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In-pipe robot with automatic wheel span adjustment

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Abstract: The wheeled in-pipe robot with automatic adjustment of the wheel span according to the diameter of the pipeline is intended for movement in pipelines. This robot includes a mechanism for adapting the width of the wheels according to the inner diameter of the pipe. The developed motion module can be used multiple times and thus realize a robot with a larger number of modules to achieve greater traction force.

1 Introduction

The wheeled inpipe robot is intended for movement inside the pipeline for the purpose of inspection or repair of damaged pipelines or for the purpose of transporting cables or other equipment inside the pipeline. Existing solutions mostly use the wheel principle of movement in the pipeline, but the problem with these devices is that their use is problematic if there are dirt, deposits, changes in diameter or other obstacles in the pipeline, for example associated with the technology of the production of pipeline networks such as couplings, elbows, T - piece, reductions, etc. [1-7].

The robot enables movement in the pipeline with the help of wheels, the span of which can be adjusted according to the current value of the diameter of the pipeline, and it is also possible to adjust the normal pressing force of the wheels on the pipeline wall so that the wheels of the device inside the pipeline do not slip or collide.

2 Principle of the robot drive module

The robot (Figure 1) is designed to move inside the pipeline with the possibility of automatic adjustment of the width of the robot's wheels according to the internal diameter of the pipeline.

For its movement in the pipeline, the robot uses three groups of wheels evenly distributed around the perimeter of the device on a retractable mechanism, which can be used to change the width of the wheels, that is, the distance of the wheels from the axis of the device. Between the main body and the fixing body, three guide rods are attached, along which the slide moves with the movement nut and the guide screw located in the middle of the guide rods. In the main body, the servo drive of the guide screw is located, which turns the movement screw and thus allows the slide to change its position. The drive wheel carrier moves on the guide rods, which is connected to the slide by means of a spring. The idler wheel carrier is placed on the auxiliary guide rods, which is connected to the slide by springs. The main arms of the driving wheels are attached to the drive wheel carrier by a rotary joint, the movement of which is tied to the main body of the robot by the auxiliary arms. At the end of the main arms of the drive wheels, the drive wheels are mounted on a drive shaft with a bevel gear, with the help of which the torque from the servo drive of the drive wheels is transmitted. The idler carrier is mounted on the auxiliary guide rods attached to the slide with the movement nut. The idler arms with the attached idler wheels are attached to the idler carrier by rotary joints. The drive and idler wheels are connected by connecting rods. Three such groups of mechanisms for such wheel adjustment are attached to the device, which are evenly distributed around the perimeter of the device at an angle of 120°. Between the slide and the drive wheel carrier is a position sensor composed of a permanent magnet and a sensor sensitive to the magnetic field. This position sensor detects the deformation of the spring located between the slide and the drive wheel carrier. This deformation of the spring is caused by a change in the internal diameter of the pipe and thus an increased or decreased normal pressure force of the wheels.

The principle of operation of the drive module of the robot consists in the fact that the information about the normal pressure force of the wheels on the pipe wall obtained from the position sensor is used in the control unit to automatically adjust the slide using the servo drive of the lead screw, and thus the span of the wheels will be adjusted, that is, the distance between the driving and driven wheels in a direction perpendicular to the pipe wall.

The advantage of this principle is that there is an automatic setting of the normal pressure force of the wheels on the pipe wall, and thus the wheels of the invention do not slip or get in the way of the pipe. From the principle of equality of forces, it follows that with this arrangement of groups of wheels at an angle of 120° around the perimeter of the device, there is an automatic centering

