INSPECTION OF NON-PIGGABLE PIPELINES USING
ULTRASONIC “PIGLET” TECHNOLOGY.

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Synopsis

In this paper the following topics are covered.
- Development of on-line inspection of non-piggable pipelines
- What to do with the on-line information, and how to process them

1. INTRODUCTION

Pipelines have been laid worldwide for some 100-year’s, and more often than not, once operational, are left without any planned maintenance and the internal condition of these pipelines remains unknown. The normal management approach has been to prioritise on a failure consequence basis, selecting maintenance and inspection options on a failure mode and effect analysis.

Intelligent pig inspection systems are important tools to manage the integrity of the pipelines. An intelligent pig survey enables the operator responsible for the integrity of the pipeline, to assess the failure risk due to metal loss corrosion using the findings of the inspection survey. However, not all pipelines can be inspected using intelligent pig technology, due to the pipelines origin. In addition the inspection results are not directly available during the inspection process and therefore important decisions can not be made until the inspection report has been issued which can be in excess of two weeks dependant on size & length.

This paper discusses recent developments on the application of inspecting “non-piggable” pipelines using intelligent inspection pigs with on-line information.

2. NON-PIGGABLE PIPELINES

The history of pipeline pigging is interesting and it is reported that the first pigging operation took place in the year of 1870. During the first two years of operations, it was noticed that the flow began to decrease and the pumping pressure increased. This indicated that there were deposits building up on the internal walls, which reduced the pipeline diameter. In order to remove these deposits a bundle of rags tied and shaped into a ball was sent through the pipe with positive results.

At the time the pipelines were laid, pigging and inspection services were not thought of. Pipes were laid to transport the product and how the pipeline was constructed was of minor importance. This meant that the majority of these pipelines were built without launching/receiving facilities, consisting of varying diameters, mitred bends etc made normal pigging techniques impossible. Modern day pipelines are constructed using special design
codes (DEP’s) which include these launching/receiving facilities allowing Ultrasonic Inspection techniques to be utilised.

These codes are not commonly used for the relative short “connection” lines i.e. transport pipeline to the storage tanks, which meant that these lines, being of standard design were not-piggable. We observed that most of the problems occur in these relative short pipelines, due to lack of protection. In addition the ownership of these pipelines is not clearly defined and a lack of responsibility is observed. This implies that the integrity program for these pipelines is of less importance than the larger/longer transfer pipelines.

These connection lines are in most cases non-piggable because\(^2\)\(^3\):
- Pipe material (SS, ductile, exotic materials, GRE, coatings, linings)
- Bend restrictions (forged bends \(<1.5\ D\), one cut mitre bends, mitre bends, field bends, back to back bends)
- Off takes (un-barred tees, barred tees, sphere, Laterals)
- Offset junctions (Convergence angle, Bores), Diverters
- Valves (In-line block valves, check valves)
- Relative position of features (pig-signalling)
- Operation conditions (product, pressure, temperature, fluid velocity)
- No entrance point or single entry (availability of launchers and receivers)

Examples of such pipelines are:
- Loading lines
- Off-plot pipelines
- On-plot piping/pipelines
- Tankfarm connection lines
- Connection Piping in refineries
- Furnace piping (180 degrees 1D bends)

3. ON-LINE INSPECTION TOOLS

On-line inspection tools are commonly attached to an umbilical, which is used to transfer the inspection data to the inspection computer. Umbilical tools can be propelled into the pipeline by a fluid, pulled into the pipeline with a cable or crawl into the pipeline either by driven wheels or pneumatically in a similar way as a caterpillar. The inspection speed of most umbilical tools is much lower than that of free swimming intelligent pigs. The maximum distance, which can be inspected with umbilical tools, is dependent on the cable type and length and on the number of bends in the line. The friction in the bends, so called the “Capstan Effect”, increases the force needed to move the tool. The limiting factor is not the bend radius, but the cumulative number of degrees of bends the tool has to pass. The location of the tool in the pipeline and thereby the location of detected defects is in most cases determined by the length of the umbilical which has entered into the pipeline.

An advantage of umbilical tools is the real-time information on the measurements, which are available during the inspection via the umbilical. This enables a direct assessment of detected features and the possibility to stop and re-inspect certain sections of the pipeline. However these umbilical tools have the disadvantage of passing no more than approx. 7 bends, counting up to approx. 360 degrees. However, the recent developments within A.Hak
industrial services inspection department has made it possible to inspect the majority of “Un-piggable” pipeline sections as detailed above.

