Solutions for monitoring the technical condition of metal structures and pipelines located at an altitude

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Abstract. Periodic monitoring of the technical condition of metal constructions and pipelines at an altitude is an important part of their safe operation. For this purpose, as a rule, drones or methods of industrial climbing are used. In this research we propose a method of robotic inspection of such structures, which will substantially reduce the costs of maintenance work at an altitude and increase their level of safety. The main scientific interest is the creation of a universal kinematics adjusted to different obstacles not only on the pipelines but also on the metal constructions. In the course of the works there was conducted a fundamentally different experience in the mounting of supporting structures and metal constructions. The received knowledge was systematized in an album of the obstacles, on the basis of which the kinematics of the robotic device was modified.

1. Introduction
Periodical monitoring of the technical condition of metal structures and pipelines located at heights is an important part of their safe operation. For this purpose, as a rule, unmanned aerial vehicles or methods of industrial climbing are used [1].

In this article, we propose a method of robotic inspection of such structures, which will significantly reduce the cost of regulatory work at height and increase their safety. At the stage of preparation for the development of the technical monitoring device more than 243 literature sources were analyzed, including 168 foreign literature sources, a review of 72 patents was conducted, including more than 40 foreign patents. The results of the work were discussed at the 75th International Youth Scientific Conference "Oil and Gas - 2021" in Moscow.

2. The main part
2.1. Topicality of the problem
More than 35 thousand km of above-ground pipelines belonging to gas distribution organizations have been constructed and are in operation in the Russian Federation as of 2021. More than 70% of them belong to the group of pipelines located at a height of more than 3 meters, laid on support structures, metal trestles or on the walls of buildings.

Technical condition monitoring of pipelines of complex spatial configuration located at the height, as well as of large vertical technological installations and metal constructions is a well-known difficulty. For this purpose, as a rule, either industrial alpinism or unmanned aerial vehicles are used.

These methods are not able to solve the whole range of problems, in this connection it is proposed to supplement them with a device remotely controlled from the ground, moving on the outer surface of...
the pipeline, which will allow to detect leaks, assess the condition of the corrosion protection coating and identify defects of pipelines [2]. The main difficulty and scientific interest lies in the creation of a universal kinematics, which can overcome various irregularities not only in pipelines, but also in metal structures.

2.2. Description and characteristics of the designed robotic device

The device under development is a controlled robotic complex for remote monitoring of above-ground gas pipelines, designed for performing the following activities under the operator's control: detection of natural gas leaks, visual inspection of the gas pipeline and its supports while monitoring the technical condition of gas pipelines in the range of nominal diameters DN50 - DN200, laid on the walls of the building at a height of over 3 meters from the ground, without climbing and working at height [3].

Figure 1 shows an image of the 3-d model of the RCDM prototype with its main elements and components, allowing you to visually familiarize yourself with the visual component of the device.

![Figure 1. Sketch of RCDM: 1 – neodymium magnets; 2 – telescopic rods; 3 – gear motor; 4 – pipeline; 5 – directional cameras; 6 – surveillance cameras; 7 – protective cover.](image)

Table 1 also provides a brief technical description of the RCDM prototype shown in Figure 1.

| Parameter of characteristic | Unit      | Value               |
|----------------------------|-----------|---------------------|
| Width                      | mm        | 180                 |
| Length                     | mm        | 136                 |
| Height                     | mm        | 140                 |
| Weight                     | kg        | 1.9                 |
| Kinematics                 |           | Tilting caterpillar tracks with neodymium magnets |
| Existence of gas analyzer  | -         | yes                 |
| Radio control channel      | -         | Wi-Fi               |
| Video stream               | -         | FPV                 |
| Telemetry transmission     | -         | LoRa                |
| Wireless signal range      | m         | Minimum 100         |
| Dust and water resistance  | -         | Not lower than IP67 |
| Operating temperature range| °C        | -10...+40           |
2.3. Calculation of effective magnetic cohesion force with the pipe surface

Taking into consideration the fact that the surface, along which the RCDM moves, has a cylindrical shape, then at any given moment the effective contact area between each of the magnets and the pipeline surface will be less than the total area of the magnet [4]. As a consequence, the bonding force of each magnet will also decrease. In addition, the unevenness of the paint coating of the pipeline and its negative effect on the adhesion force must be taken into account. Figure 2 shows a scheme of the contact patch of a magnet with the surface of a gas pipe in two planes.

![Figure 2. Scheme of the contact between the magnet and the gas pipe: w – width of magnet; l – length of magnet; h – height of magnet; r – outer diameter of pipe.]

Therefore, to obtain the effective cohesion force of the magnet at each time point, we need to integrate the decreasing cohesion values along the sides of w/2 [5]. The above described parameter can be expressed and calculated by formula (1).

\[
\int_{0}^{\frac{h}{2}} \int_{0}^{\frac{w}{2}} \frac{C_b \cdot B_r \cdot l}{(E_0 + r + \sqrt{r^2 - x^2})^2} \cdot dx \cdot dy = F, E_0 \approx 0
\]

where \( h \) – magnet height; \( w/2 \) – interval equal to half of the magnet width; \( C_b \) – coefficient decreasing the magnet’s adhesion force; \( B_r \) – residual magnetic induction; \( l \) – length of magnet; \( E_0 \) – minimum bond radius; \( r \) – outer diameter of pipe; \( F \) – effective bond force.