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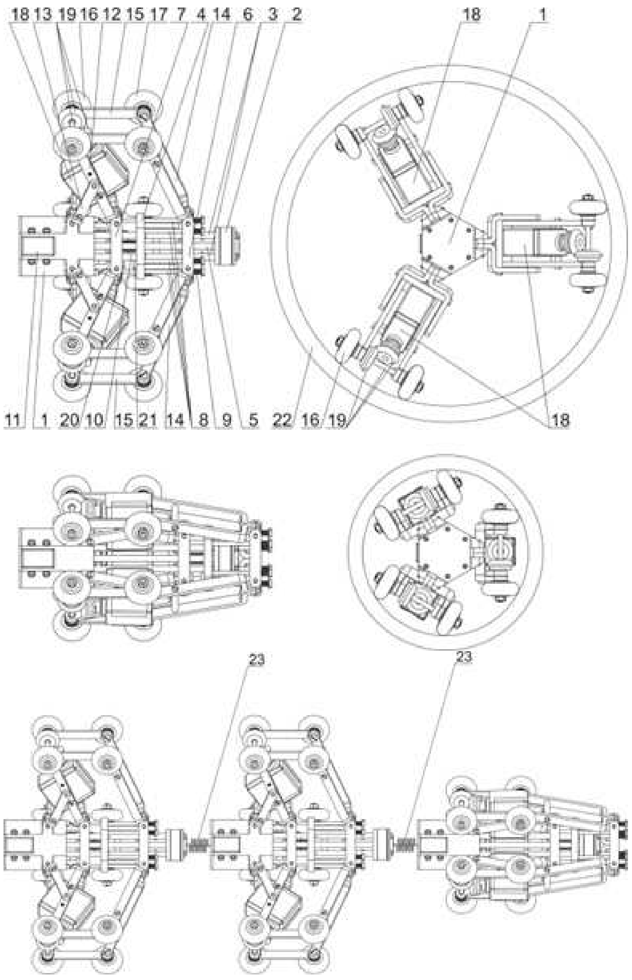
of the wheels with respect to the wall of the pipe and an even distribution of normal pressure forces on all drive wheels. Several such drive modules can then be connected behind each other using joints or connecting springs to create a modular robot with the ability to traverse even complicated pipe networks containing elbows, T-pieces and branches. Another advantage of the robot is that with this arrangement it is possible to change the width of the wheels to a large extent in relation to the overall dimensions of the device. Another advantage is that there is a spring between the slide and the drive wheel carrier and the idler wheel carrier, which also enables passive compensation of pipe unevenness.



1 – The main body of the robot; 2 – Fixing body; 3 – Guide rod; 4 – Slide with movement nut; 5 – Guide screw; 6 – Freewheel carrier; 7 – Drive wheel carrier; 8 – Auxiliary guide rod; 9 – Auxiliary guide rod spring; 10 – Guide screw spring; 11 – Servo drive of the guide screw; 12 – Main drive wheel arm; 13 – Auxiliary drive wheel arm; 14 – Arm of idle wheels; 15 – Connecting rod; 16 – Drive wheel; 17 – Freewheel; 18 – Drive wheel servo drive; 19 – Drive shaft with bevel gear; 20 – Position sensor; 21 – Permanent magnet; 22 – Pipeline; 23 – Connecting springs.

Figure 1 Overall layout of the wheeled inpipe robot with automatic wheel span adjustment according to the pipe diameter

However, if the degree of unevenness of the pipe or the change of the diameter of the pipe exceeds a certain set limit, then the control unit will adjust the wheel span to a new value using the servo drive of the adjusting screw, so that the movement of the equipment in the pipe is efficient.

