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Requirements for the automated monitoring system to reduce environmental risk during operation of trunk pipelines

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Abstract. The paper deals with the Ground-Climate-Pipeline system and provides requirements for a continuous automated monitoring system. To prevent accidents on pipelines and mitigate their consequences, it is proposed to monitor the condition of the Ground-Climate-Pipeline system in time. The parameters for which it is necessary to organize continuous complex monitoring are given. The recommendations on placing the complex of technical means of control points are offered.

1. Introduction

The Russian Federation is one of the main exporters of oil and gas. Due to the geographical peculiarities of the production region, it has an extensive trunk pipeline network functioning since the beginning of the XX century [1]. Despite the measures taken to improve the reliability of the pipeline network operation, its accident rate is not decreasing as fast as it is necessary to ensure the environmental safety of the adjacent territories [2]. Accelerating climate change and forcing of oil pumping regimes lead to the imbalance in the Ground-Climate-Pipeline (GCP) system and the growth of accidents, and one of the serious consequences of accidents at such facilities is the emergence of environmental risk [3-4]. This risk is qualified as an assessment at all levels (from point to global) of the probability of negative changes in the environment caused by various natural and anthropogenic factors [5]. The modern methodology of environmental risk assessment provides for parallel consideration of the risk to human health and environmental risk caused by disturbance of ecosystems, as well as harmful effects on the components of the environment, the risk of quality reduction, and deterioration of living conditions [6-7].

To prevent and mitigate the consequences of pipeline accidents, it is necessary to timely monitor the status of the GCP system, which is discussed in this research. In this regard, the application of monitoring systems for the trunk pipeline route is a necessary measure.

The monitoring system allows tracking not only the cases of accidents that have already occurred, but also more frequently observed and measured parameters of the phenomena – precursors or indicators of hazardous manifestations [8].

In this article, the authors consider the requirements for a continuous automated monitoring system, namely, to the selection of locations of control means, types of sensors, and measured parameters of elements of the GCP system [9-11].

To solve the problems of choosing places for installing control devices, the concept of a digital twin was developed (Fig. 1). Figure 1 shows the main features of the digital twin, which combines a detailed digital description of the elements and their interaction. The parameters of the atmosphere are most susceptible to change, which, through changes in the properties of the soil, affect the pipeline. The digital twin makes it possible to identify places and dangerous tendencies of changes in the bearing capacity of the soil, the distribution of loads on the pipeline, its stress-strain state, and geometric deformations.

When choosing the location of the sensors, the points of the digital twin are selected, which, according to the forecast of their state, most of all change their parameters. When choosing the measured parameters, information on the most significant factors influencing the risk of stress-strain state exceeding the threshold values is used. The factors are identified during experiments with the digital twin of a specific section of the pipeline.

