Residual Operation Life Estimation of Trunk Oil Pipeline Submerged Crossing

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Abstract. Commonly known, diagnostic results show that all pipelines contain a large number of defects that are unacceptable in terms of standards and building codes. An attempt to eliminate all defects can lead to the fact that the costs of further operation will become prohibitively large and not economically justified. In practice, the only way to ensure safety is to exclude only those defects that really pose a danger to the pipeline, taking into account the operating conditions. This is how the problem of assessing the residual resource of objects that have been in operation for a long time appears.

Authors do not always use the same meaning in the term “residual resource”. To avoid confusion in terms, the article provides some considerations defining this term and accepts an interpretation in which it is a value derived from the strength and safety of the pipeline. A number of factors are given, which in a key way affect the strength and safety, which should be involved in the assessment of the residual resource. As a result, this approach, in contrast to the previously available ones, allows taking into account all the main factors affecting the strength, durability and safety of the pipeline.

1. Introduction

In recent years, many methodological works have appeared on the assessment of the residual resource of various complex and industrially hazardous technical objects, including main oil pipelines \cite{1-6}. This is mainly due to the need to extend the service life of facilities, provided their safety is ensured, which in turn requires periodic inspections.

As the diagnostic results show, all pipelines contain a large number of defects that are unacceptable in terms of standards and building codes \cite{7, 8}. It is unrealistic to exclude all defects with the current level of production technology. In practice, the only way to ensure safety is to exclude only those defects that really pose a danger to the pipeline, taking into account the operating conditions \cite{9}. Since defects have the property of developing and leading to destruction after some time \cite{10}, it becomes necessary to predict the terms of safe operation of pipelines with defects \cite{11, 8, 12}. This is how the problem of assessing the residual resource of objects that have been in operation for a long time appears \cite{8, 13, 14}.

Authors do not always use the same meaning in the term “residual resource”. To avoid confusion in terms, here are some considerations.

There are technical devices that operate under certain specified conditions and are not subject to repair (for example, light bulbs, radio parts, integrated circuits, processors). These include, for example, underwater crossings constructed using directional drilling. For them, the term "residual life" means the time of operation before failure under standard operating conditions. Since this value is a
random variable, for its correct description such characteristics as “mean value”, “variance”, “confidence interval”, “coefficient of reliability”, etc. are used.

2. The peculiarities of pipelines and statement of a problem

The peculiarity of pipelines is that in most cases they are repairable objects. By repairing or replacing defective areas, you can maintain their technical condition at the required level for as long as you like. True, for this it is necessary to bear certain material costs. If these costs become prohibitively large and are not justified economically, then we can talk about the irrationality or inadmissibility of the further operation of pipelines. Thus, for repairable objects, the "residual life" is determined by their technical characteristics (properties of pipes, metal, composition of defects, etc.) and is limited by economic criteria.

The intensity of the development of defects is determined by the operating conditions of the pipelines [7]: operating pressure, parameters of the corrosion protection system, etc. For example, under equal conditions, a decrease in operating pressure increases the time of development of defects, therefore, their residual resource. Therefore, speaking about the residual resource, it is necessary to indicate what operating conditions it corresponds to.

Another feature of pipelines is that they are extended underground (or underwater) structures that are difficult to access for diagnostics. In addition, there is a wide variety of types of defects, mechanisms of damage accumulation and destruction of pipelines. Estimation of the residual resource requires a reliable forecast of the technical condition for a long time, measured by several tens of years. This, in turn, requires very detailed information about the characteristics of all defects [14, 17], the stress state of the pipeline [18], the laws of change in the mechanical properties of metal and welded joints, the state of insulation, loading parameters, etc. Any inaccuracy in determining the initial data leads to significant errors in assessing durability (time to destruction). Therefore, it is not possible to estimate with acceptable accuracy the moment and place of pipeline failure, even using diagnostic information obtained by modern in-line and other means of control.

Another feature of oil trunk pipelines is that they must be safe. Therefore, the period of safe operation of the oil pipeline is of practical importance, and not the time of its destruction from any defect [13]. On the one hand, this complicates the task, since the methodological issues related to safety assessment have not been fully studied. On the other hand, the task is facilitated, since it is not required to accurately determine the time until the destruction of the pipeline. Safety is ensured by margins of strength and durability, periodic monitoring of the technical condition and repair of pipelines, as well as the extent of the damage that will be caused in case of destruction. This raises the following questions:

• are the applied diagnostic methods sufficient to ensure the safety of pipelines?
• what should be the frequency of the pipeline diagnostic examination to ensure safety?

Obviously, the required frequency of the examination will somehow depend on the diagnostic methods used.

