**Paper 31**

# PIPE FEATURES IDENTIFIED DURING INLINE INSPECTION USING MFL PIGS

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## ABSTRACT

A safe and economical operation of pipelines requires extensive integrity tests. For that purpose pig inspections have proved to be an efficient tool for the systematic analysis of pipeline integrity in recent years. In particular for detection of corrosion based wall thickness reduction, magnetic flux leakage tools (MFL) are commonly used. Modern MFL pigs detect wall thickness reductions with high accuracy and deviations of small amount.

Line pipe material is delivered by pipe manufacturers who have to fulfill specifications. During the pipe manufacturing process certain cosmetic repairs are permitted in the tolerance frame of technical delivery conditions. Mill made features/repairs are examined and registered by the pipe supplier. Once in operation, in-line inspections (ILI) of the pipeline are carried out. In some cases, mill made features and possible repairs as previously accepted in the mill, cannot be identified in the sequel of assessments based upon MFL data. Signals where the discrimination between mill related defects (e.g. grindings) and corrosion based wall thickness reduction is not possible, lead to a need of further investigations regarding a certain characterization of these indications. Those actions (e.g. excavation and nondestructive tests) are often time and cost intensive.

In the frame of a research project within the European Pipeline Research Group (EPRG) a systematic collection of structural defects has been carried out, which are related to the line pipe manufacturing process of high strength steel tubes and which are possibly able to cause indications during inline inspection. The first part of the study presents an overview of typical defect types, which are classified as common for specific tube types by literature. Secondly, the results of a voluntary questionnaire to the EPRG members are summarized. The questionnaire was distributed to gather data in the range from manufacturing up to the operating conditions of onshore-pipelines. This was done for pipe manufacturers and for pipeline operators. The extracted database shows a range of MFL inspection results in comparison with further examination on the excavated pipe at these positions, in particular for cases, where mill related defects were found.

## 1. INTRODUCTION

A safe and economical operation of pipelines requires extensive integrity tests. Already the line pipe material is subjected by several integrity checks in the pipe mill. The specialized pipe manufacturers have to fulfill specifications. In the pipe manufacturing process, every pipe is examined in the frame of quality control processes. If a geometric inhomogeneity has been detected, e.g. by using Ultrasonic Testing, minor repairs are permitted in the tolerance frame of technical delivery conditions. Such mill related features are commonly registered by the pipe supplier before pipe delivery.

After laying and during the pipeline's lifetime, extensive inspections are carried out to validate the structural integrity. Inline inspections have been established as a very efficient tool for the systematic analysis of the pipeline integrity. Such inline inspections (ILI) have been proved to provide reliable results considering deviations in pipe geometry, pipeline mapping or metal loss in the pipe wall. In particular for detection of corrosion based wall thickness reduction, the most common tools are magnetic flux leakage (MFL) devices. Modern MFL tools detect wall thickness reductions in high accuracy and deviations of small amount.

However, despite the high performance of the ILI methods, in some cases mill made features and possible repairs, as previously accepted in the pipe mill, may not be identified in the sequel of assessments based upon MLF data. Signals where the discrimination between mill related defects (e.g. grindings) and corrosion based wall thickness reduction is not possible, are in case of doubt classified as corrosion. Further investigations regarding characterization of these indications, are commonly time and cost intensive (e.g. excavation and nondestructive tests). In some cases, the classification of individual MFL indications is possible by comparing with the mill feature protocols, but that requires also a high time and cost effort for clarification between pipe supplier, pipeline operator and ILI service provider. Therefore, it would be helpful to increase the probability of identification with view on mill related defect types, to distinguish more precisely between those ones and defect types caused by shipment, construction or operation, in order to avoid unnecessary excavations.

In the following a collection of structural defects is presented which are related to the line pipe manufacturing process of steel tubes and which are possibly able to cause indications during inline inspection. Subsequently the results of a voluntary questionnaire to the EPRG members (European Pipeline Research Group) are summarized. The questionnaires included pipe manufacturing up to the operating conditions of on-shore pipelines by involving European pipe mills as well as European pipeline operators.

