MACHINES FOR INSPECTION OF PIPES

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Abstract: Machines for inspection of pipes are locomoted inside pipe via used various types of locomotion. This arcticle deals with wheeled in-pipe locomotion. Developed in-pipe machines are described. Pipe is as constrained space and it is complicated to design the machine for this purpose. Problems that are necessary to solve can be divided into several groups, small dimension and scalling effect of actuators, power supply and cables, impurities inside pipes etc.

1 Introduction

In-pipe micromachines are able to move in the pipe to inspect or to repair the pipe or other special tasks. Pipe is as confined space i.e. this is constraint for micromachine dimensions, degrees of freedom etc. There are a lot of interdisciplinary problems in design and realisation of in-pipe micromachine. It is difficult to choose suitable actuators, sensors, and power supply etc.

In term of biological analogy, it is possible to divide ways of locomotion into two main groups [1-15]:

- artificial locomotion,
- biological inspired locomotion.

In term of physical principle, we can divide both these groups into several basic locomotion ways. It is important to say that it is not final and changeless dividing [1-15].

Wheeled locomotion principle: Wheels are standard synthetic components, which are very often used for locomotion purposes. However inner pipe wall is not perfect. There are a lot of obstacles, which have various characters. When inner pipe wall is dirty, wheels tend to slipping.

Crawled locomotion principle: Tracks is also unfinished rotating element. It is most adaptable to surface then wheels but it is not so often used as wheels.

Legged locomotion principle: Legs are components, which have inspiration in biology (e.g. spider, cockroach etc.). Many biological organisms reach high speed, which locomote via legs. These organisms overcome difficult obstacles and there are fascinating for designers.

Inchworm-like principle: The inchworm strategy comes from biological example. The inchworm is capable of manoeuvring in extremely small spaces, it can do so in arbitrary orientations to gravity and can withstand substantial external forces attempting to diverge it from its intended course. It can do these things because its mobility system is governed by a simple rule: "Never let go of what you're holding until you're holding something else!“.

Inertial stepping locomotion principle: The principle based on fact that a part of device (inertial mass) oscillates with suitable frequency. Backward tendency of motion is damped.

Worm-like locomotion principle: The locomotion uses anisotropic properties of friction between device and pipe wall. Forward friction force is less then backward friction force. It causes that device locomotes in forward direction.

Travelling wave locomotion principle: Device has articulated body and generates travelling wave from head to tail [1-15].

In-pipe inspection is considered as objective method for crack detection and in some cases it is only one possible way of pipe inspection. There are very known facts about accident in nuclear power plant, which has very bad impact to people and environment. These damages caused with pipe crack are higher than value of the pipe system. These facts were the initial impulse for in-pipe inspection developing. Some pipe systems are placed in environment, which is dangerous for people, so this is area right for in-pipe micromachine. In-pipe inspection is always cheaper than eliminating of accident results. It is very difficult to develop universal inspection in-pipe micromachine. In the most cases is possible to determine concrete conditions, in which the micromachine will locomotes. Following this condition, the way of locomotion and sensing system are selected. Situation is more complicated if inner pipe diameter decreased [1- 15].

2 Wheeled modular machine for constant inner pipe diameter

At first a compact machine MATALU for in-pipe locomotion has been developed for pipe with inner diameter from 34 to 36 mm (Figure 1). This concept has low traction force and problem with crossing of T – joint.

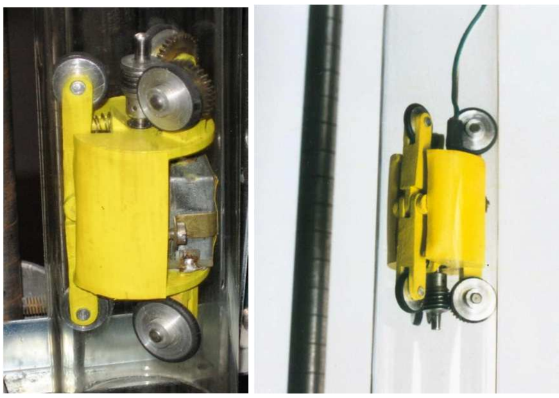

Figure 1 Compact in-pipe machine MATALU

Next developed wheeled machine FENAUS has been arranged as modular mechatronic system for pipe inspection of inner diameter from range 34-36 mm. (Figure 2) [16, 17].