It is also obvious that the frequency of diagnostics can be increased, except for the most dangerous detected defects by repair methods.

So, let us draw some conclusions on the problem statement.

1. It is practically impossible to determine the time to the destruction of the pipeline based on diagnostic information obtained by modern methods.
2. Even if you know the time before the destruction of the pipeline, this will not be a residual resource, since its service life can be extended by repair methods.
3. The question of the residual resource should be formulated as follows: based on the available diagnostic information, determine "the period of safe operation of the pipeline without repair work." This period will be called conditionally "residual resource".
4. The remaining life of the pipeline depends on the parameters of the pipeline, the composition of defects, and operating conditions. By eliminating the most dangerous defects and reducing the working pressure, you can increase the residual resource.
5. The period between diagnostic examinations should not exceed the remaining life of the pipeline.
6. The scope of repair work must correspond to the frequency of diagnostics and the required residual resource of the pipeline.

3. Methodology for assessing the residual resource of the main oil pipeline section

Let us move on to the methodology for assessing the residual resource of the main oil pipeline section. For this, we will give some reasoning.

“Residual resource” in the accepted interpretation is a value derived from the strength and safety of the pipeline. Therefore, all factors affecting strength and safety must be involved in the residual life assessment. These factors include:

- design characteristics of the pipeline (diameter, wall thickness, steel grade, design and test pressure),
- duration of operation, composition of defects (pipes and insulation),
- mechanical properties of metal (pipes and welded joints),
- stresses (annular and axial, residual and operational),
- pipeline loading mode (working pressure and its drops),
- channel processes at the transition (erosion),
- the state of the buffer zone and bank protection structures,
- availability and condition of onshore valves,
- the ability to skip flaw detection shells, etc.

The complex effect of these factors on the residual life is practically impossible to describe with precise mathematical expressions. For an approximate description of this influence, let us take advantage of the fact that many of these factors act on the residual resource of the pipeline independently of each other. For example, the action of channel processes does not depend at all on the state of insulation, the presence of coastal valves, the state of the buffer zone, the degree of aging of the metal, the composition of defects and other factors. Therefore, the calculation formula for assessing the residual resource can be constructed in order to take the main mechanism of pipeline destruction as a basis, and take into account the effect of all other factors using correction factors. Since all pipeline failures occur on defects, we will take as a basis the mechanisms of static, low-cycle and fatigue failure, which can be described by a single mathematical apparatus. In this case, we get a formula of the following form:

\[
T = T_{\text{def}} \cdot f_{\text{herm}} \cdot f_{\text{isot}} \cdot f_{\text{mech}} \cdot f_{\text{stress}} \cdot f_{\text{base}} \cdot f_{\text{safe}} \cdot f_{\text{control}}
\]  

(1)

where \( T_{\text{def}} \) – time to failure on a defect (in years) that can be found, for example, by the method [1].

Correction factors \( f \) with the corresponding indices depend on the deviation from the norm of individual indicators of the oil pipeline. The values of these coefficients are in the range \((0, 1)\). If the corresponding characteristic of the oil pipeline is within the norm, then the correction factor is equal to one. In other cases, this ratio is less than one. The degree of deviation from the unit of the correction factor depends on the degree of deviation from the norm of the corresponding oil pipeline indicator. Precise methods for calculating the correction factors are currently practically not developed. Only experts can estimate the values of some coefficients. In the expert assessment of the correction factors, the approaches used in the methodological guidelines for assessing the degree of risk of accidents on main oil pipelines can be used [2].

Coefficient \( f_{\text{herm}} \) takes into account the possibility of pipeline depressurization without destruction. The most likely reason for such a leak is the formation of deep corrosion pits. In this case, you can take the following formula:

\[
f_{\text{herm}} = \frac{\delta_{\text{resid}}}{\delta_{\text{nom}}},
\]  

(2)
where \( \delta_{\text{nom}} \) – nominal wall thickness; \( \delta_{\text{resid}} \) – minimal residual wall thickness at the most corroded area.

Correction factor \( f_{\text{isol}} \), taking into account the condition of the insulation can be estimated from the results:
- Inspection of insulation defects with devices such as USI,
- visual and instrumental examination in pits,
- potential of electrochemical protection along the route,
- protective current,
- values of contact resistance.

Factor value \( f_{\text{isol}} \) is possible to evaluate only expertly from a comprehensive analysis of all the listed data on the state of insulation.

Factor \( f_{\text{mech}} \) takes into account the deviation of the mechanical properties of the pipe metal from the standard values. As is known [3], during long-term operation of main oil pipelines, the mechanical properties of the metal of pipes and welded joints undergo changes. The most significant changes are expressed in the fact that the impact strength, the plastic elongation of the sample at break \( \delta_s \), plastic contraction of the sample at rupture \( \psi \), parameters of static and cyclic crack resistance.

