suitable non-destructive test methods to ensure that it is still within the acceptable tolerances.

Repair of defects:

Generally, in buried underground pipelines, deformations such as bulges, dents and ovalizations are caused by additional loads. In most cases, they can be remedied by uncovering the pipeline and removing the point of constraint (rocks, insufficient packing). In special cases, dimensionally stable sleeves preventing "breathing" may be fitted around a defect. This measure may eliminate the need for the defective pipe segment to be removed, which would involve an interruption in operation.

When it comes to rehabilitating cases of wall thinning, sleeves, e.g. "hot sleeves" have proved their worth in practice. These sleeves are fitted around the defect using heat shrinkage and can absorb additional stress caused by internal pressure which the pipeline, due to material loss, would otherwise be unable to absorb. On such sleeves, the effectiveness of stress absorption is easy to verify. This measure allows interruptions in operation for rehabilitation purposes to be avoided.

Conclusions:

Inspection pigs have been used to examine pipelines for defects for almost 30 years. These inspections, in conjunction with qualified evaluation of pigging results, allow the operational strength of a pipeline to be ensured. Damage statistics by European pipeline operators clearly demonstrate the success of this procedure.