The direction of metrological assurance development for pipeline ILI in the framework of conformity assessment

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THE ARTICLE IS DEVOTED to the main development directions of metrological assurance for ILI(ILI) in Transneft within the industry system for assessing conformity. A brief overview is given of the results of analysing international, Russian, and American standards establishing the requirements for classifying pipeline defects. Methods of guaranteeing reliable measurement results for ILI in the Russian Federation are examined, and specifically the main features of the concept of metrological assurance for ILI in Pipeline Transport Institute (hereafter referred to as the Concept).

The steps necessary to implement the Concept are enumerated: mandatory metrological requirements, measurement methods, standard defect measures, and ILI tools (measuring instruments), and information about the testing areas is provided for ILI tools in Russia and the USA. This article presents the results of Pipeline Transport Institute’s work setting-up a reference database of defects and developing regulatory documents. The expected results of implementing measures in accordance with the Concept are also stated, including obligatory metrological requirements for measurements taken during an ILI, a reference database of standard defect measures with specified metrological characteristics, a normative database for metrological evaluation of ILI tools, and an accredited metrological testing area for the tools. The positive effects of implementing the Concept in Russia are described, in particular regarding consumer protections from unreliable ILI results.

Key words: in-line inspection, ILI tool, metrological assurance, obligatory metrological requirements, conformity assessment

Reliability of measurements taken during an ILI

One of the conditions for ensuring pipeline reliability and preventing accidents is monitoring the technical state of trunk pipelines. The most effective method of monitoring is ILI(ILI) which helps to obtain information about defects, welds, and features in pipelines and their location through the use of ILI tools. The geometric dimensions of the defects calculated during an ILI and their subsequent interpretation are used as the initial data to calculate a pipeline’s strength and durability, and the time-frame for eliminating any defects that are found. Determining defect parameters with minimum error is the most important aspect of ensuring the pipeline’s reliability.

The accuracy of pipeline calculations is ensured by the reliability of the results of measurements taken during ILI. For more than 10 years the Pipeline...
Transport Institute has been performing calculations to determine the safe service life of pipelines in long-term operation (over 30 years) according to its own methods, as well as according to American and European standards NG-18, ASME B31G-2009, DNV RP-F101, API 579/ASME FFS-1, and BS 7910:2013.

As a rule, manufacturers of ILI tools in Russia, Europe, and the United States form their metrological assurance only by means of calibration, and certificates of calibration are issued as approvals. It is therefore impossible to confirm the reliability of their measurement results with reference to national standards. Also, in the absence of generally accepted ‘rules’ or mandatory metrological requirements, it is impossible to assess the compliance of measurement results obtained during an ILI.

In the Russian Federation, measurement accuracy is guaranteed by the provisions of the Federal law On Assurance of Measurement Uniformity and the regulations it contains. Measurement accuracy is achieved by:

- establishing and complying with mandatory metrological requirements, including indicators of measurement accuracy;
- applying the regulatory framework (international and national standards);
- applying standards based on national standards;
- testing measuring tools to approve their type;
- calibrating measuring tools;
- using measurement techniques.

The Concept of metrological assurance for ILI

To implement these measures, the Pipeline Transport Institute developed the Concept of metrological assurance for ILI within the industry’s conformity assessment system, which includes the requirements of the above-referenced Federal law. So far, measurements taken during ILIs have not been included within the scope of state regulation ensuring measurement uniformity. To solve this problem, the Pipeline Transport Institute developed compulsory metrological requirements based on the experience of previously conducted studies in the field of metrology. Accuracy indicators were thus established for measuring:

- flow cross-section diameter;
- distance travelled;
- pipe wall thickness using ultrasonic and magnetic methods, etc.

These mandatory metrological requirements have been introduced to Federal regulations and the Safety rules for hazardous production facilities of trunk pipelines, which is a binding regulatory document at the Federal level in the Russian Federation.

A brief overview of the requirements for classifying defects

In order to establish unified requirements for classifying defects, taking into account standard practices in Europe and the USA, the Pipeline Transport Institute analysed the following international, Russian, and American standards:

- American Petroleum Institute (API) standard API STD 1163: ILI systems qualification;
- National Association of Corrosion Engineers (NACE) standard NACE SP0102-2010: Standard practice: ILI of pipelines;
- Pipeline Operators’ Forum (POF) document Specifications and requirements for intelligent pig inspection of pipelines (2009);
- Russian standards for ILI of pipelines.

