Pipeline monitoring technology in Nord Stream 2

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Abstract. This article proposes to use ROV technology to assess the stability of an underwater gas transmission system. The assessment methodology should be based on the methods of magnetoscopy and visual monitoring using differential magnetometers. The monitoring technology was developed and tested at JSC «YUZHMORGEOLGIYA» during the inspection and technical supervision of the Dzhubga-Sochi subsea pipeline.

Keywords: Remotely Operated Vehicle (ROV). Subsea gas pipelines. Pitting Corrosion. In-line inspection tool (IIT).

1. Introduction

The stability of main pipelines is regulated by a set of organizational and technical measures aimed at ensuring the required operating parameters, controlled by the geometry of the pipeline, the appearance of dangerous defects, metal loss, hydroabrasive wear and stress corrosion cracking.

When calculating strength and stability, the most unfavorable combination of functional, natural, construction and accidental loads that can occur simultaneously must be taken into account [1].

The organization of monitoring a subsea pipeline faces the problem of inability to access the subsea part of the pipeline from the inside. Onshore control is provided by passing in-line shells. For this, special chambers are provided for placing the shell inside the pipeline. Possible control is provided only from the outside using remote-controlled underwater vehicles, which are equipped with special ships [13, 14].

The integration of possible methods for monitoring pipelines according to the parameters of monitoring the pipe body from the inside and from the outside by remote-controlled vehicles makes it possible to predict hazardous and emergency situations associated with the emergence and development of dangerous defects in offshore subsea pipelines [2].

2. Materials and methods

According to the UK Standard "Smart pigs and defect assessment codes: completing the circle", determined types of defects available for investigation by in-line inspection shells are given in Table 1 [3]. There is a lack in studying pitting corrosion damages - pitting corrosion. The mechanism for the formation of pitting damage is associated with the physics and the structure of a metal. The most informative diagnostic method is research using inline inspection shells on a pipeline route [4, 15].

Inspection projectiles detect and measure defects in the pipeline. The received information contains data [5]:
- metal defects, metal losses
- the location of a defect
- the geometry in terms of depth, length and width.

The degree of confidence in the definition of defects as defect depth as $+/-15$, wall thickness % (weight), 80% of the time, is determined by the frequency of checks, as shown in Figure 1 [3, 6].

The theoretical aspects of the inspection shells use are well studied: the pipe body is magnetized and any change in the pipe cross-sectional area caused by the presence of defects leads to magnetic flux losses, the level of which can be used to conclude that there is a defect. Taking into account the projectile velocity parameter and scanning by the system of orthogonal sensors, it is possible to construct a picture of the distribution of defects in the pipe body.

Monitoring the development of the depth of defects testifies to the operational stock of underwater pipelines in terms of the parameters of the working pressure in a pipe and, accordingly, the volume of gas pumped and to the effectiveness of the project [7].

The use of inspection shells is possible only in areas with special cameras for the use of IIT.

Table 1. Definition and classification of pipe defects based on monitoring results [3]

| Defect             | Loss of metal $^6$ | Damage determination tools | Geometry tools | Positioning |
|--------------------|-------------------|-----------------------------|----------------|-------------|
| Corrosion          | MFL SR            | MFL HR, UT, UT, MFL $^7$    | Caliper        |             |
|                    | D&S$^1$           | D&S, D&S                   | NO, NO         |             |
| Cracks - Axial     | NO                | NO, D&S                    | NO, NO         |             |
|                     |                   | NO, D$^3$ & S$^4$          | NO, NO         |             |
| Cracks - circulation | NO           | D$^4$, D&S$^5$             | NO, NO         |             |
| Dents              | D                 | D, D, D, D                 | D&S, D&S, D&S  |             |
| Layering           | D                 | D, D, D, D                 | D&S, D&S, NO   | D&S, D&S   |
| Manufacturer defects | D                | D, D, D, D                 | NO, D&S, NO   | D&S, D&S$^5$ |
| Ovality            | NO                | NO, NO, NO                 | NO, D&S, NO   | D&S, D&S$^5$ |

D = DETECTS. S = SIZE
1 - intact inner / outer surface
2 – detection by scanning (by combining sensors by 90°)
3 - lower value, reduced resolution
4 - underestimated value 's' caused by inability to calibrate
5– equipped with a measuring tool
6 - ‘SR’ standard recognition, ‘HR’ high requirements, ‘UT’ obtained in the course of ultrasound test, ‘MFL’ - obtained using the method of magnetoscopy
7 - MFL area of damage in the transverse plane

The existing criteria in Table 1 are "1", "6" and "7" allow the use of unmanned underwater vehicles, and actually control the operational parameters along the outer wall of the pipelines. In this case, an accurate description of the processes requires mathematical models to accurately describe the state of pipelines. The main observed signs include the stability of a pipeline shape, the presence of pitting damage along the outer wall and the presence of bulges and concavities along the pipe body caused by stretching and compression along the longitudinal axis of the pipeline [8].
Determination of defects such as ulcers and various cavities is complicated by the complex defect shape, as shown in Figure 2.

![Diagram 1](image1.png)

**Figure 1.** Actual defect depth (% wt) determined by in-line inspection shells, type "Magnescan" [3]

Detecting defects of this type involves scanning at different speeds in order to determine the exact boundaries of the damage.

Then, defects can be divided into two sets:
- half of these defects can be placed in a set of "checks";
- the other half into the "training" set.

