Methods for illegal tapping detection using non-destructive testing tools

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Abstract. The article discusses the statistics of accidents occurred as a result of illegal tapping or sabotage at the sections of the main oil pipeline. The authors analyzed existing methods for determining illegal tapping, revealed the need to develop such an advanced method for detecting tapping, which would combine several predominantly promising properties for the oil and gas industry. One of the main conditions for the development prospects is the environmental and economic feasibility of the development introduction. Significant advantages of the impulse reflectometry method are established, which consists in oil pipeline sounding, presented in the form of a two-wire electric line and detecting the wave resistance deviation at heterogeneous sections of oil pipeline. Various defects can present such deviations in comparison with the already existing control methods, which mainly depend on human factor during patrolling along the main oil pipelines.

1. Introduction

Nowadays in oil and gas complex, there is an acute problem of the detection and prevention of illegal tapping and sabotage at sections of the main oil pipeline. This is primarily explained by the perfection of tapping equipment methods, as well as human factor when patrolling pipeline sections [3].

According to the statistics of accidents shown in Table 1 [2] we can conclude that the causes of most accidents and as a result environmental pollution are tapping and sabotage. Since individual parts of main oil pipelines sometimes reach several thousand kilometers in length, the number of illegal tapping can reach ten, or even hundreds. As a result, there are the huge losses from the budget of the operating pipeline organizations, associated with both the loss of raw materials and environmental consequences in the case of poor-quality tapping.

The important difference between illegal tapping and emergency leak is the absence of traces of raw material leakage in case of illegal tapping exactly at the tapping point next to the oil pipeline. However, in the case of emergency leak of raw materials, an oil spill or traces of oil leakage are present near the oil pipeline.
Table 1. Statistics of accidents on the main oil pipeline

| Cause of accident                           | Number of accidents (in a year) | Share, % |
|--------------------------------------------|--------------------------------|----------|
|                                            | 2013  | 2014  | 2015  | 2016  | 2017  | In total |
| Defect in construction and installation activities | 0     | 2     | 2     | 0     | 0     | 4        | 2.68     |
| Organizational reasons                     | 0     | 0     | 3     | 0     | 2     | 5        | 3.35     |
| Mechanical impact during groundworks       | 0     | 0     | 1     | 0     | 0     | 1        | 0.67     |
| Corrosion                                 | 0     | 0     | 2     | 1     | 0     | 3        | 2.01     |
| Illegal tapping                            | 15    | 8     | 12    | 10    | 2     | 47       | 31.49    |
| Production defect                          | 2     | 2     | 0     | 3     | 0     | 7        | 4.69     |
| Other issues                               | 0     | 0     | 0     | 0     | 0     | 0        | 0        |
| **Total**                                  | **17**| **12**| **20**| **14**| **4**  | **67**   | **100**  |

According to the annual data of the Federal Service for Ecological, Technological and Atomic Inspection, it is possible to estimate the rate of accidents along the route of oil trunk pipelines. The average statistical rate of accidents in recent years is 0.27 accidents per 1000 kilometers of the pipeline, 58% of which occur due to illegal tapping and sabotage [1].

2. Problem statement

In order to solve this problem, it is necessary to provide appropriate preventive measures.

Methods: The existing today methods for detecting illegal tapping are either insufficiently effective or require huge capital investments for to be implemented in production.

In order to solve the problem of detecting illegal tapping, it is proposed to use impulsive reflectometry.

The principle of operation is similar to the determination of the coordinates of a cable break section, thus, a main pipeline with anticorrosive insulation is an equivalent two-wire electrical line with different values of wave resistance in such sections as a weld seam or illegal trapping.

The method of impulse reflectometry is based on the property of an infinitely long uniform line, from which it follows that the ratio between currents and voltages introduced into the electromagnetic wave line is equal at any point of the uniform line.

This relation has the following form (1)

\[
W = \frac{I}{U} \quad (1)
\]

And it is called the line resistance.

To implement this method of pulse reflectometry, it is necessary to send a probe pulse to the line in order to measure the interval \( tx \) - time during which the pulse will pass twice to the source of damage or interference (the place where the heterogeneity of the wave resistance is detected). In order to
understand at what the distance the heterogeneity of the wave resistance from the impulse source is, the following formula is used (2)

\[ L_x = t_x \frac{V}{2} \]  

(2)

where \( V \) - impulse velocity

The ratio of the amplitudes of the reflected \( U_0 \) to the sounding \( U_3 \) pulse is called the pulse reflection coefficient \( K_{pr} \)

\[ K_{pr} = \frac{U_0}{U_3} = \frac{W_l - W}{W_l + W} \]

Where \( W \) - line resistance at line homogeneity zone,
\( W_l \) - line resistance at damage zone or heterogeneity.

A distorted signal appears in the places of a line where the wave resistance deviates from its mean value: in places of raw material leakage, illegal tapping, oil leakage, etc. If the output resistance of reflectometer differs from the wave resistance on the line, then reflections appear in the area where the reflectometer is connected to the oil pipeline, which are reflections from the resistances of the reflectometer input of the reflection signals that occurred in the connection of reflectometer. The input and output resistances of reflectometer are equal.

In order to make the pulse values sufficiently reliable, it is necessary to match the line resistance with the output resistance of reflectometer. The reason for the change in polarity and amplitude of the reflectometer is the ratio of the characteristic resistance to the output resistance of the reflectometer (Figure 1).

**Figure 1.** Matching of the wave resistance with the output resistance of the reflectometer

The pulse signal tends to subside when it passes the line. It means that the amplitude decreases.
Line damping is determined by the materials used in the production of the pipeline and the insulation protection. As a result, the pulse signal is frequency-dependent.

![Diagram](image)

**Figure 2.** Reflectograms with (a) and without (b) impulse damping

One of the problems in the determination of the exact distance to the tapping point is the change in the sounding pulses, since not only the pulse resistance changes, but also its form, which characterizes the duration of the pulse front and its cut. This phenomenon is called "pulse spreading". The greater the distance to the defect, the more diffuse the signal and the smaller the pulse amplitude. The examples of traces with and without damping (ideal line) are shown (Figure 2.)

### 3. Conclusion

During the sounding of such an electrical circuit with impulse signals, electromagnetic energy is reflected from heterogeneous internal sections of oil pipelines. These pulses are fed back to the reflectometer, which is used to compare this value with a standard. If a mismatch is found, the coordinate is determined and the corresponding technical operations are performed in order to eliminate the tapping.

This method is convenient due to the simplicity of equipment installation. It can be installed at any end of the pipeline.

### References

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