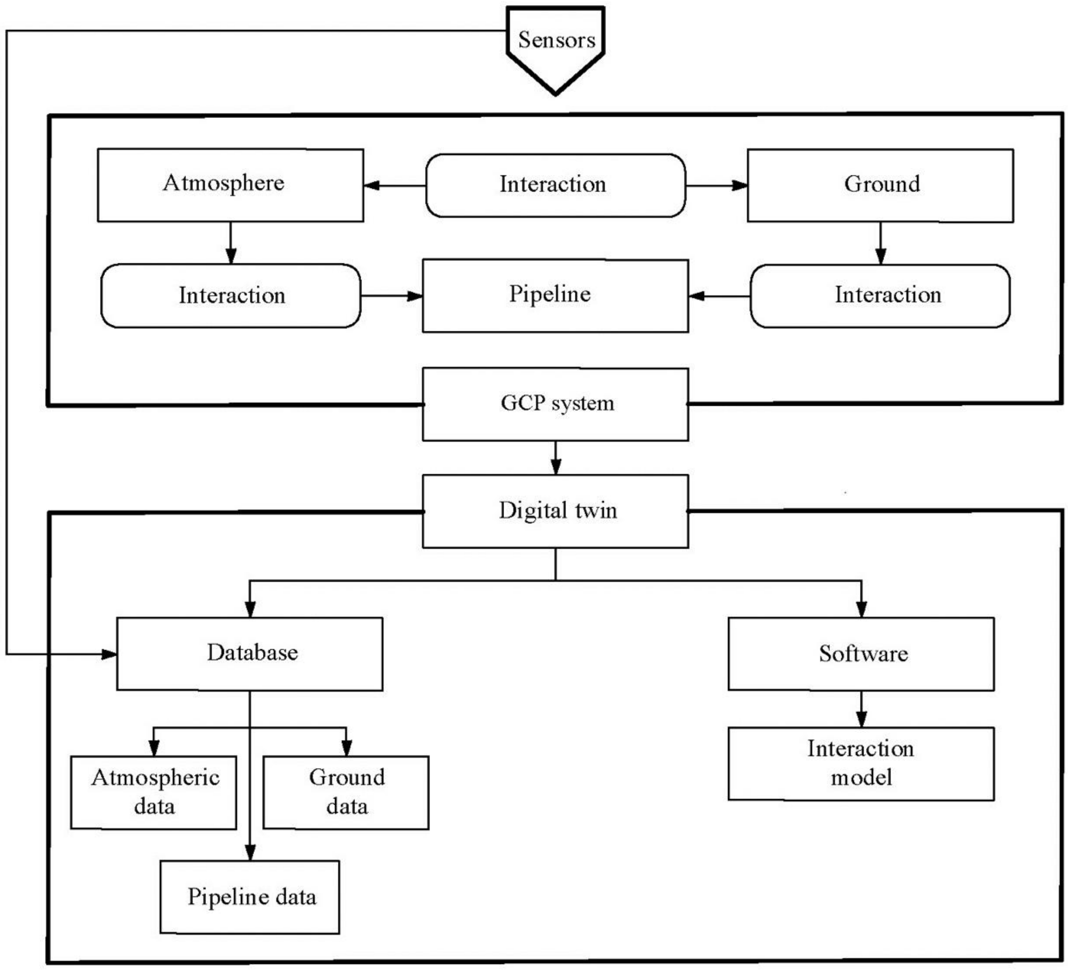

Figure 1. The concept of a digital twin of the GCP system.

2. Methods

Each section of the pipeline with the adjacent territory, ground thickness, surface, local facilities, and climate is considered as a single system, all significant states of which can be described by a set of measurable parameters [12].

Means of monitoring the condition of the GCP system should include a set of measures, methods, software, and hardware designed to monitor and record the state of the trunk pipeline, the state of the atmosphere, and changes in the parameters of the soil condition [13-14]. Monitoring means should provide users with complete, accurate, and reliable information on the state of controlled parameters of GCP system elements, as well as on the development of hazardous processes (HP) causing emergency and preemergence situations [15].

The authors identify the following requirements for monitoring means:

1. The monitoring of pipelines in the section exposed to HP should be carried out simultaneously with the observation of the ground environment and atmosphere parameters, taking into account their mutual influence.
2. When combining the monitoring means, the compatibility of methods for measuring the values of each of the monitored parameters of the GCP system should be taken into account, as well as the ranking of sections according to the degree of emergency danger, changing in time.
3. Control of the section with the highest degree of danger should be carried out by automated measuring equipment (sensors).
4. Control of the stress-strain state of the GCP system – one of the integral indicators of the degree of danger, should be carried out periodically for all selected areas, the importance of assessing the dynamics of changes in the integral indicators, their analysis, and prediction of values taking into account the noted trends are recorded. All the listed steps will allow revealing such areas on the route, where HPs are developing and prompt intervention is required to prevent an emergency.
5. All information collected from sensors should be transmitted to the data collection and transmission unit (DCTU) in real-time.
6. The assessment, collected from the information sensors, should be carried out within the framework of single information technology using GIS and mathematical modelling of the interaction of soil masses, pipeline, and climate.
7. Automated control points, working in real-time, should carry out regular communication exchange of operational information with confirmation of their operability.

Thus, to provide comprehensive monitoring, which allows assessing the danger of the GCP system pipeline section, it is necessary to organize continuous monitoring of the following parameters:

- forecast (short-term, medium-term, and long-term) of climate parameters for pipeline sections;
- the size of the displacement of the soil mass and the pipeline relative to each other;
- groundwater level;
- changes in air and ground temperature and humidity;
- change of parameters of the flow rate, transported in the pipeline system of the substance;
- changing the position and preventing the destruction of the pipeline in sections subject to hazardous processes.

3. Results

All sensors of the monitoring system shall continuously measure the required indicators and transmit them to the control points. When selecting and placing the control points, where the parameters measured by sensors are monitored, it is necessary to take into account: peculiarities of laying the pipeline section in difficult climatic conditions, the possibility of unauthorized access by third parties, the lack of power supply network and data transmission channels in some sections of the pipeline laying.

Placing of the complex of technical means of control points is carried out in three variants:

1. placement in wells drilled in the ground at depths from 5 to 30 m;
2. placement directly on the surface of the main pipe;
3. placement in the zone of influence of the pipeline, including in the ground or above the surface on special supports.

The first variant provides for placing the complex of technical monitoring means in the points of clinometric control and groundwater level control, which provides the consideration of impact and influence of low temperatures, precipitation, and unauthorized access.

The second option involves placing the equipment at the control points to determine the position of the pipeline.

Measurements from the sensors are collected at control points. After measuring and preliminary automatic quality control of measured parameters, the information is transferred to DCTU. This unit accumulates the information received from the control points and analyses it for compliance with individual measurements. If there are no contradictions between the individual data portions, received from different sensors, the information goes to the monitoring database, where it should be checked for consistency of the computer simulation results.

4. Conclusion

The requirements proposed by the authors for the continuous automated monitoring system contribute to the prevention of accidents on pipelines or in case of their occurrence, as well as to the reduction of the probability of the environmental risk. The automated monitoring system allows for the timely monitoring of the Ground-Climate-Pipeline system due to the selection and placement of control points for the parameters measured by sensors.

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