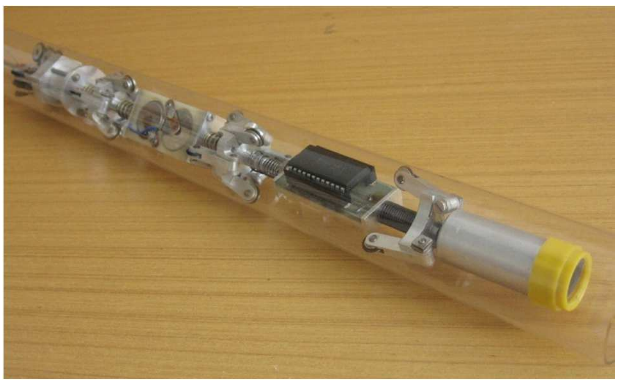

Figure 2 Modular in-pipe machine FENAUS

Machine consists of energy module, connecting module, end module, control module and drive module. Composition of machine can be arranged in accordance with application. Minimum configuration contains driving module and end module (Figure 3). Nevertheless, it is possible to make configuration with two drive modules and three energy modules analogous to train.

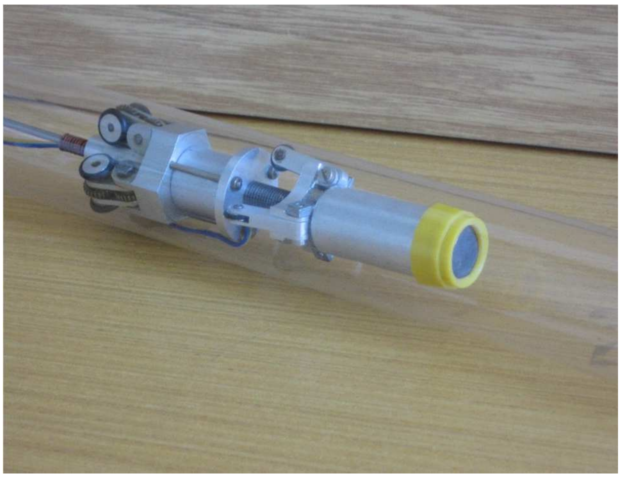

Figure 3 Modular in-pipe machine FENAUS in short version

Every module is connected to other via using the spring joint, which enables very good manoeuvring to cross also elbow and T – joints (Figure 4).

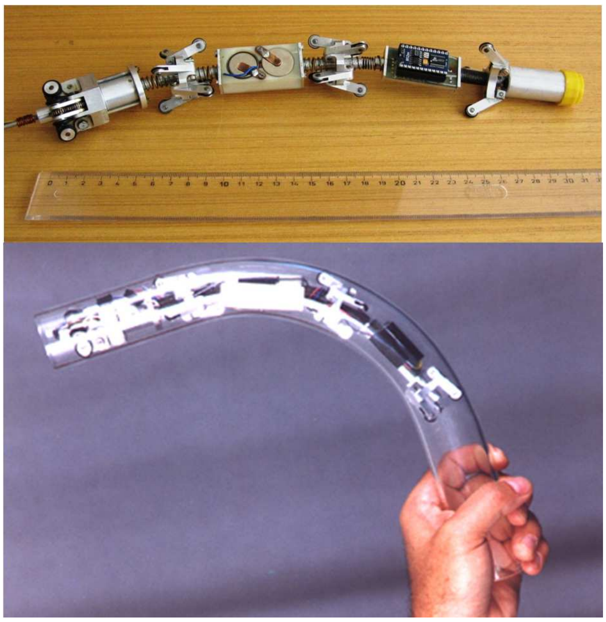

Figure 4 Modular in-pipe machine FENAUS in elbow

Drive module (Figure 5) consist of DC brush motor with 2 stage cylindrical-worm gearing. Torque is distributed to wheels through the worm gear that are connected on the every shaft of traction wheels. Traction wheels are in three pairs around the driving module body. Normal force between the wheels and inner pipe wall are generated via using the helical springs.