## 2. MANUFACTURING RELATED DEFECTS

The first part of this study describes the most relevant manufacturing related defects, which might arise in the frame of the production process from the production of semi-finished products (e.g. plates, strips or ingots) to the manufacturing of the pipe body using different methods (e.g. seamless, ERW and SAW/Spiral pipes). All descriptions are based on literature [1], which provides a comprehensive overview on common mill related defects.

### 2.1 Plate Defects

Defects that might occur at plates and pipes are summarized in the following. Some exemplary pictures are given in **Figure 1**.

Segregations are concentrations of non-metallic material in the mid-wall position including carbon and manganese rich bands. They can be microscopic or macroscopic. In the former, the segregation occurs within individual grains, between dendrite arms. Macroscopic segregation on the other hand results in concentration gradients over large distances. This latter type may cause problems in the processing chain due to unexpected ductility differences and if it remains until later stages may cause non-uniform properties, local differences in composition leading to corrosion problems, embrittlement and sections of the material that are out of specification [2].

Indentations are depressions in the pipe surface. The grain structure in the steel follows the outline of the depression.

Laminations are an internal metal separation creating layers which are usually marked by concentration of non-metallics. They are generally orientated in parallel to the plate surface.

Laps are a flap of metal lying flat on the plate surface, usually with a trapped residue of oxide or scale beneath it.

Slivers are thin elongated flaps of metal rolled into the plate surface, often with oxide or scale trapped beneath it. Slivers may be the result of a billet defect that carries through the hot rolling process.

Inclusions are non-metallic inclusions in the plate wall. Inclusions may cause subsequent cracks in the pipes subjected to internal pressure or bending moment.

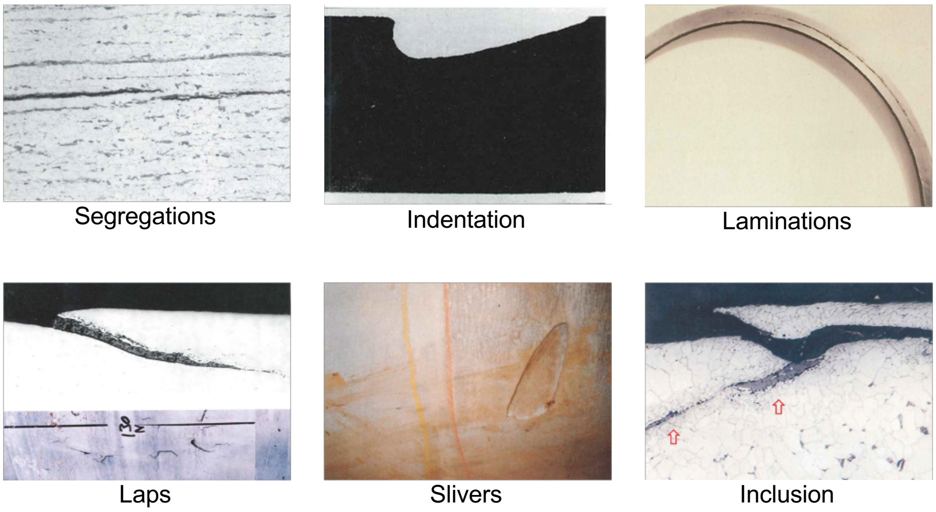


Figure 1: Plate defects [1]

## 2.2 Seamless Pipe Defects

According to [1], typical seamless pipe defects are: laps, slivers and rolling marks. Furthermore, linear surface defects (e.g. quench cracks) can occur on the inner and outer surface as single events or in groups.
Surface Defects appear at the pipe surface (**Figure 2**). The predominant direction of the defect structure is normally the rolling direction, which must not be necessarily the longitudinal direction of the pipe. Most defects of that type are structurally not significant, but they may act as an initiation point for pitting corrosion [1].

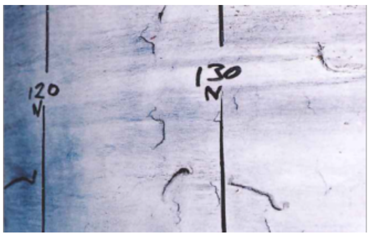

Figure 2: Surface defects related to seamless pipes [1]

## 2.3 ERW Pipe Defects

ERW (Electric Resistance Welded) pipe defects are often related to the longitudinal ERW weld, see **Figure 3**.

