Reliability assessment of main gas pipelines

M Kh Abduev1, B V Malozyomov2, O A Vlasov2

1 Chechen State University named after A. H. Kadyrov, 17а, Dudaev Boulevard, Groznyy, 364015, Russia
2 Novosibirsk State Technical University, 20 Karla Marks Ave., Novosibirsk, 630073, Russian Federation

E-mail: radc5@mail.ru

Abstract. The article is devoted to assessing and predicting the reliability of gas compressor stations and pipelines. The issues of equipment safety are discussed, which is also reflected in the linear control of main gas pipelines, which involves ensuring comprehensive and constant monitoring of the operating parameters of the system. It is shown that technically similar tasks are implemented with the help of automatic equipment, which is equipped with control rooms and compressor stations.

1. Introduction
The basis for the functioning of the gas industry at the present stage is the previously created and constantly developing unified gas supply system, which is an organically inseparable unity of gas fields, main gas pipelines, underground gas storages, and distribution systems that carry out a continuous technological process of supplying gas to consumers [1–3]. A special place in it is occupied by the process of gas transportation since it is characterized by the highest capital and capital intensity among the branches of the gas industry. The size of cost of transporting gas on average in the system is three times higher than its production costs [4–6].

The main gas pipeline is a complex set of engineering structures designed to carry out the process of transporting gas. The gas pipeline (Figure 1) includes head facilities, a pipeline with shutoff valves, bends and corrosion protection, compressor stations, underground storage facilities, gas distribution stations, etc. To service the production process, the gas pipeline has power and water supply facilities, power lines, transformer substations, boiler houses, pumping stations, artesian wells, and a number of other facilities [7–10].

2. Materials and methods
The main production process of gas transportation is as follows. Purified and dried gas in the process of field treatment is supplied to the head facilities of the gas pipeline, where it undergoes additional processing and odorization. After that, it is sent directly to the gas pipeline. Its linear part can be of constant or variable diameter. In some areas (usually the head ones), it consists of several pipes (of the same or different diameters) laid in parallel in one corridor [11]. Shut-off valves are installed every 20–25 km of the route to shut off, if necessary (repair, accidents), individual sections of the gas pipeline. To prevent the pipeline from corrosion, means of cathodic sacrificial protection and electrical drainage
installations are used [12]. Research should be carried out in the field of strength and microstructure [16].

Transportation of gas through the pipeline is provided by gas compression at compressor stations (GCS). The distances between compressor stations are determined by hydraulic calculation, taking into account the throughput of the gas pipeline, the maximum pressure at the outlet of the compressor station, the characteristics of compressors and turbines, as well as local conditions – the terrain, the availability of sources of energy and water supply, the proximity of settlements, etc [19; 20]. Usually, the distance between stations is approximately 120-125 km.

![Figure 1. Main elements of the gas compressor station.](image)

The pipeline itself is a pipe welded into a continuous thread. Usually, the upper generatrix of the main pipelines is buried in the ground to a depth of 0.8 m, unless a different laying depth is dictated by special conditions. When laying pipelines in areas with permafrost soils or through swamps, pipes are laid on supports or in artificial embankments. For them, seamless or welded pipes with a diameter of 300–1220 mm are used. The wall thickness of the pipes is determined by the design pressure, which can reach 10 MPa. In addition to the main pipelines, there are field, technological and distribution pipelines. At the intersections of large rivers, pipelines are weighted with loads or concrete coatings and buried below the river bottom. In addition to the mainline of crossing the rivers, a reserve line of the same diameter is laid.

Depending on the relief of the route, valves are installed on the pipeline at intervals of 10–30 km to block sections in the event of an accident or repair. Gas compressor stations are located along the route with an interval of 70–150 km and are equipped with electric centrifugal pumps. The supply (flow rate) of main pumps can reach 12500 m³/h. The head gas station is located near the gas field and differs from the intermediate ones by the presence of a tank farm with a volume equal to the three-day throughput capacity of the MN. If the length of the MN exceeds 800 km, it is divided into operational sections 100–300 km long. Within which independent operation of the pumps is possible. Intermediate gas stations located at the boundaries of production sites have tank farms with a volume of up to 1.5 day throughput capacity of MN.

An analysis of the causes of accidents in heat networks shows that of the totality of factors leading to a violation of the tightness of the linear part of these structures, the main role is played by defects of various origins, leading to loss of the coolant and a decrease in the reliability of heat supply to consumers. The formation of defects is possible at all stages of the life cycle of the pipeline: during the production of pipes, during construction and installation works, during operation. To ensure the safe
operation of pipelines, it is necessary to implement a set of measures to improve the maintenance and repair of pipelines based on the systematic control of the pipeline system by non-destructive methods.

Technical diagnostics is becoming a kind of indicator and guarantor of the quality and reliability of the Russian pipeline system, so its application is relevant. To date, there are quite a variety of methods of in-line diagnostics, let us dwell in more detail on those that are already successfully used at the leading enterprises of thermal networks in Russia. PJSC MOEK actively uses in-line diagnostics based on the acoustic resonance method (Unicom ZSK). An in-line inspection device (VTIP) is shown in Figure 2.

![Figure 2. VTIP by acoustic resonance method.](image)

The main advantages of this method are the high speed of diagnostics, which makes it possible to map the residual thicknesses of the pipeline along the entire length of the surveyed section with a 360-degree sweep. Limitations are the maximum scanning length in one direction is 750 m in one direction, the examined pipe diameter is 300-600 mm, the measurement accuracy is ± 0.25 mm, the pipeline must be filled with water at a temperature not exceeding 40 °C. In-line diagnostics by the magnetic method of alternating magnetization (MMK) (Gazproekt DKR company) has found wide application at JSC “Teploset of St. Petersburg”. The in-line diagnostic complex (ITDK) is shown in Figure 3.