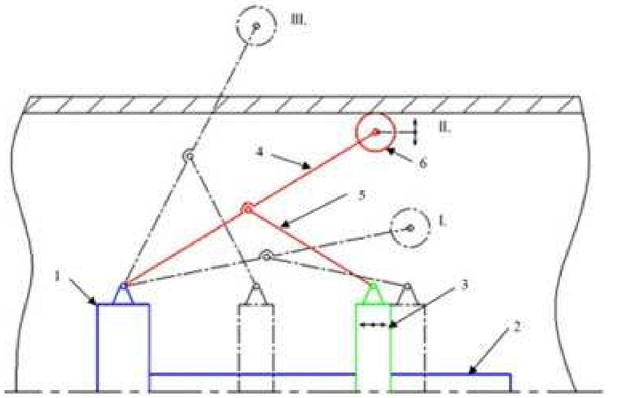
The robot (Figure 1) includes a main body (1) and a mounting body (2), between which guide rods (3) are attached. The slide with the movement nut (4) moves along the guide rods (3) with the help of the movement of the guide screw (5) driven by the servo drive (11). The drive wheel carrier (7) also moves along the guide rods, and the idler wheel carrier (6) moves along the auxiliary guide rods. There is a spring (10) between the slide (4) and the drive wheel carrier (7), and the springs (9) are located between the slide (4) and the idler wheel carrier (6). The main arms of the driving wheels (12) are attached to the carrier of the driving wheels (7) by means of a rotary joint, and they are connected to the main body of the robot (1) by means of the auxiliary arms of the driving wheels (13). On the main arms of the driving wheels (12) there is a driving shaft and bevel gear (19) which is connected to the servo drive (18). The freewheel arms (14) are attached to the freewheel carrier (6) by means of a rotary joint. Drive and wheels (16) and idler wheels (17) are connected by rotary joints using a connecting rod (15). On the main body (1) there are three such mechanisms consisting of arms (12, 13, 14), connecting rods (15), drive wheels (16), idler wheels (17), drive wheel servo drive (18) and a drive shaft with a conical gears (19). A position sensor (20) sensitive to the magnetic field is located on the drive wheel carrier (7) and a permanent magnet (21) is located on the slide (4). Drive wheels (16) and idler wheels (17) are in contact with the pipe wall (22). The device according to the proposed solution can be connected modularly with other such devices by means of connecting springs (23) and thus create a device with a higher traction force and wider application possibilities.

3 Kinematics of the robot drive module

The kinematics of the robot should ensure the change of wheel span so that it is possible to change the position of the wheels as needed (Figure 2).

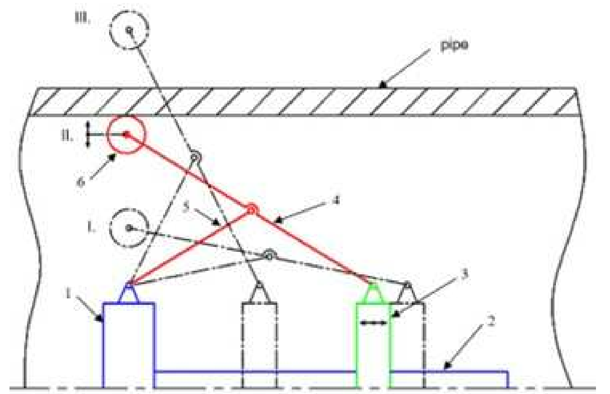
Members 1 and 2 are firmly connected. Member 3 slides over member 2, which changes the lift height of the arm formed by 4, 5 and the pressure wheel. In this way, the arms are able to adapt to a relatively large range of pipe diameters.

The main disadvantage of this solution is that in position I. for the smallest diameter of the pipe, the entire mechanism of the arms moves backwards and thus also the wheel, which moves the entire center of gravity of the inpipe robot significantly forward. Also, the distance between the point of contact of the wheel with the pipe and the origin of the inpipe robot will increase to a large value in proportion to the diameter of the pipe. As a result, it would be impossible for the robot to pass through the curved pipe. For these reasons, it is more appropriate to choose the design in Figure 3.



1 – basic member, which is immovable; 2 – member on which member no. 3; 3 – sliding member; 4, 5 – arm elements; 6 – pressure wheel; I., II., III. – positions of the inpipe robot in its working range

Figure 2 Design of the basic kinematics of the inpipe robot - variant 1



1 – basic member, which is immovable; 2 – member on which member no. 3; 3 – sliding member; 4, 5 – arm elements; 6 – pressure wheel; I., II., III. – positions of the inpipe robot in its working range

Figure 3 Design of the basic kinematics of the inpipe robot - variant 2

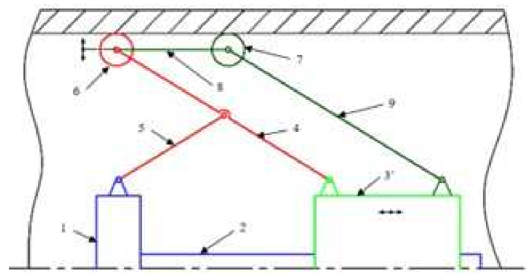
The position of the wheels relative to the origin of the inpipe robot does not change to the same extent as in the previous design. With a suitably chosen length of arms, this distance does not change at all.