3.1 Development of the Piglet inspection system.

Based on our experience in inspection of pipelines, and the development & fabrication of such tools, we were approached by a major oil company and asked to develop a system, which was capable of inspecting furnace piping/tubes utilising the ultrasonic technique internally.

4 THE INSPECTION PIG “PIGLET”

The PigLet is consist of various modules, such as: ultrasonic measuring head, electronics, odometer, battery pack’s and glass-fibre modules. Either these modules are build into a Bi-directional pig (larger diameters) or are used as single modules with discs for the inspection of smaller diameters see figure below).

![Piglet diagram](image)

1. Pig transmitter
2. UT measuringhead
3. Electronics
4. Odo-meter
5. Batteries
6. Glass-fibre unit

Figure 2) 8” PigLet in-line inspection tool

The various modules are connected by flexible connectors to each other and the various modules are in more detail described below. The PigLet is pumped through the pipeline with product like an ordinary pig.

4.1 Pig Transmitter

For internal pipeline inspection it could be necessary to monitor the inspection tool’s exact location in the line during a run as well as to connect the data recorded by the inspection tool with well-known reference points above ground. For this our PigLet is equipped with a pig transmitter module is placed in the pig. The transmitter is sending a ultra low frequency signal which is detected by a hand held receiver to pin point the exact location.

4.2 Ultrasonic measuring head
In the ultrasonic measuring head consists of an ultrasonic transducer and a rotating “mirror”. The ultrasonic signal is transmitted to the pipe surface via the rotating mirror, and is received via this mirror as well.

A sound pulse is send from the transducer in the middle of the pipe in the direction of the pipe wall. From the inner wall the sound pulse will be partially reflected back to the centre of the pipe were it is detected by the same ultrasonic transducer. A part of the sound pulse at the pipe wall will not be reflected but will travel through the pipe steel and will be reflected back from the outer pipe wall. The time difference between both reflections (inner and outer pipe wall) determines the wall thickness at that point. The above explanation is graphically represented in the figure.

![Figure 3: explanation of the ultrasonic principle](image)

The UT sensor device uses a rotating mirror to enable to measure the complete circumference of the pipe wall. This enables the UT sensor device to scan the full 100% of the pipe wall. The step motor which rotates the mirror can be adjusted in various steps to the proper number measurements per revolutions.

To increase the detectability or measuring quality, different ultrasound sensors with different frequencies and crystal size can be used. The type of transducer depends on the size of the pipeline, size of defects which have to be detected, product and the cleanliness in the pipeline. Various measuring configurations can be made to optimising the system to comply with the clients wishes.

Prior to the job the measuring head will be prepared and calibrated, and will be re-calibrated prior to the inspection.

### 4.3 Electronics

The electronics on board of the PigLet are for powering and controlling the UT-sensor and for transmitting the gathered data via the glass-fibre cable.

The electronics also generated transducer trigger pulses, control the step motor rotation speed and detects the odo-meter wheel and clock position pulses.

The pipe wall reflections, the clock position and distance are subsequently send over the attached glass-fibre cable. The data send by consists out of:

- Complete Analog A-scan measurement send,
- inner and outer wall reflection
- distance measurement (X-coordinate -odometer pulses)
- the rotation angle data frequency modulation (clock position)
- The pitch (Y coordinate), Pressure and temperature could be send if these options are adapted to the inspection pig.
The print circuit boards are developed and made in house and are build with SMD components to minimise the size of the print circuit boards.

4.4 odo-meter

The odometer unit is equipped with distance measuring wheels. Two or four wheels are mounted in order to increase the distance measurement accuracy. The distance measurement software will calculate the proper distance by taking the highest pulse count of one of the wheels over a short fixed time period.

4.5 Batteries

Depending on the inspection speed and length of the pipeline the amount of batteries required can be calculated. The battery life time which is being placed into the PigLet will be not less than two times the inspection time duration.

4.6 Glass fibre unit

The fibre spool is located inside the Glass fibre unit, which is placed at the rear of the PigLet. Depending on the length of the pipeline the proper amount is spooled onto the spool canister. One end of the fibre is connected to the electronics inside the PigLet, the other end is connected to the fibre connection on the blind flange of the pig launcher. While propelling the PigLet through the pipeline the glass-fibre is being unwound from the fibre spool and will transfer all measured data to the data acquisition system outside the pipeline.

Figure 4: One module 20” PigLet, 1.5 D.
5 DATA ACQUISITION SYSTEM

The data acquisition system is specially developed for the PigLet system, used to capture the data and control the Piglet. The core features are high data storage capabilities per second, floating window, state-of-the-art computers, high resolution TFT screens.

The data acquisition system consists of two parts namely the hardware consoles and the software.