Seam Overtrim, Seam Undertrim, Seam Misplaced trim
The flash in EW pipe is removed via scraping tools for bead removal and flash removal (internal and external) after welding. Excess scraping may cause seam overtrim, which is axial groove or depression on the line of the seam weld. Seam undertrim is a linear feature standing proud of the pipe surface on the line of the seam weld, caused by insufficient weld flash removal. Misplaced (or missed) trim is where the trimming tool is not aligned on the bond line and a groove is left to one side of the bond line. Some of the flash may be left untrimmed.

Aligned inclusions, e.g. oxides along the centerline of the weld, can lead to a decrease of the weld strength.

Lack of fusion is an axial, crack like, planar fault at the midpoint of the weld. This effect can be caused by incorrect welding parameters.

Beyond the defects mentioned above, hook cracks were a phenomenon sometimes occurring at very early ERW processed pipes. A hook crack is a lamination that exists in the weld zone that curves, or hooks, towards the inside or outside surface of the pipe. Whilst hook cracks do not occur in modern pipe produced using high quality strip, they belong to the types of defects that can occur in old pipelines and may be detected by crack detection tools.

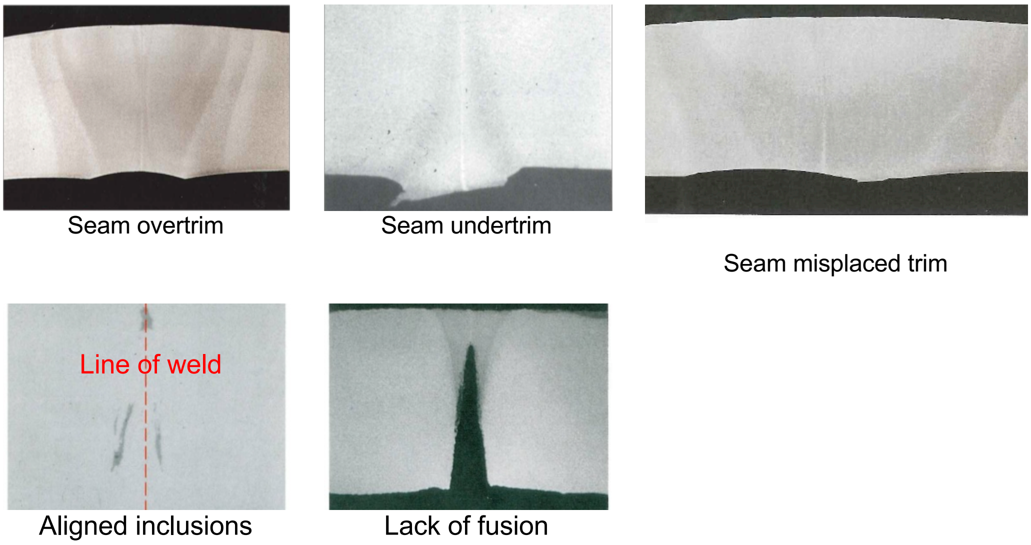


Figure 3: Defects related to ERW pipes [1]

### 2.4 SAW/Spiral Pipe Defects

Hot cracks are solidification cracks in the centre line of the weld bead. They tend to occur towards the end of a pipe in the last metal to solidity.

Porosities are voids in the weld metal which can be isolated, clustered or in the form of piping.

An undercut is a linear defect at the edge of the internal or external weld bead.

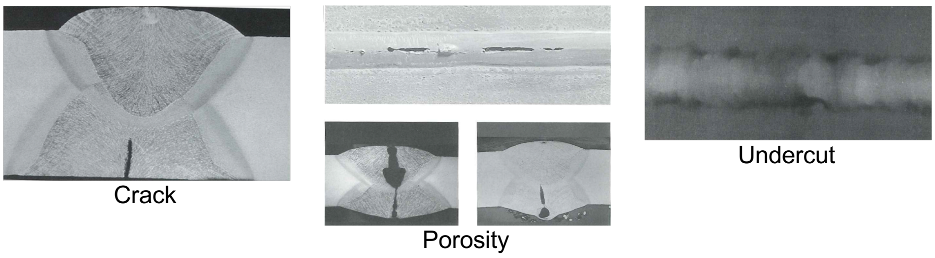


Figure 4: Defects related to SAW/Spiral pipes [1]

### 2.5 Grindings

Pipes which are affected by features listed above can be repaired by grinding within the wall thickness tolerances. The maximum dimensions of the grinding surface and of the depth depend on technical delivery conditions, e.g. according to [7].