By moving member 3, the center of gravity moves in the direction of its displacement. Assuming that the member is several times smaller (has a lower weight) than member 1 and the proposed drive for moving member 3 will be located in the front part, the change in the position of the center of gravity in this case is smaller than in the first case.

With this design, in the case of horizontal movement of the inpipe robot relative to the earth's surface, due to the influence of gravity and the uneven distribution of weights to the right and left of the pressure wheels, the proposed robot would tip over, i.e. fall. By designing another trio of wheels connected by arms to the original wheels, this problem is eliminated (Figure 4).

The problem with this solution arises when the pipe diameter changes (Figure 5). If the diameter of the pipe decreases, the front pressure wheels copy the change in diameter and the entire structure shrinks. In this way, the rear wheels cannot copy the wall of the pipe, which is behind the front wheels of a larger diameter.

When expanding, the opposite situation occurs and the front wheels cannot copy the pipe wall.



1 – basic member, which is immovable; 2 – member on which member no. 3; 3' – member 3 extended and supplemented with a pin for arm 9; 4, 5 – arm elements; 6 – pressure wheel; 7 – rear pressure wheel; 8 – connecting arm; 9 – rear pressure arm

Figure 4 Design of the basic kinematics of the inpipe robot - variant 3

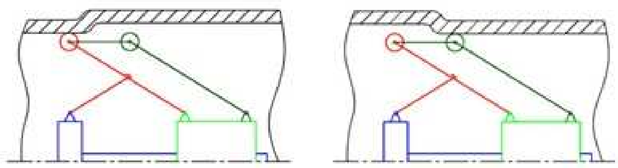


Figure 5 Changing the pipe diameter

From the above, it follows that with any change in the diameter of the pipe, not all pressure wheels will be in contact with the pipe.

By dividing the part 3' (Figure 4) into two separate parts 3 and 10, which will be connected by a flexible member 11 (e.g. a spring), this problem is eliminated (Figure 6). The part 10 is pressed and pushed away by the spring 11 from the member 3, thereby adapting to the shape of the pipe.

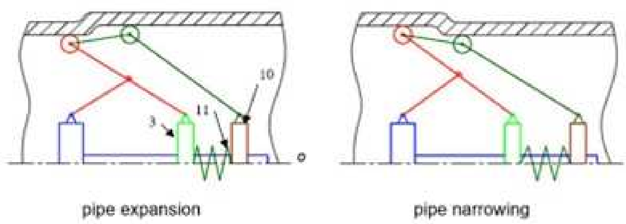


Figure 6 Adaptation to change in pipe diameter

In this design, two pressure wheels are used with an average distance *l* from each other (Figure 7, Figure 8).