Energy module (Figure 6) are made from plastic and includes NiMH accumulators and Lithium monocells for supplying energy to DC motor, sensors and microcontroller. This module is used in case if wireless working of in-pipe machine is required.

Control module (Figure 7) includes the microcontroller Basic Stamp 2SX and other electronics for DC motor controlling and data capturing from sensors.

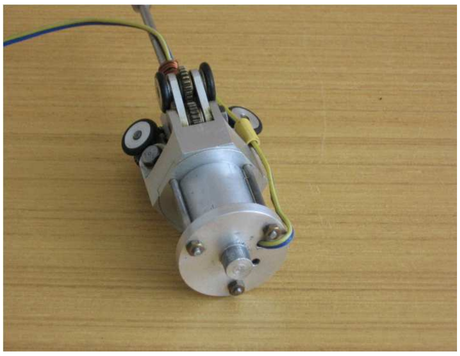
Figure 5 Drive module of machine FENAUS

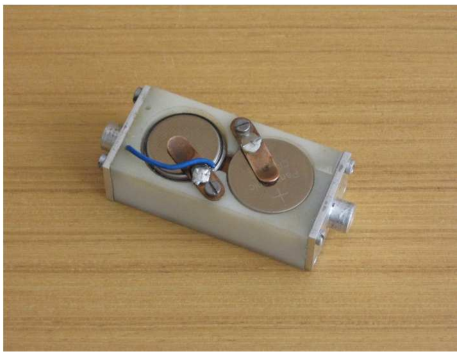
Figure 6 Energy module of machine FENAUS

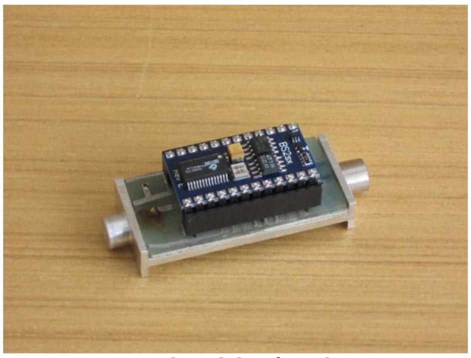
Figure 7 Control module of machine FENAUS

Connecting module (Figure 8) is designed for improving of overall machine stability. Also this module connects other modules without wheels.

End module (Figure 9) is dedicated for carrying of the sensors of pipe crack and sensor for navigation and camera for tele-operator using.

Overall length of the machine is 280 mm nut it depends on selected configuration. Minimum bend radius of elbow is 135 mm. Maximum velocity is 30 mm/s with one drive module, one control module, one end module, one energy module and two connecting modules.


Figure 8 Connecting module of machine FENAUS


Figure 9 End module of machine FENAUS

Another problem, which is necessary to solve, is slipping of wheels on inner pipe wall. There is a possibility to do wheels with controlled compressive force in order to minimise slipping. This idea could bring to FENAUS intelligence and improve the overall performance and energy saving which is very necessary in autonomous FENAUS [16, 17].

3 Wheeled machine with adjustable wheels

Traditional conceptions of wheeled in-pipe machines tend to wheels slipping or self-blocking. Next designed in-pipe mechanism CEREVKA has adjustable wheels. It means that wheels are able to adapt to inner diameter inside pipe in range from 100 to 200 mm. Only mechatronic conception design allows solving of this problem. One of the possible ways of the wheeled in-pipe machines is placement of the traction and stabilization wheels to the arms regularly placed around the machine body (Figure 10) [18-21].