Factor value \( f_{\text{mech}} \) can be estimated as follows:
- by reduce in the plastic elongation of specimens at break \( \delta_s \) in accordance with Table 1:

| \( \delta_s \) | 0.2 | 0.19 | 0.18 | 0.17 | 0.16 | 0.15 | 0.14 | 0.13 | 0.12 | 0.11 | 0.10 |
|----------------|-----|------|------|------|------|------|------|------|------|------|------|
| \( F_{\text{mech}} \) | 1.00 | 0.90 | 0.80 | 0.72 | 0.64 | 0.57 | 0.50 | 0.44 | 0.38 | 0.33 | 0.28 |

- by reduce in the impact strength in accordance with the formula:

\[
 f_{\text{mech}} = \left( \frac{KCV_t}{KCV_0} \right)^2 
\]  
(3)

where \( KCV_0 \) - standard value of metal impact toughness; \( KCV_t \) - impact toughness of the metal at present (after operation for \( t \) years).

If \( KCV_t > KCV_0 \), we should assume \( k_{\text{st}} = 1 \);

- by the formula:

\[
 f_{\text{mech}} = \frac{1}{1 + 0.025 C_{\text{eq}} t} 
\]  
(4)

where \( t \) - pipeline operating time (years);
\( C_{\text{eq}} \) - the carbon equivalent of the metal, expressed as a percentage.

- according to the results of special experiments on samples cut from the pipe-wire.

For the calculated value of the correction factor \( f_{\text{mech}} \) the smallest of the obtained values is taken.

Correction factor \( f_{\text{stress}} \) takes into account the presence of residual stresses in the pipeline wall that arose during construction, testing, operation, repair, and diagnostics of a section of the main oil pipeline. When assessing these stresses, you can use the recommendations of work [4]. The general stress state of the pipeline consists of two components: hoop stresses \( \sigma_{\text{ring}} \) and longitudinal stresses \( \sigma_{\text{ls}} \). During the operation of the pipeline, each of these components should not exceed the permissible stress \( [\sigma] \):

\[
 \sigma_{\text{ring}} \leq [\sigma] \; ; \; \sigma_{\text{ls}} \leq [\sigma] 
\]  
(5)

The calculated tensile (compression) resistance of the metal R1 and R2 in accordance with [5] should be taken as the maximum permissible stress.
Hoop stresses always satisfy requirement (5), since they are controlled by internal pressure, which is determined precisely on the basis of this requirement. Longitudinal stresses are controlled not only by internal pressure, but also by many other factors and parameters, including the action of soil, water, other external loads, and temperature. Since the effect of each factor on the longitudinal stresses of the pipeline is difficult to control separately, it is advisable to periodically inspect the underwater crossing of the oil pipeline and calculate the estimated total longitudinal stresses $\sigma_{ls}$. The value of the correction factor should be determined by the formula

\[
\begin{align*}
    f_{\text{stress}} &= 1 \quad \text{at } \sigma_{ls} < [\sigma] ; \\
    f_{\text{stress}} &= \frac{[\sigma] - \sigma_{ls}}{0.7 \sigma_{ls}} \quad \text{at } 0.3[\sigma] < \sigma_{ls} < [\sigma] ; \\
    f_{\text{stress}} &= 0 \quad \text{at } \sigma_{ls} < 0.3[\sigma] .
\end{align*}
\]  

(6)

Factors values $f_{\text{base}}$ and $f_{\text{safe}}$, taking into account the condition of the river bed and the safety zone are evaluated by an expert method.

Factor value $f_{\text{control}}$ is determined depending on the possibility of passing inline shells of different generations according to the formula

\[
f_{\text{control}} = \frac{26 - \Pi}{30}
\]

(7)

where $\Pi$ - generation of a diagnostic projectile according to the classification [6].

If the section of the pipeline under consideration is not suitable for the passage of in-line inspection shells, then it is recommended to assume $f_{\text{control}}=0.6$.

4. Conclusion

Thus, this approach to assessing the residual resource, in contrast to those previously proposed, allows taking into account all the main factors that affect the strength, durability and safety of the pipeline. He does not pretend to the completeness of solving the problem and allows improvement, which is inevitable with the accumulation of experience. Depending on the specific circumstances, some correction factors may be excluded, added, or specified. This approach can be used in both deterministic and probabilistic settings. This will only affect the calculation of the parameter $T_{\text{def}}$ and will not affect the calculation of the correction factors $f$.

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