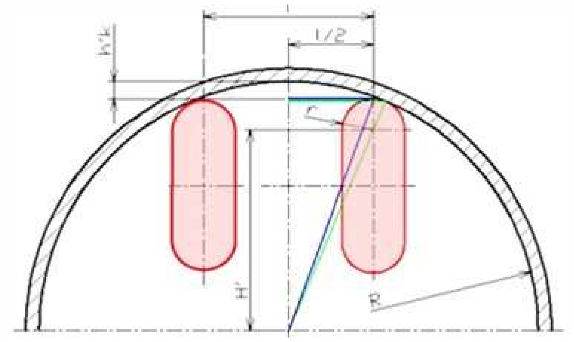


Figure 7 Contact of the pressure wheel with the pipe wall

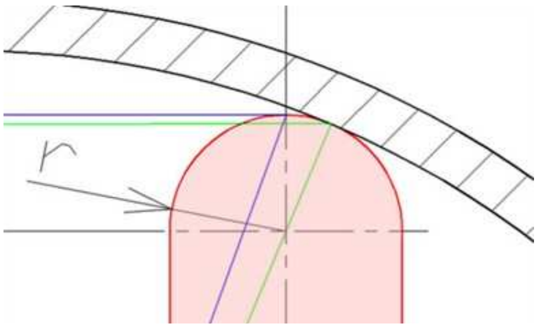
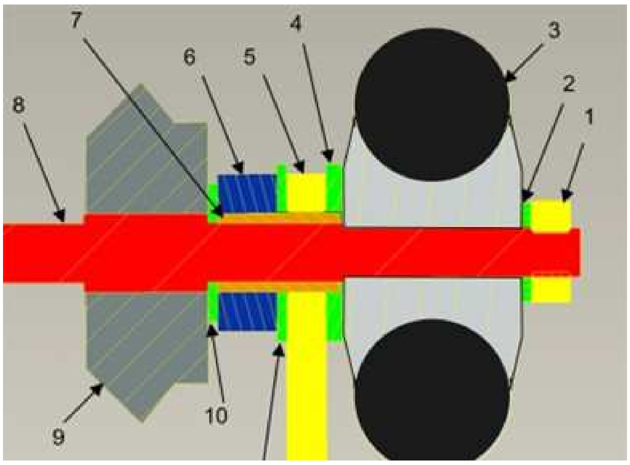


Figure 8 Detail of the contact of the pressure wheel with the pipe wall

4 Design of the robot mechanism

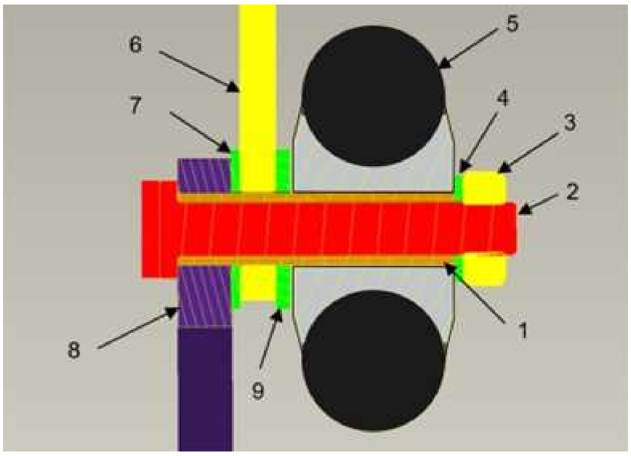
The design of the structure of the robot arm mechanism is created according to kinematic variant 3 (Figure 4). The wheels are housed in sliding bearings with direct transmission using a bevel gear (Figure 9). The bevel wheel 9 (Figure 7) is pressed onto the shaft 8. The sliding bearing also serves as a pin which is pressed into the arm 6. The arm 5 rotates freely around this pin (7). The driven wheel is slid onto the shaft and secured with a lock washer and nut. Sliding bearing 7 is designed from a brass rod blank of intermediate cross-section, due to the favorable coefficient of friction between steel and brass.



1 – nut; 2 – flexible mat; 4, 10, 11 – mat; 3 – driven wheel; 5 – connecting arm; 6 – shoulder; 7 – sliding bearing; 8 – shaft; 9 – bevel wheel

Figure 9 Construction of the driven wheel

The idler wheel (Figure 10) is designed to stabilize the robot when moving in the pipeline. It is mounted on a sliding bearing and carries part of the load caused by the normal force on the pipe wall. The normal force on the pipe wall is necessary to ensure sufficient contact for the robot to be able to move even in a vertical pipe.



1 – sliding bearing; 2 – screw; 3 – nut; 4, 7, 9 – mat; 5 – idle wheel; 6 – connecting arm; 8 – arm

Figure 10 Construction of the idle wheel

5 Adaptable wheel adjustment mechanism

The opening of the arms of the inpipe robot is ensured by the movement of member 3 (Figure 11). The movement of this member can be ensured by using a threaded rod 7 located in the axis of the pipe stand. This rod is placed in bearings at both ends and passes through the face 3, in which there is a thread. The rotary movement of the threaded rod causes the movement of member 3 and thus also the opening and closing of the arms of the inpipe robot. Due to the ability to adapt to the change in the pipe diameter of the front and at the same time the rear wheels, the threaded rod passes through part 4 freely, so it does not affect its position.

The guidance of member 3 and 4 is secured by guidance formed by 3 rods of circular diameter 6. By using 3 guide rods, rotation of member 3 relative to member 1 in a plane perpendicular to the direction of movement of the inpipe robot is prevented. This also prevents twisting of the shoulders.