![Figure 3. In-line diagnostic complex variable magnetization method.](image)

The main advantage of HTDC is the combination of the MMC method and the ultrasonic method. Restrictions are the maximum scanning length in one direction is 550 m in one direction, the examined pipe diameter is 600–1200 mm, the measurement accuracy is ± 1 mm, the pipeline must be empty, the air temperature in the pipe must not exceed 40°C.
In difficult operating conditions, maintaining the reliability and safety of pipeline operation is a rather important task, which determines the preservation of a clean environment and the absence of the need to spend on unscheduled pipeline repairs. Ensuring safety is impossible without an integrated approach, which includes the study of the patterns of changes in the state of the pipeline during operation and the analysis of reliability indicators [17, 18].

The article presents the existing assessment methods, as well as a new method that allows you to calculate the probability of failure-free operation of pipelines depending on the length. The article analyzes statistical data on pipeline failures in the fields of Western Siberia, calculates the probability of failure-free operation in accordance with the proposed methods.

**Table 1.** Dynamics of the causes of pipeline failures in percentage terms.

| Causes of failures        | All period | Years |
|---------------------------|------------|-------|
|                           | 2017 2018  | 2019  | 2020  | 2021  |
| Corrosion internal        | 3          | 30    | 77    | 80    | 93    | 63    |
| Corrosion outdoor         | –          | 2     | 1     | –     | –     | 1     |
| Localized corrosion       | 71         | 28    | 13    | 15    | 2     | 19    |
| Stream corrosion          | 22         | 35    | 8     | 3     | 2     | 13    |
| Pipe marriage             | 1          | 1     | –     | 1     | 1     | 1     |
| Construction marriage     | 1          | 1     | –     | 1     | 1     | 1     |
| Mechanical damage         | –          | –     | 1     | –     | –     |       |
| Others, not defined       | 2          | 3     | –     | –     | 1     | 1     |

Table 1 shows the values of the generalized reliability index (the number of failures per 1000 km of pipes per year) for pipes of various diameters. It can be seen from the table that there is a trend towards a decrease in the number of failures per 1000 km for larger diameter pipes compared to smaller diameter pipes. However, low values for pipes Ø530 rather speak of the insufficiency of statistical data.

**Table 2.** Generalized reliability index.

| Pipeline diameter, mm | Failure rate, km/year |
|-----------------------|-----------------------|
| 114                   | 527                   |
| 159                   | 300                   |
| 168                   | 91                    |
| 219                   | 208                   |
| 273                   | 267                   |
| 325                   | 145                   |
| 426                   | 78                    |
| 530                   | 4                     |
3. Results and discussion
Figure 4 shows the distribution of failures by operating time for the entire range of pipelines in the considered field. It can be seen that the largest number of failures (about 75%) falls on the period from 3 to 10 years of operation. According to the qualitative analysis, the time distribution of failures does not contradict the Weibull distribution. Analyzing the data in Figure 4, one can notice the presence of two local maxima at the 3rd and 6th years of operation, and the maximum at the 3rd year is also global.

![Figure 4. Distribution of failures by operating time for the entire range of pipelines.](image)

A number of models are proposed for determining reliability characteristics based on operational data, taking into account the fact that the gas collection and pumping system is a system with distributed parameters:

$$
P(t,l,n) = \frac{L_0(t) - l_0 \cdot \sum_{i=1}^{t/\Delta t} n_i}{L_0(t)},
$$

where $l_{av}$ is the weighted average length of the pipeline section in case of failure, m, is calculated by the formula:

$$
l_{av} = \frac{\sum_{i=1}^{t/\Delta t} l_i(\Delta t)}{t/\Delta t},
$$

As an example, we will calculate the reliability of pipeline sections with a length of 150 and 300 meters using formulas (1) and (2). Figure 5 shows the probability of failure-free operation for the entire range of pipelines depending on the operating time for sections 150 and 300 m long: 1 – calculation by equation (1), 2 – calculation by equation (2). Figure 4 shows the probability of failure-free operation calculated by equation (2) for the entire range of considered pipelines from 1 to 21 years of operation. Figure 5 shows the change in the probability of failure-free operation over 3-year periods.

4. Conclusion
With an increase in operating time up to 20 years, the difference in the probability of failure-free operation for a section 300 m long is 0.07, or about 10%. Note that the discrepancies in the results obtained by formulas (1) and (2) are greater than longer the length of the pipeline section and the period of its operation.
Figure 5. Probability of failure-free operation of pipelines: 150 m long (purple cubes); 300 m long (yellow triangles).

The specificity of the construction and operation of gas pipelines is, in principle, determined by the increased requirements for the serviced environment. From this point of view, safety issues play a special role, which is also reflected in the linear management of main gas pipelines, which involves ensuring comprehensive and constant monitoring of the system's operating parameters. Together with the pressure, the indicators of flow, temperature, humidity and the state of the electromechanical circuits are recorded. These and other parameters of the network make it possible to control the efficiency indicators of gas supply to target facilities. Technically, similar tasks are implemented using automatic equipment, which is equipped with the same control rooms and compressor stations.

Regular patrols of gas pipelines are carried out in order to detect malfunctions or malfunctions in certain areas. After analyzing possible accidents or breakdowns, a plan of repair procedures is drawn up. Next, preparations are made for work with cleaning the working area. The nature of the repair of the main gas pipeline depends on the location of the breakdown and its severity. The technical control service, in particular, can correct the position of shut-off valves, control, and measuring devices and eliminate the leakage of fasteners. As preventive repair and restoration procedures, replacement of fences, painting of structures, strengthening of support blocks, and restoration of insulation contacts with dielectrics are carried out.

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