### 2.6 Mechanical Damage

Mechanical damages are typically gouges and dents. They are irregular scores and gouging of the metal surface may be contained within a dent (**Figure 5**).

Figure 5: Gouge and dent [1]

## 3. MAGNETIC FLUX LEAKAGE INSPECTION TOOLS FOR PIPELINE INTEGRITY

The major tasks of in-line inspection tools in general are the detection, localization and characterization of potential defects and flaws along a pipeline. **Figure 6** shows an overview of inspection types, which are typical for specific integrity analyses, e.g. with focus on geometric aspects, metal losses, cracks or on the mapping and evaluation of the pipeline route.

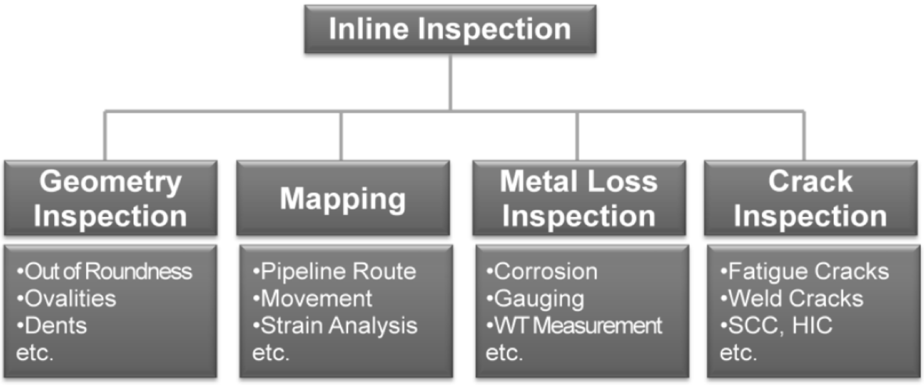


Figure 6: Inline inspection grouped by targeted analysis [3]

There is a huge choice of ILI-tools on the market today. Each of them has specific characteristics. **Figure 7** shows the most common inspection techniques grouped by measuring principle.

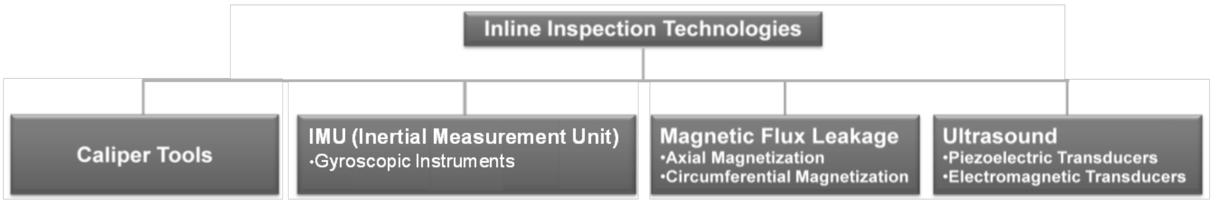


Figure 7: Inline inspection tools grouped by measuring principle

Caliper tools are related to geometric inspections and hence suitable to detect ovalities or dents. IMU (Inertial Measurement Unit) techniques are applied for mapping the pipeline route and for detecting curvatures or deflections of the pipe string. Magnetic Flux Leakage tools (MFL) are commonly used for the detection of wall thickness losses, e.g. corrosion. It is also possible to detect flaws with the MFL technique, but the ability for detection depends on the angle between the flaw and the direction of the magnetic flux lines. Considering this fact, different approaches exist for the MFL inspection tools. While tools with magnetization in axial direction of the pipe are able to detect circumferential flaws, tools with circumferential magnetization are basically able to detect flaws in the length direction of the pipe wall. MFL measuring methods have been proven as very reliable for detection of wall thickness losses and have become a standard tool for inline inspection. Ultrasonic inspection tools are designed to detect flaws, the methods considering their predominant direction in the pipe wall. Hence, ultrasonic inspection tools are rather applied on integrity issues where crack related failure mechanisms are expected. Since the ultrasonic probes need a liquid coupling to the inner surface of the pipe wall, this method requires a huge effort especially on gas pipelines. Therefore, ultrasonic inspections are less common as MFL inspections for gas pipelines. As an exception EMAT (Electromagnetic Acoustic Transducer) technology may be mentioned, which can be used without coupling and therefore is applicable to gas pipelines. However, for quality checks in the pipe production, Ultrasonic measurements represent a standard inspection tool.