The guide rods 6 are firmly attached by means of screws in members 1 and 2 (Figure 11). Member 2 can freely pass through member 5, which shortened the total length of the inpipe robot compared to the solution if member 5 abutted member 2. In this case, member 2 abuts up to member 3. The extreme positions are equipped with rubber stops 11.

Adaptation of the robot in the pipeline is ensured by force control using a spring and servo drive system.

The adaptation of the in-pipe robot to the inner surface of the pipe is a key function in terms of ensuring the movement of the robot in the pipe, especially when moving in a vertical pipe, where it is also necessary to overcome the weight of the robot. The pressure of the wheels on the pipe wall creates the necessary friction force between the wheels and the pipe wall. Since the internal dimensions of the pipe are not the same and, in addition, there are also technological residues after joining the pipe inside, it is also important to ensure the adaptability of the robot's wheels.

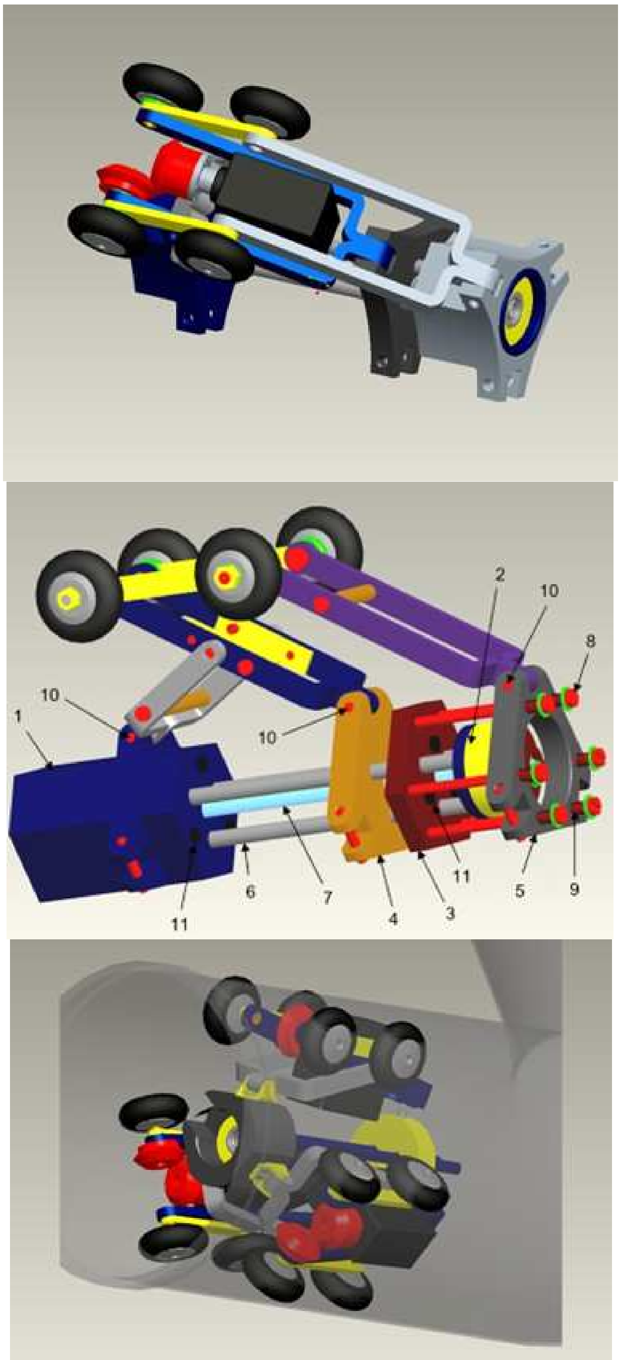


Figure 11 Adaptable wheel adjustment mechanism

6 Conclusion

In this article, an inpipe robot was designed, which is able to move in pipes with an internal diameter from 100mm to 200mm. It has the ability to adapt to the current internal diameter in order to ensure sufficient traction force and speed of movement of the robot. The robot is intended for service activities such as pipe inspection and repair.

The design of such devices that are used in confined spaces requires a comprehensive approach in the design of the concept of this device, and the design of mechanics, electronics and controls for the proposed device must be created at the same time [8-19].

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Review process

Single-blind peer review process.