5.1 PigLet console

The PigLet console consists of the electronics and a high capacity computer with special developed AD-board to digitise and analyse the raw data. The computer is also used for analysing the raw data, controlling the PigLet speed, rotation and data communication between the PigLet and the Computer console. Storage of the data is done on hard disc and on tape. The console is built in a frame with two 19" flat screen monitors. One monitor shows the ultrasonic C-scan images and A-Scan images and the second monitor will be used to change the parameters during inspection without interference to the inspection. In addition, the system can be used for “on-line” post processing, and produce a valuable on-site report.

The upper menu bar shows the travelled distance, ultrasonic coverage, average coverage per pipe sections, clock position and others. The information is available on-line and is monitored by the inspection engineer. In the left upper window the wall thickness is displayed in colour ranges. In the left window below the internal radius is displayed while in the right windows the amplitudes are given used to discriminate between internal and external defects.

In the lowest figure the complete ultrasonic A-scan is displayed, including the multiple backwall echo’s used to determine accurately the remaining wall thickness.

5.2 software

The software used on the PigLet console has been developed in-house. The software is designed to show and give the field engineer direct information about the condition of the
pipe using the online ultrasonic C-scan information. In addition the travel speed, travelled distance and the rotation of the PigLet is given on-line. For optimising the quality of the data and the inspection coverage the measurement parameters can be changed on-line. Therefore the second monitor will be used. The software installed is designed to show on-line the measurements of the PigLet in four view pictures. The size and the place of the C-scan could be changed on-line this to obtain a better overview of i.e. the wall thickness measurements.

6 DATA ANALYSE SOFTWARE

After the inspection has been carried out two types of reports can be issued, namely the on-site report and the final report.

6.1 “on-site” reporting

The on-site report is an overview of the events taken place and an overview of the main defects, which are detected during the inspecting. The software has been developed to process the data just after the inspection has been carried out. This makes it possible to provide the client with a valuable report which allows the client to take immediately corrective actions. The content of such a limited report is given below:

- max. 10 worse anomalies including dig-up sheet, Min Wt, L, W, int/ext, distance, clock pos,
- velocity plot
- C-scan images of the complete line
- Operations & remarks
- Calibration information
- Service tickets

6.2 final reporting

The final report is compiled at our head offices. All data is processed on our post-processing computer systems and a detailed analysis is made of the defects or anomalies, which are detected during this post-processing. These defects are listed in a tabular format allowing the client to make a quick judgement of the major defects. In order to assist the client in visualising the type of defects and its size in comparison to the pipe circumference, colour scans (C-scans) are inserted in the report of these defects.

Figure 7: C-scan image of sever external pitting corrosion

Figure 8: actual defect which has been detected during the inspection
Above an example is shown of a typical ultrasonic C-scan image is given with corresponding found external corrosion pit.

![Image of ultrasonic C-scan](image)

**Figure 9**: Ultrasonic a-scan image, using multiple backwall echo approach for the most accurate wall thickness measurements.

Furthermore the actual A-scans from each pixel can be retrieved from these colour scans as well, thus allowing both the data processing engineer and the client to make a qualitative judgement on the data. This is extremely important for somewhat more corroded pipelines were signal levels can be deformed as a result of the rough pipe surface. At the same time it will show the difference between internal and external defects.

All anomalies found are reported in the final report, the report will contain, but not limited to, the anomalies as given in the table below, including a full geometry report:

<table>
<thead>
<tr>
<th>Anomaly Type</th>
<th>Measurement Type</th>
<th>Measurement Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>General corrosion</td>
<td>General wall thickness</td>
<td>Weld locations</td>
</tr>
<tr>
<td>Pitting/pinholes</td>
<td>Minimal wall thickness at anomalies</td>
<td>Distance plots</td>
</tr>
<tr>
<td>Laminations</td>
<td>Length and width of anomalies</td>
<td>Speed plots</td>
</tr>
<tr>
<td>Dents</td>
<td>Internal/external discrimination</td>
<td>Coverage</td>
</tr>
<tr>
<td>Ovalities</td>
<td></td>
<td>Coverage diagrams</td>
</tr>
</tbody>
</table>

![Image of waterfall plot](image)

**Figure 10**: Waterfall plot of A-scans used for analyses of the data.

![Image of ovality plot](image)

**Figure 11**: Ovality plot of calibration pipe, wall thickness changes can also clearly observed.

Should the client wishes to have an even more detailed analysis of some defects or areas of interest, the original raw data, which are still on tape, can be used. Correlation of previous inspections can be made to determine corrosion growth. In addition MaOP calculations of the found features will be calculated using the B-31G Code.
6.3 Defect assessment

After the inspection report is finished a defect assessment can be carried. The most commonly used method is ANSI B31.4/8. The results of these defect assessment methods is to calculate the maximum allowable operating pressure (MAOP) and determine the factor with the design pressure (DP).