With view on the main objective of this study, which means to improve the distinction between mill related anomalies and corrosion defects, the MFL principle is focused in the following. For a deeper discussion and some comparative aspects, the study refers to the specific literature (e.g. [3] or [4]) and to the current specifications for inline inspection, e.g. [5] or [6].

The information provided by MFL reports basically consists of geometric data regarding a flaw or anomaly found, namely:

- Length / depth / width
- Circumferential and longitudinal position

This data is then used to analyze the structural integrity of a pipeline systematically. Integrity assessment and fitness-for-purpose investigations in turn play an important role in defining and optimizing maintenance and possible rehabilitation procedures. Important specifications within this context are the probability of detection (POD) the probability of identification (POI) and the measurement accuracy (confidence level). A detected feature must be characterized and in the ideal case all manufacture related features (e.g. grindings) and all operational features (e.g. corrosion, gouges or indentations) can be distinguished clearly. The better this can be done, and the better the accuracies of the applied inspection technology are, the better will be the quality and usefulness of the fitness-for-purpose analysis [3].

The features or flaws in the pipe wall, which can be detected using MFL tools with a high POD (Probability of Detection) of 90 % must have a minimum dimension in order to be picked up by the inspection tool utilized. The minimum specified depth of feature to ensure detection is 10 % WT for MFL high resolution and 5 % WT for MFL extra high resolution. Typical values regarding the minimum defect diameters of a feature to be detected are between 1 and 3 x WT [3].

## 4. EVALUATION OF QUESTIONNAIRES

Within this study two questionnaires were created and sent to several European pipeline operators and European pipe suppliers, all of which were members of EPRG.

The enquiry for the pipe manufacturers aimed at identifying typical aspects of common practice regarding mill related features and associated repairs. The questionnaire addressed all mill defects, which were identified to potentially occur according to the literature (see **Section 2**). Some of the described defects are related to specific production methods and are therefore assigned respectively.

The enquiry for the pipeline operators was carried out to obtain some practical experience regarding excavated defects in the field (e.g. grindings), which have been indicated as operational (e.g. corrosion) by the inline inspection before. The feature definition in this questionnaire corresponds to the specifications for ILI inspection according to [5].

### 4.1 Evaluation of Pipe Suppliers Data

Feedback of pipe suppliers gives an overview about the common practice of modern pipe production. Since the collected data represent the current situation, a difference to formerly applied methods on vintage pipes cannot be excluded.

The data of SAW/Spiral pipe suppliers are summarized in **Table 1**. As expected, the mill defects caused by seamless production process do not occur in SAW/Spiral production processes. The common practice for features within the tolerance according to the corresponding specification is either to remain the feature in the pipe or the pipe will be repaired (cosmetic grinding). All other defects out of these tolerances are unacceptable and the pipes will be cut or rejected.

Table 1: Summary of the pipe suppliers' data regarding mill defects (SAW/Spiral pipes)

| SAW features | NDT testing | remarks |
|---|---|---|
| Segregation | UT | > 100 $mm^2$ → cut off |
| Indentation | Visual | depending on min. wall thickness cosmetic grinding or cut off |
| Lamination | UT | > 100 $mm^2$ → cut off |
| Slivers | Visual | depending on min. wall thickness cosmetic grinding or cut off |
| Surface defect | Visual | > 0.5 mm → cosmetic grinding or cut off |
| Crack in the weld | UT | repair not allowed |
| Cracks in the base material | UT | repair not allowed |
| Porosity | UT | > 3.2 mm → repair by manual welding |
| Undercut | UT | > 0.4 mm → repair by manual welding |
| Gouge | Visual | within tolerance |
| Dent | Visual | within tolerance |
| Grinding | Visual | acc. min. WT → cosmetic grinding |

The data of ERW pipe suppliers are summarized in **Table 2**. Similar to SAW/Spiral pipes, the features within the tolerance according to the corresponding specification are either accepted or the pipe will be repaired (cosmetic grinding). All other defects out of these tolerances are unacceptable and the pipes will be cut or rejected.