![Diagram 2](image2.png)

**Figure 2.** a) Determination of pitting corrosion by magnetoscopy;
   b) distribution of different levels of corrosion on the pipe body
From defects referred to the array, "training" expands the base of measurements. As a rule, they include measures of signal amplitude, width and length. According to the resulting base, we built a model for errors minimizing and a forecast of the defect development (Figure 3).

![Figure 3. Refined mathematical estimates of the defect parameters [3]](image)

Further, using the analytical methods, we measure the effect of the defect on the stability of the system. The calculations are carried out by the method of two curves, developed at the Battelli Institute:

\[
\frac{\sigma_f}{\sigma_0} = \frac{1-d/t}{1-d/(M \cdot t)},
\]

(1)

where: \(\sigma_f\) is fracture stress; \(\sigma_0\) are stresses of plastic deformations of the material; \(d\) is the depth of the defect; \(t\) is the pipe wall thickness; \(M\) is an empirical factor (deviations) influencing the increase in stress at the ends of defects, consisting of an external radial deflection along a defect initiating fracture, but usually a function of loading \((Y)\) and/or ultimate strength \((T)\) [10].

\[
\sigma_0 = \frac{YS + TS}{2},
\]

(2)

where \(YS\) is yield strength, \(TS\) is ultimate strength.

\[
M = \sqrt{1 + 0.4025 \cdot \left(\frac{2C}{\sqrt{RT}}\right)^2},
\]

(3)

where \(2C\) is the length of the defect; \(R\) is the radius of the pipe.

| Flow strength | M   | Mean value | Standard Deviation | Coefficient of Variations |
|---------------|-----|------------|--------------------|--------------------------|
| \((Y+T)/2\)   | A   | 1,06       | 0,16               | 0,15                     |
|               | B   | 1,02       | 0,14               | 0,14                     |
|               | C   | 0,99       | 0,13               | 0,13                     |
| \(Y+10,0001bf/in^2\) | A | 1,05 | 0,15 | 0,15 |
|               | B | 1,01 | 0,13 | 0,13 |
|               | C | 0,98 | 0,12 | 0,13 |
The forecast of the defect development from the pipeline inspection to the next inspection is based on the analysis of two curves, presenting pressure calculated during tests to the curve of the maximum allowable operating pressure (MAOP).

The determination of defects and the stability forecast are based on the principles of mathematical modeling with the calculation of correction coefficients according to the equations of NG – 18 of the Battelli Institute.

The methods for an approximate assessment of the stability of underwater pipelines can be based on the use of remotely controlled underwater vehicles.

In the Russian Federation, the direction of research of systems of underwater pipelines with the use of remotely controlled unmanned vehicles RCUV is actual [10].

### 3. Results

The standard equipment of RCUV is shown in Table 3. Unlike piston shells, RCUV requires high costs associated with the involvement of specialists trained to operate underwater complexes, the involvement of a carrier vessel, navigation conditions favorable for the use of ships.

The view from the video surveillance systems and diagnostic windows of the ROV is shown in Figures 4 and 5.

Table 3. Equipment for remote-controlled unmanned underwater vehicles of JSC "Yuzhmorgeologiya"

|                          | Pipeline tracker                     | Underwater navigation transponder |
|--------------------------|--------------------------------------|-----------------------------------|
| Acoustic 2-antenna profiler |                                      |                                   |
| CP probe                 |                                      |                                   |
| Digital camera           |                                      | Metal thickness gauge             |
| High-resolution color TV camera (2 pcs) |                    | Underwater Differential Magnetometers |
Figure 4. Screenshot from CCTV cameras and the diagnostic window of the RCUV magnetometer

Figure 5. Screenshots of CCTV cameras of RCUV

The control of the parameters of the offshore subsea pipeline is ensured by remotely operated unmanned underwater vehicles when performing verification calculations of steel subsea pipelines for stability (collapse) under the influence of hydrostatic pressure and corrosion damage. The stability parameters are determined by calculating the ovality coefficient according to criterion "7" in Table 1 (Rules for the Classification and Construction of Submarine Pipelines, Part I of the Register of Shipping in the Russian Federation).

4. Discussion

The use of in-line inspection projectiles for the purpose of inspecting underwater gas pipelines is possible only in areas with special inspection chambers and allowing the projectile to pass through the section.

In all other cases, it is necessary to use remotely controlled underwater vehicles. A feature of the wear of the route sections is local isolation at the ends of the pipeline. Therefore, the greatest loss of metal is observed near the turbulent sections of the route, where there are irregularities that are not covered with a special coating.

Usually these areas include shut-off valves, control valves and chambers for the passage of in-line inspection shells. The issues of control of the route according to the quality criteria of stability, in particular,
the collapse of a part of the pipeline due to corrosion damage, is ensured by the use of remotely controlled underwater vehicles.

It is obvious that the use of VIS and RCUV allow to effectively solve the issues of environmental safety of the Nord Stream-2 project.

5. Conclusions
Efficient operation of an offshore subsea pipeline is possible if the operating (maximum allowable) pressure in the pipeline is ensured. Then the maximum gas pumping is provided with practically equal rates of gas transportation costs.

Provision of the maximum pumping rate is achieved by continuous technological and technical control of the pipeline route, with fixing the temperature of the pumped product. The use of ROV technology, together with the available control of magnetoscopy, makes it possible to maintain the desired optimum performance of the Nord Stream-2 offshore main underwater gas pipeline.

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