Based on this analysis, it became clear that approaches to classification in Russian and international practice are broadly similar. There are, however, some differences, for instance:
• Crack defect. According to the Russian classification, this is a rupture in the pipe’s metal surface, characterized by a sharp tip and high ratio of length to width and to opening; while according to international classification, it is a flat, two-dimensional feature with displacement of fracture surfaces.

• Buckle defect. According to the Russian classification, this is the

### Table: ILI tool characteristics in Russian and international regulatory documentation:

<table>
<thead>
<tr>
<th>No</th>
<th>Measurement method</th>
<th>Parameter</th>
<th>Requirements of Russian regulatory documentation</th>
<th>Requirements of POF 2009: Specifications and requirements for intelligent pig inspection of pipelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Magnetic</td>
<td>Error in anomaly length measurement</td>
<td>From 15 to 30 mm for corrosion, pits, grooves, laps, cavities</td>
<td>From 10 to 20 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>From (0.1 ∙ L or 30) to (0.1 ∙ L or 50) mm (which is more) for cracks</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error in anomaly width measurement</td>
<td>From 15 to 30 mm for corrosion, pits, grooves, laps, cavities</td>
<td>From 10 to 20 mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50 mm for cross cracks</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error in anomaly depth measurement</td>
<td>From 0.1 ∙ δ to 0.2 ∙ δ for corrosion, pits, grooves, laps, cavities</td>
<td>From 10 to 15 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.15 ∙ δ for cracks</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Profilometry</td>
<td>Error in dent length measurement</td>
<td>20 mm</td>
<td>10 % of internal diameter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error in dent width measurement</td>
<td>40 mm</td>
<td>10 % of internal diameter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error in dent depth measurement</td>
<td>From 2 to 3 mm</td>
<td>1 % of internal diameter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dent registration threshold</td>
<td>From 3 to 6 mm</td>
<td>2 % of internal diameter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Error in inner diameter measurement</td>
<td>From 0.003 ∙ D_H to 0.005 ∙ D_H</td>
<td>1 % of internal diameter</td>
</tr>
</tbody>
</table>

*Fig.1. ILI tool characteristics in Russian and international regulatory documentation:*

\[ L – \text{length of the defect or crack zone, mm; }\]
\[ D_H – \text{external pipe diameter, mm; }\]
\[ \delta – \text{nominal wall thickness of pipe, mm.} \]
deformation of the pipe wall due to external impact, in the form of convexity and concavity that are larger than the wall thickness. According to the international classification, it is partial collapse of the pipe due to excessive bending or compression caused by soil instability, landslides, erosion, frost heaving, earthquakes etc.

- Corrosive loss of metal defect. This is, according to the Russian classification, a pipe section with a measured reduction in wall thickness, as a result of corrosion damage; while according to the international classification, it is any pipeline anomaly arising due to metal loss. The loss of metal is usually the result of corrosion or the formation of grooves, notches, scores and scratches.

For reference, 24 defect types are defined in Russian documentation and 17 in international documentation. In many cases the defect definitions developed by PJSC Transneft more accurately reflect their characteristics for interpretation.

It should also be noted that some criteria for ILI tools in Russia, Europe, and the USA differ both by boundary values (minimum and maximum limits of measuring range) and by the way errors are expressed (in a percentage of the parameter and in millimetres for Europe and the USA; by formulae that include defect length, pipeline diameter, wall thickness, etc., for Russia).

The Pipeline Transport Institute is developing a national standard Metrological assurance of ILI to establish a unified set of requirements for classifying and schematizing defects that is aligned with international requirements.

Measurement methods and methodology of interpreting defects

Based on research results, the Pipeline Transport Institute has developed measurement methods for ILI:

- for measuring the pipeline flow cross-section diameter;
- for measuring the defect length;
- for measuring the depth of external-type defects by the position in the pipe wall, etc.

With regard to methods for measuring the defect depth, the pipe wall thickness at a defect-free section is determined by ultrasonic thickness measurement, as well as the remaining pipe wall thickness at the section with the defect. An ultrasonic pulse, emitted by the piezoelectric transducer, passes through an intermediate couplant, enters the object under inspection, is reflected from its rear wall and returns to the receiving sensor of the piezoelectric transducer. Given the known speed of sound, the thickness of the object is thus calculated according to the measured delay time of the ultrasonic pulse relative to its emission.

The mathematical data processing method is the calculation of the defect depth $h_d$ in the pipe wall (Fig.2) from the difference between the pipe wall thickness at the defect-free section $t$ and the residual pipe wall thickness $t_{res}$ at the section with the defect.

