SCIENCE FOR PRODUCTION

EVALUATION OF THE DURABILITY OF A PIPE OF OIL PIPELINE WITH SURFACE CRACK UNDER BIAXIAL BLOCK LOADING

O. E. Andreikiv, Ya. L. Ivanyts’kyi, Z. O. Terlets’ka, and M. B. Kit

We propose an energy approach to the evaluation of the residual service life of structural elements with cracks for the two-frequency loading mode of biaxial tension-compression. This approach is applied to a pipe of oil pipeline containing a crack on its inner surface. The pipe is regarded as an infinite plate with surface semicircular crack loaded by longitudinal tension-compression caused by the processes of heating and cooling of the pipe. The pipe is also squeezed by the soil and subjected to the action of internal pressure formed in the process of pumping of oil. The two-frequency variations of pressure in the pipe are caused by the turbulence of the flow of oil (high frequency), opening and closing of the gate valves, and the shutdowns of the pumps (low frequency). It is shown that if we neglect the longitudinal tension-compression of the pipe and the oscillations of pressure of oil in the evaluation of durability of the pipes of oil pipelines, then we can get strongly overestimated predictions of the residual service life.

The prediction of the residual service life of structural elements under variable loads is an urgent problem of engineering practice. This is especially true for variable loads [1] (multifrequency, package, with known law of variation of amplitudes, etc.). Since the theoretical aspects of this problem are developed insufficiently and the required amount of experimental data is not accumulated due to significant technical difficulties, the required dependences that can be used for the evaluation of the service life of structures are absent.

In the present work, on the basis of the energy approach developed in [2–4], we propose a method for the determination of the residual service life of structural elements with cracks under block loading by bilateral tension-compression. The proposed method is applied to the evaluation of the residual service life of a pipe with surface crack subjected to longitudinal bilateral tension-compression caused by the processes of heating and cooling of the pipe, its squeezing by the soil, and the action of internal pressure formed in the process of pumping of oil. The two-frequency variations of pressure in the pipe are explained by the turbulence of the flow of oil (high frequency), closing and opening of the gate valves, and shutdowns of the pumps (low frequency).

Model of Loading of a Pipe

Oil mains are, as a rule, very long (at least 50 km). The diameter of pipes is never smaller than 500 mm. The pressure of oil in the mains can be quite high to guarantee their high throughput capacity. The deviations of working pressure caused by the startups and shutdowns of the pump stations can be as large as 2–3 MPa [5], in the case of successive pumping of different types of oil, these deviations do not exceed 1 MPa, the deviations caused by the startups and shutdowns of separate aggregates vary within the range 0.5–1.0 MPa, and the deviations caused by the pollution of the pipeline and formation of air blocks, as a rule, do not exceed 0.5 MPa.
Due to the turbulence of the flow of oil, a disbalance of the pumps, and the oscillations of the frequency of flow, the pressure in the pipeline deviates from its mean value by 0.2–0.3 MPa [6]. The design-basis pressure for the reinforcement of pipelines at the intermediate pump stations is usually set equal to 4 MPa because a pressure close to this level is formed after the shutdown of this station.

The restriction imposed on the input pressure of the station, i.e., 2.1 MPa, is connected with the action of a regulating valve of the protective system of the oil main. The rate of increase in pressure depends on the response time of the rotor of a pump. Thus, the steepness of the shock wave decreases as the indicated response time increases. In the course of closing of a gate valve, the level of pressure specified by the rate of interruption of the flow rapidly increases. The pressure wave propagates with the sound speed toward the previous pump station, reflects from it, and, thus, leads to the formation of a wave of lower pressure. The amplitude of the pressure waves formed in the process of closing of gate valves can be as high as 4.44 MPa [5]. Thus, the variation of pressure in the pipes of oil mains is, in fact, two-frequency and can be simulated by block loading (Fig. 1).

The experimental graphic dependence of the variations of pressure in the pipe in the process of repumping of oil (Fig. 2) [5] is qualitatively similar to the model diagram.

As a result of the increase in the diameters of oil mains, pressure, and temperature of oil products, the levels of stresses formed in the walls of the pipes become much higher, especially in the longitudinal direction. The changes in the properties of soil along the route of the pipeline result in different conditions of its squeezing. This may lead to the formation of significant longitudinal stresses $Q$ between fixed points of the pipeline. These stresses depend on temperature and pressure and can be found by using the formula [7]:

![Fig. 1. Schematic diagram of the variations of pressure in the oil pipeline.](image1.png)

![Fig. 2. Variations of pressure in the pipe in the process of repumping of oil.](image2.png)