The MAOP is said to be de-rated when the de-rating factor MAOP/DP is below 1. At lower MAOP/DP, deeper defect can be tolerated by a shift of the defect acceptance/rejectance curve to larger length and depth. MAOP/DP is one of the most important factors that determine defect detection and sizing requirements for inspection tools.

The critical defect depth is defined as the defect depth of localised corrosion with a maximum length according to its definition, that lies exactly on the acceptance/rejectance curve, see figure below.

The defect assessment curve and hence the critical defect depth is dependent on the method (ANSI B31.4/8, RSTRENG, SHELL92, DNV), the de-rating factor (MaOP/DP), the pipe diameter (D) and the pipe wall thickness (WT). The defect acceptance curve is also dependent on pipe steel grade and different equations on critical defect depth have to be derived.

<table>
<thead>
<tr>
<th>Pipeline Code</th>
<th>Location Class</th>
<th>Design Factor</th>
<th>Present MAOP</th>
<th>Calculaion Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASME B31.8</td>
<td>Loc.Class1 Div 2, 0.72</td>
<td>0.720</td>
<td>7000 [Kpa] = 70 [Bar]</td>
<td>ASME B31.8</td>
</tr>
<tr>
<td>API 5L- gradeB</td>
<td>Nominal Diam.</td>
<td>Nominal WT</td>
<td>SMUTS</td>
<td>SMYS</td>
</tr>
<tr>
<td>323.9 [mm]</td>
<td>7.8 [mm]</td>
<td></td>
<td>413 [N/mm2]</td>
<td>241 [N/mm2]</td>
</tr>
</tbody>
</table>

Figure 12: Graphically presentation of the MaOP calculation.

7. LIMITATIONS OF THE TOOL

The Piglet can be used for the inspection of relative short pipelines commonly know as being Non-piggable.

However also some limitations of the tool must be mentioned.

Due to the ultrasonic technology a liquid is required to transport the ultrasound through the pipe. Normally water is used, but also inspections using products such as crude, petrol, kerosene, NAFTA, etc has been successfully carried out. If the inspection has to be carried out in other type of product tests have to be carried out to determine the suitability of the product.

Due to the mechanical design of the measuring module (one sensor and rotating mirror) the capturing of data in bends is limited due to misalignment. Data coverage range from 10 to 100 percent depending on diameter and bend radius.
All ultrasonic tools have a problem with the scattering of the ultrasound by debris and gasses in the pipeline. Therefore a good cleaning and a fully filed line is required for the optimum inspection results.

Our piglet system is limited in inspection length due to the length of the glass fibre, depending on the diameter the maximum length to be inspected is 12 km, however for larger diameters a spool of 30 km has been developed on special request of a client. It must be noted that a pipeline could be inspected from both sites which means that 24 km (2 * 12 km) can be inspected.

In addition you should keep in mind that due to the mirror design the inspection speed is relatively low (200 up to 1000 m/h) depending on diameter and coverage required.

Specifications of the PigLet are given in the next chapters.

8 EQUIPMENT SPECIFICATIONS

Due to the fact that the transducer/mirror combination can be changed in order to meet the specific conditions of the pipe which has to be inspected, a broad range of possibilities exists, which is summarised in the table below.

**Ultrasonic performance:**

<table>
<thead>
<tr>
<th>Wall thickness</th>
<th>: 2 mm and larger</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average wall thickness accuracy</td>
<td>: 0.15 mm</td>
</tr>
<tr>
<td>Average inner radius accuracy</td>
<td>: 0.08 mm</td>
</tr>
<tr>
<td>Measurements per revolution</td>
<td>: 72 – 576 mpr</td>
</tr>
<tr>
<td>Sound</td>
<td>: ultrasound with frequency 3 – 5 MHz</td>
</tr>
<tr>
<td>Data storage</td>
<td>: All individual A-scans are recorded</td>
</tr>
<tr>
<td>Bend</td>
<td>: No limitations to the number of bends</td>
</tr>
<tr>
<td>Radius of bends</td>
<td>: R = 1D bens and larger</td>
</tr>
</tbody>
</table>