The defect depth $h_d$ in the pipe wall is found according to the formula:

$$h_d = t - t_{res}$$

where $t_{res}$ is the residual pipe-wall thickness and $t$ is the defect-free pipe wall thickness.

The measurement result is presented in the documents providing for its use in the following form:
where $\Delta h$ is the characteristic of error in the pipe wall defect depth measurement, in mm.

The error margin when measuring defect depth in the pipe wall $\Delta h$ is calculated in the following way:

$$
\Delta h = \left( \frac{\hat{c}_h \Delta t}{\ell_t} \right)^2 + \left( \frac{\hat{c}_h \Delta t_{\text{res}}}{\ell_{\text{res}}} \right)^2
$$

where:

- $t_{\text{res}}$ is the residual pipe wall thickness, mm;
- $t$ is the defect-free pipe wall thickness, mm;
- $\Delta t_{\text{res}}$ is the error in measuring the residual pipe wall thickness, mm;
- $\Delta t$ is the error in measuring the defect-free pipe wall thickness, mm.

In order to analyse and evaluate technical solutions with respect to metrological assurance for interpreting results from using ILI tools, the Pipeline Transport Institute has organized expert metrological examination of data interpretation methods for trunk pipeline ILL.

**Defect measures and reference database of defects**

The Pipeline Transport Institute has developed documents to regulate:

- the nomenclature of defect measures with normalized metrological characteristics;
- the manufacture, storage and control of metrological characteristics of defect measures;
- the provision of equipment to the department for manufacturing, testing, and verifying metrological characteristics of defect measures.

The basis for storing and transmitting units of length when calibrating ILI tools is the set of standard samples which forms the defect-reference database, which is a set of defect measures, in the form of pipe lengths, consisting of pipe sections with various wall thicknesses, containing natural or artificial defects in geometry and in the pipe wall, as well as defects in welds in accordance with the classification of pipeline defects.

The metrological characteristics of these defects (length, width, depth) are known, and their nomenclature is consistent with the results of ILIs over more than 940,000 km of trunk pipelines, carried out by PJSC Transneft in Russia, Europe, Middle East, Latin America, and South America.

Defect measures are calibrated in accordance with verification methods, thus ensuring the traceability of the following measurements in the progression: the state standard from the state verification scheme $\rightarrow$ legal.
entity standards (defect measures, signal generators) \rightarrow working measuring instrument (ILI tool). This also ensures the transferring of the length, time, and electromagnetic oscillation attenuation unit dimensions with metrological characteristics.

The given reference database of defect measures acts as the basis of the metrological testing area for verifying and calibrating ILI tools (hereafter – metrological testing area).

At present the Pipeline Transport Institute has carried out tests to approve the type of nine defect measures with diameters ranging from 159 mm to 1220 mm, containing 45 defects of four types (notch, dent, metal loss, non-uniform thickness).

The defect reference database is also used to improve methods of interpreting defects, which define:

- the rules for interpreting data from ILIs, including pipe sections, defects, connective and structural components, weldable fittings, repair structures, and other features of the pipeline, detected as a result of running ILI tools;
- the rules for interpreting combined defects during data processing of ILI tools of various types, using data about defects from a specialized defects database;
- the rules for defining and recording defect repair methods.

Fig. 4. Defect test pipes.

**Metrological test areas for ILI tools**

PJSC Transneft’s metrological test facility consists of a liquid test rig and dry pull-through test rig. This test rig consists of pipelines of various diameters (from 159 mm to 1220 mm) and wall thicknesses (from 4 mm to 29 mm). The liquid used is 30% aqueous glycerin solution, with properties as close as possible to petroleum products, which enables the test rig to be in operation year-round. The dry pull-through test rig is designed for calibrating magnetic-type tools and simulating gaseous environments. The test rig is equipped with more than 11,200 of the various defects that can appear in oil, oil product, and gas pipelines. The design of the testing area allows the defects to be changed using flanged inserts.

The metrological test facility is currently being accredited with official state body for the recognition of the test facility’s competence. This is conducted to provide confidence in the measurement results at the level of the Russian Federation, and also to make them recognisable by other countries, including the Russian Federation’s trading partners.