Table 2: Summary of the pipe suppliers' data regarding the mill defects (ERW pipes)

| ERW features | NDT testing | remarks |
|---|---|---|
| Segregation | UT | cut off |
| Indentation | Visual | depending on min. wall thickness cosmetic grinding or cut off |
| Lamination | UT | cut off |
| Laps | Visual | depending on min. wall thickness cosmetic grinding or cut off |
| Seam overtrim | calliper | depending on min. wall thickness → cut off |
| Seam undertrim | calliper | grinding |
| Gouges | Visual | cut off |
| Grinding | UT | acc. min. WT → cosmetic grinding |

The data of Seamless pipe suppliers are presented in **Table 3**. Typical seamless pipe defects are: laps, slivers or rolling marks. The features within the tolerance according to the corresponding specification are either accepted or the pipe will be repaired (cosmetic grinding). All other defects out of these tolerances are unacceptable and the pipes will be cut or rejected.

Table 3: Summary of the pipe suppliers' data regarding the mill defects (seamless pipes)

| seamless pipe features | NDT testing | remarks |
|---|---|---|
| Indentations | UT, MFL, VT | depending on depth grinding |
| Slivers | UT, MFL, VT | depending on depth grinding |
| Laps | UT, MFL, VT | depending on depth grinding |
| Inclusions | UT | cut off |
| Surface defects | UT, MFL | depending on depth grinding |
| Dents | VT, UT | cut off |

## 4.2 Evaluation of Operators Data

The evaluation of the operators' data focused on the probability of identification (POI) of defects, on the defect dimensions (length, width, depth) and on the defect position (internal/external). The results are summarized in **Table 4**. It must be noted that the database is not representative to assess the accuracy of ILI in general, since these cases were specially selected by the pipeline operators to be only those ones, where discrepancies between ILI result and excavations had been observed. The great amount of 'matched' cases is not included in the data base. Therefore, a reliable statistical analysis cannot be carried out. The given evaluation represents rather a characterization of the extracted database.

Probability of identification with focus on mill defects
The results in Table 4 show that, if a mill anomaly was predicted as such by ILI, then the result was always confirmed by the NDT results while excavation. In contrast, a range of features were indicated as corrosion by ILI, which was not confirmed as such due to the subsequent excavation. In total, an amount of 138 features (that means 85 % of the data investigated) had been stated as corrosion or metal losses, which were finally proved as mill related anomalies later. Especially for such cases, an improved probability of identification (POI) would contribute to a reduction of unnecessary excavations.

Defect position (internal/external)
The defect position (inside or outside) was relatively accurately predicted, except of one provided in-line inspection data with 62 measurement positions in which the predicted defect position was inverted to the actual defect position (see **Table 4**).

Defect dimension (length/width, depth)
The predicted and actual defect length and width were partly very different, but no conspicuous tendencies could be found. Regarding the defect depth the major amount shows a moderate scatter, where the majority of defects was overestimated by the ILI measurements (defect depth inspection > defect depth excavation). The accuracy of mill defect prediction seems to be independent of the actual defect depth. But due to the small database of confirmed mill defects, this evidence can only be considered as a tendency.