The basic part (Figure 11) is the machine body (1), which is connected with guiding rod (2). Carrier (3) is moving on guiding rod (2). Wheel holder (4, 5, 9) are connected to the machine body (1) and carrier (3) via plane joints. Wheel holder (4) holds driven wheel (6) and wheel holder (9) holds stabilization wheel (7). Stabilization wheel provides the better stabilization of machine locomotion inside pipe. Connecting part (8) is placed between these wheels (6, 7). Parts (3, 4, 8, 9) compose the parallelogram mechanism. This mechanism can be as source of the problems in described situation of locomotion inside the pipe. For this reason carrier (3) has to be divided (Figure 12) into the part (3) and part (10). These parts will be connected via spring (11). This configuration allows assuring of connection of the every wheel with inner pipe wall. This divided carrier with spring allows the passive compensation of the pipe deviations. Active adapting to change of inner pipe diameter is able to realize via change of the carrier position (3) from the machine body (1). This position change is can be obtained through the position servomechanism in combination with screw mechanism [18-21].

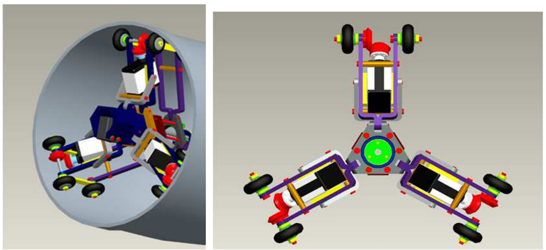

Figure 10 Wheeled machine with adjustable wheels CEREVKA

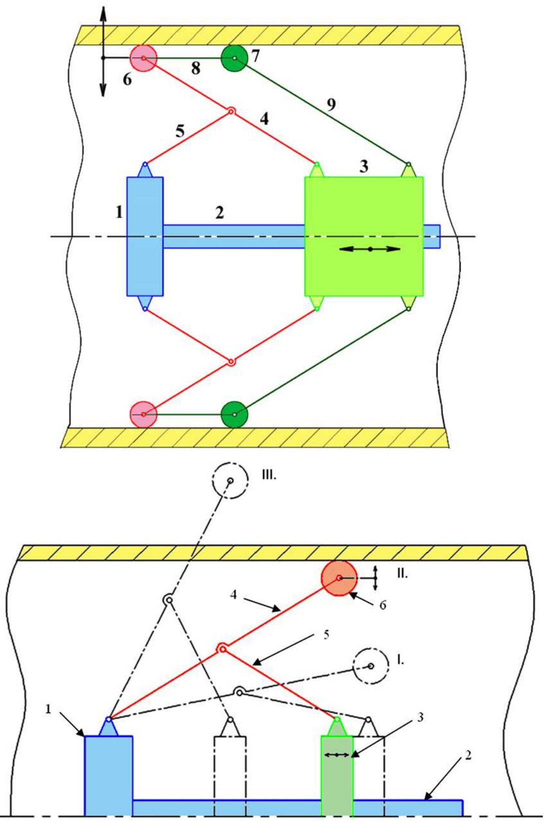

Figure 11 Machine arm arrangement of wheeled machine with adjustable wheels CEREVKA

Every driven wheel (6) is driven via independent actuator (16) (Figure 13). The placement of this actuator (16) has been proposed nearest to the driven wheel (Figure 13). Actuator is placed between the wheel holders (4, 5) because of elimination of the parts collision in process of adaptation to changed inner diameter of the pipe.