In Houston, Texas (USA) the PRCI Technology Development Center set-up a testing area with a similar purpose in 2012. It incorporates three standard sizes of the pipeline under inspection (300, 400, and 600 mm) and 1100 pipes with real defects, a dry pull-through test, rig and a liquid test rig for ILI tools.
ILI tools

The following ILI tools were tested for type approval:

- inspection system from the CMC series - multi-channel caliper tool;
- inspection system from the UD series - ultrasonic thickness tool for WM (wall-thickness measurement);
- inspection system from DMC series - magnetic thickness tool for TFI (transverse-field inspection) and MFL method (magnetic-field leakage);
- inspection system from the CDC series - combined thickness tool, formed of three sections: MFL, ultrasonic WM, and ultrasonic CD (crack detector, an ultrasonic inspection method, designed to detect and measure crack parameters in the pipe wall and longitudinal welds);
- inspection system from the DCP series - combined ultrasonic thickness gauge that includes two sections: ultrasonic WM and ultrasonic CD.

The methods of calibrating these ILI tools, developed during testing, provide two possible sets of verification tools, comprising:

- defect measures in the form of the pipe sections mentioned above;
- serially-produced standards (thickness and length measures).
Results

The main results of the Pipeline Transport Institute’s activities described above are:

- unified state mandatory metrological requirements for measurements taken during ILIs;
- a unique reference database for defect measures with specified metrological characteristics;
- a normative framework for metrological evaluation of ILI tools;
- an accredited metrological test facility for ILI tools.

Future plans

To further develop this system, the Pipeline Transport Institute will carry out the following measures in 2017-2020:

- expanding the reference database by creating new defect measures using various methods of manufactured defects: mechanical (milling, welding, drilling notches) and using additive technologies (3D-printer);
- inter-laboratory comparisons of measurement units contained in defect measures, with the engagement of leading international metrology institutes, for example, the Dutch National Metrology Institute VSL;
- testing ILI tools in the interests of

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>PJSC Transneft test facility, Russia</th>
<th>PRCI Technology Development Center, USA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipeline diameter range</td>
<td>6 – 48 in (159 - 1220 mm)</td>
<td>12 in, 16 in, 24 in (300, 400, 600 mm)</td>
</tr>
<tr>
<td></td>
<td>11 standard sizes</td>
<td>3 standard sizes</td>
</tr>
<tr>
<td>Number and type of defects for testing</td>
<td>More than 11,200 artificial and</td>
<td>1100 pipe samples with natural defects</td>
</tr>
<tr>
<td>in-line inspection tools</td>
<td>natural defects, including over 6,500</td>
<td></td>
</tr>
<tr>
<td></td>
<td>defects of the pipe base metal</td>
<td></td>
</tr>
<tr>
<td>Test facility features</td>
<td>3 circular and 4 semi-circular test</td>
<td>Dry pull-through test rig ILI tools of</td>
</tr>
<tr>
<td></td>
<td>loops of various diameters</td>
<td>3 standard sizes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(12 in, 16 in, 24 in)</td>
</tr>
<tr>
<td></td>
<td>Dry pull-through test rigs for ILI</td>
<td>Liquid testing facility for ILI tools</td>
</tr>
<tr>
<td></td>
<td>tools of various standard sizes</td>
<td>of 2 standard sizes</td>
</tr>
<tr>
<td></td>
<td>1.5D, 3D, 5D bends</td>
<td>(6 in, 12 in)</td>
</tr>
<tr>
<td></td>
<td>Aerial crossing</td>
<td></td>
</tr>
</tbody>
</table>
Conclusion

This approach, within the industry system of conformity assessment, will allow for independence and impartiality when implementing metrological assurance of ILI, when testing, verifying (calibrating) ILI tools, etc. The approach will also involve the future exchange of technological information with leading Russian and foreign organizations in the field of ILI, and the joint development and adoption of normative procedures and standards.

It will also ensure consumer protection from unreliable results of ILI and, as a consequence, prevention of:

- the risks associated with pipeline incidents occurring because of dangerous undetected defects;
- additional financial costs in connection with the unnecessary replacement of pipelines due to inaccurately defined (classified) defects, as well as remediing environmental damage due to pipeline accidents;
- risks to reputation (the risk of losing business reputation) due to non-performance of hydrocarbon transportation services promised to the consumer;
- the use ILI tools and software which do not meet technical and metrological requirements for measuring instruments.

The activities examined within the framework of the industry system of conformity assessment provide increased accuracy and reliability for ILI results and reduce the risk of pipeline accidents. ILI measurements included in state regulation allow to establish unified, transparent, and obligatory requirements for all market participants.

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