Table 4: Evaluation of the operators' data regarding the prediction accuracy of detected features (feature identification and feature position)

| | **inspection** | **analogy** | **excavation** | **quantity** | **fraction** |
|---|---|---|---|---|---|
| **feature identification** | mill anomaly | = | mill anomaly | 9 | 5% |
| | girth weld anomaly | = | girth weld anomaly | 3 | 2% |
| | lamination | = | lamination | 1 | 1% |
| | dent | = | dent | 1 | 1% |
| | longitudinal weld anomaly | = | mill anomaly | 1 | 1% |
| | metal loss | ≠ | mill anomaly | 24 | 15% |
| | corrosion | ≠ | mill anomaly | 114 | 70% |
| | corrosion | ≠ | indentation | 7 | 4% |
| | corrosion | ≠ | gouging | 2 | 1% |
| | | | Σ | 162 | 100% |
| **feature position** | external | = | external | 33 | 21% |
| | internal | = | internal | 7 | 5% |
| | external | ≠ | internal | 72 | 46%* |
| | internal | ≠ | external | 3 | 2% |
| | - - - not given - - - | | | 47 | 26% |
| | | | Σ | 162 | 100% |

* Results strongly depend on one case: 1 ILI measurement on 62 positions

Construction defects
In 3 cases, ILI indicated girth weld anomalies were confirmed by the excavation. The origin couldn't be reliably verified in the frame of this research. As experience shows, such anomalies may be carried out on purpose in the construction phase, e.g. by grinding to reduce High-Low situations at girth welds. In 2 cases, gouges were found by excavation instead of the indicated corrosion. Whether these were inserted by laying or later during operating conditions couldn't be resolved. As a result, the distinction of constructional defects from operating defects could not be solved in this study, even though they may be a cause for indicated anomalies during inline inspection.

Initiated repairs with focus on the given database

The amount of initiated repairs couldn't be extracted from the given database. Basically, the evaluation of the structural integrity depends on the applied assessment criteria. Hence, a focused discussion on this aspect with reference to the obtained data could not be carried out in the frame of this work. In case of serious impairment on the pipe strength, an operator will certainly apply appropriate actions to ensure the pipeline safety.

## 5. CONCLUSION

In the frame of this study, a systematic collection of structural defects has been carried out, which are possibly related to the manufacturing process of high strength steel tubes and which are able to cause indications during subsequent inline inspections.

The results of voluntary questionnaires to several members of the European Pipeline Research Group (EPRG), shows a range of common testing procedures related to the production process and provides a frame of 'practical experience' regarding operational integrity aspects.

- The first part of the collected data gives an overview on the handling with structural defects, which potentially occur during the manufacturing. The results show, that production related defects are always classified as unacceptable when they are out of the tolerances given by corresponding specifications. Those pipes will be cut or rejected. Only slight structural defects, which are within the given tolerances, remain either in the pipe or the pipe will be repaired (e.g. due to cosmetic grinding). The collected data represent the present situation. A difference to formerly applied methods on vintage pipes with relation to some older delivering specifications cannot be excluded.

- The second part of the data comprises a total of 162 datasets, provided by several European pipeline operators. The extracted data show results of MFL indications compared with on-site examination on the excavated pipe at these locations, specifically for cases where mill related defects were found. The collected cases are directly linked to recent inspection projects with European grid operators. It is clearly noted, that the given results are based on specially selected cases regarding the focus of this study and are hence not representative for the accuracy of inline-inspection tools in general. The findings represent an informational extract of practical experience and are not to be seen as a kind of benchmark. The range of the collected data shows, that mill anomalies, which were predicted as such by ILI, were always confirmed by the NDT results on-site during excavation. In contrast, a range of features were indicated as corrosion by ILI, which were not confirmed as such due to the subsequent excavation.

The results show in a positive way, that inspections regarding corrosion are on the safe side. In case of doubt, a feature will be classified as corrosion, so that real corrosion will not stay undetected. Once a feature has been classified as corrosion, the growth rate will be monitored further over the pipeline's service time. On the other hand, a range of defects seems to be classified as corrosion, although subsequent investigations may show that they are mill related defects.

This conclusion leads to potential chances for the future. It refers to the question, if the available database might contribute to an improvement of automated signal interpretation algorithms for inline inspections. If the distinction between mill related anomalies (e.g. grindings) and corrosion related wall thickness losses would be improved, a range of time and cost extensive measures could be avoided, e.g. subsequent excavations or discussions between the involved parties.

## 6. ACKNOWLEDGEMENTS

The authors would like to thank the European Pipeline Research Group and their members for their support within this work.
The paper was presented at the Pipeline Technology Conference (PTC), Berlin 2016 [8]. The authors wish to express their gratitude to the organising team of PTC for permitting publication at this 3R volume.

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