**PigLet inspection range:**

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Max inspection length</th>
<th>Inspection speed</th>
<th>Bend radius</th>
<th>UT coverage</th>
</tr>
</thead>
<tbody>
<tr>
<td>4”</td>
<td>2 km</td>
<td>1000 m/h</td>
<td>1.5D 90°</td>
<td>200 %</td>
</tr>
<tr>
<td>6”</td>
<td>6 km</td>
<td>1000 m/h</td>
<td>1.5D 90°</td>
<td>150 %</td>
</tr>
<tr>
<td>8”</td>
<td>12 km</td>
<td>1000 m/h</td>
<td>1.5D 90°</td>
<td>100 %</td>
</tr>
<tr>
<td>10” - 18”</td>
<td>12 km</td>
<td>750 m/h</td>
<td>1.5D 90°</td>
<td>&gt; 100 %</td>
</tr>
<tr>
<td>20” – 36”</td>
<td>12 km</td>
<td>200 m/h</td>
<td>1.5D 90°</td>
<td>&gt; 100 %</td>
</tr>
<tr>
<td>40” – 48”</td>
<td>12 km</td>
<td>200 m/h</td>
<td>1.5D 90°</td>
<td>&gt; 100 %</td>
</tr>
<tr>
<td>Furnace PigLet</td>
<td>1 km</td>
<td>500 m/h</td>
<td>1.0D 180°</td>
<td>&gt; 100 %</td>
</tr>
<tr>
<td>4”</td>
<td>1 km</td>
<td>500 m/h</td>
<td>1.0D 180°</td>
<td>&gt; 100 %</td>
</tr>
<tr>
<td>6”</td>
<td>1 km</td>
<td>500 m/h</td>
<td>1.0D 180°</td>
<td>&gt; 100 %</td>
</tr>
<tr>
<td>8”</td>
<td>1 km</td>
<td>500 m/h</td>
<td>1.0D 180°</td>
<td>&gt; 100 %</td>
</tr>
</tbody>
</table>
Defect detection:

<table>
<thead>
<tr>
<th>Feature</th>
<th>Yes (POI&gt;90%)</th>
<th>No (POI 50%)</th>
<th>May be (50% &lt; POI &lt; 90%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal/external discrimination</td>
<td>&gt;90%</td>
<td>&gt;90%</td>
<td>&gt;90%</td>
</tr>
<tr>
<td>Metal-loss feature</td>
<td>&gt;20mm</td>
<td>&lt;10mm</td>
<td>&gt;10mm</td>
</tr>
<tr>
<td>Metal-loss pipe mill feature</td>
<td>&gt;20mm</td>
<td>&lt;10mm</td>
<td>&gt;10mm</td>
</tr>
<tr>
<td>Midwall feature</td>
<td>&gt;20mm</td>
<td>&lt;10mm</td>
<td>&gt;10mm</td>
</tr>
<tr>
<td>Grinding</td>
<td>&gt;20mm</td>
<td>&lt;10mm</td>
<td>&gt;10mm</td>
</tr>
<tr>
<td>Gouge</td>
<td>&gt;20mm</td>
<td>&lt;10mm</td>
<td>&gt;10mm</td>
</tr>
<tr>
<td>Dent</td>
<td>Depending on diameter, dents of approx. 2 mm depth can be detected</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dent with metal-loss</td>
<td>Depending on diameter, dents of approx. 2 mm depth can be detected</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spalling</td>
<td>Will be seen as &quot;Metall loss feature&quot; not recognizable as spalling</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Axial crack</td>
<td>&gt;20mm</td>
<td>&lt;10mm</td>
<td>&gt;10mm</td>
</tr>
<tr>
<td>Circumferential crack</td>
<td>&gt;20mm</td>
<td>&lt;10mm</td>
<td>&gt;10mm</td>
</tr>
<tr>
<td>Eccentric pipeline casing</td>
<td>Depending on diameter deviation of 2 mm can be detected.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleeve repair</td>
<td>Depending on metal contact</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fitting</td>
<td>Welding will be seen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valve</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tee</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bends (5D or less)</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Defect detection and sizing accuracy for metal-loss features in body of pipe

<table>
<thead>
<tr>
<th></th>
<th>General Metal-loss</th>
<th>Pitting</th>
<th>Axial Grooving</th>
<th>Circumferential Grooving</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth at POD=90%</td>
<td>0.3 mm</td>
<td>0.3 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth sizing accuracy at 80% confidence</td>
<td>0.15 mm</td>
<td>0.15 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Width sizing accuracy at 80% confidence</td>
<td>10 mm</td>
<td>5 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length sizing accuracy at 80% confidence</td>
<td>10 mm</td>
<td>5 mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The probability of detection is graphically represented in the below figure.

9 REFERENCES

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