In table 2 you can find the calculation of effective bond force and effective shear force (for N35 series magnets - ~50% of traction force) for the most common diameters of gas pipelines in gas distribution organizations in the territory of the Russian Federation and the minimum quantity of magnets required for stable keeping the RCDM weight on the gas pipeline.

**Table 2.** Calculation results of bonding force and the area of contact between the magnet and the surface of the gas pipeline.

| Characteristics                  | Unit | DN50 | DN80 | DN200 |
|----------------------------------|------|------|------|-------|
| Bond force of 1 magnet           | kg   | 0.35 | 0.42 | 0.62  |
| Shear force of 1 magnet          | kg   | 0.18 | 0.21 | 0.31  |
| Required number of magnets for shearing force 3 kg | –    | 16   | 14   | 10    |
2.4. Description of the components of the device and the main technical modules

RCDM is a robotic monitoring complex that allows visual inspection of the gas pipeline condition and remote diagnostics of possible gas leaks.

The RCDM is equipped with a gas analyzer. To improve accuracy in detecting possible leaks, gas is taken from three locations: under the tracks and on both sides of the gas line, through air intakes placed on the telescopic arms [6]. The RCDM is powered by a replaceable lithium-polymer or lithium-ion battery. Control of mechanics, electronics, telemetry collection and transmission of the RCDM is performed by a microcontroller onboard the complex and software on the operator’s tablet (or PC). The battery and electronics of the complex are located under the protective cover [7]. A detailed description of the device can be seen in Figure 3 with the control unit cover removed.

![Figure 3](image)

**Figure 3.** Sketch of the RCDM with the control unit cover removed: A – accumulator; B – tracks; C – tubes for air intake; D – single-suction blowers; E – Gas leakage indication module; F – control unit; G1, G2 – cameras; H – telescopic boom; I – neodymium flat magnet; J – gear motor.
The complex is designed in accordance with the principle of maximum use of typical elements included in it. For example, the gas leak indicator module, air blowers, video cameras, sockets, hardware, batteries, neodymium magnets and other elements are produced in a wide range of component manufacturers and are not tied to a particular manufacturer. Therefore, the complex has a high maintainability by own efforts of the operating organization by replacing the components [8].

It is proposed to use Android tablet which will be connected to RCDM by means of router via Wi-Fi [9]. The positioning of the robotic device is carried out by means of an inertial tracker [10].

The complex is supposed to be delivered, stored and transported to the place of operation in a shock-proof case equipped with trays for the complex components [11-12]. As an existing example of the construction of aboveground pipelines with a complex spatial configuration, Figure 4 shows a photo of a section of a pipeline in operation.

![Figure 4. Photo of the gas pipeline of complex spatial configuration, laid along the wall of the building on support structures at a height on the territory of St. Petersburg.](image)

Based on the analysis of existing sections of pipelines with complex spatial configuration in the city of St. Petersburg and summarizing the most common elements of the pipeline, such as: supporting structures, pipeline bends, constrictions/expansions) in the laboratory complex located on the territory of St. Petersburg Mining University, a stand consisting of pipelines of different diameters was designed and built to test the mechanics and kinematics of the technical device RCDM.

During the analysis and classification of the existing configurations of gas pipelines laid on the walls of the buildings, ways of fixing them on supports and conditions of their location, a large number of areas of non-standard installation, as well as standard, but notoriously difficult to pass areas were identified [13]. It was found that, as a rule, such sections are located on the horizontals in the vicinity of the ground surface, but the height of the location of these sections can exceed 3 m from the surface [14].

Figure 5 shows images of the design of the stand for laboratory tests of the mechanics and kinematics of the RCDM device, as well as a photo of the test stand that has already been built.
Figure 5. Designed and constructed stand for laboratory tests of the device kinematics and mechanics (St. Petersburg Mining University).

The lab stand allows you to test various kinematic models of a robotic device on pipelines close to real ones by experiment, to see the strengths and weaknesses of the solution during the tests and to refine the shortcomings.
3. Conclusion

The result of the work was a developed working prototype with a tracked chassis and selected technical equipment, the analysis of existing complex configurations of pipelines and the construction of a stand for laboratory tests.

A promising area of development will be the definition and justification of standards for work on the inspection of aboveground gas pipelines, which can be set after the bench tests, and finally by the results of pilot operation, where at the moment the prototype device is located. The basic crawler kinematics for the device was selected, justified by the calculation of magnetic coupling and after more than 15 tests of various kinematic schemes.

The next stage of the work will be the design and creation of a prototype to test the device in real conditions. In further development of the project it is expected to consider the possibility of introducing a machine learning system, defect identification, using augmented reality glasses to improve the efficiency and accuracy of gas leak detection on gas pipelines with a complex spatial configuration located at height.

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