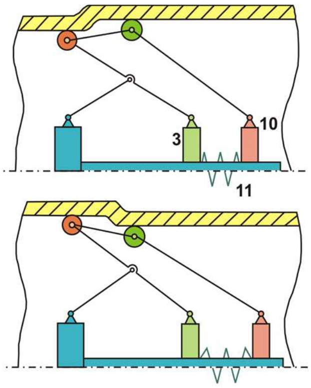

Figure 12 Adaptation to the change of the inner pipe surface geometry of wheeled machine with adjustable wheels CEREVKA

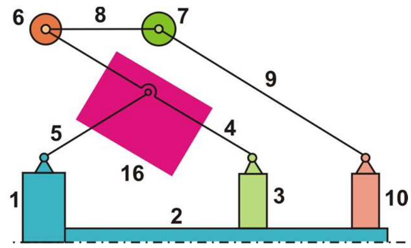

Figure 13 Servomechanism placement on wheeled machine with adjustable wheels CEREVKA

Every arm (Figure 13) is consisting of pair of parts (4, 5, 8 and 9). Final design is shown on (Figure 14).

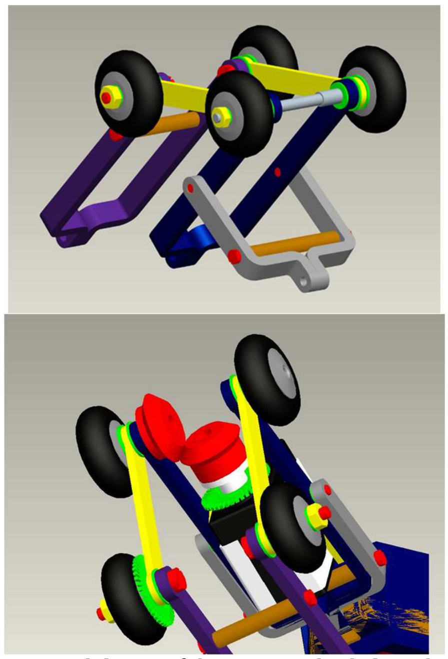

Figure 14 Final design of the arm on wheeled machine with adjustable wheels CEREVKA

Opening and closing of the arms is provided via displacement of the part (3a) (Figure 15). Displacement of the part (3a) could be secured through the screw

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mechanism placed in axis of the machine. Screw rod (2a) is at the both ends fixed in bearings. Screw rod (2a) is connected with part (3a) through thread (it is female screw). So, part (3a) and screw rod (2a) compose the screw mechanism. Rotating of the screw rod (2a) causes the displacement of the part (3a) and it means that arms of the machine will open or close.

Part (3b) has no thread (there is only simple hole) because of possibility to adaptation to change of inner pipe diameter near the driven wheels (6) and near the stabilization wheels (7).

Guiding of the parts (3a) and (3b) is provided through three guiding rods (circular cross-section) (2b).

Guiding rods (2b) is fixed in machine body (1) and end part (2c) (fig. 11). End part (2c) is able to move through the part (10). This proposition causes shortening of the overall machine length. Part (10) is used for pressing of the stabilization wheels (7) to the inner pipe wall. This is the reason that part (10) is not fixed to the part (3a). Part (10) is able to move on six guiding rods (17). The pressing of the stabilization wheels is provided through the springs (11).

Wheel holders are connected to the part (1), (3b) and (10) through the joint pins [18-21].

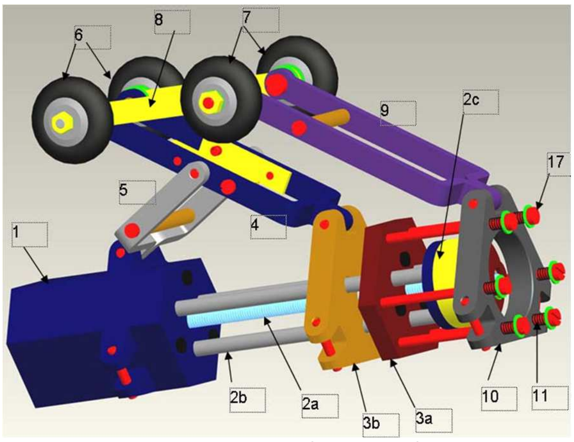

Figure 15 Opening and closing of the arm of wheeled machine with adjustable wheels CEREVKA

Part (3b) can free-run on guiding rods (2b). The spring (12) is placed between part (3a) and (3b) (Figure 16). This spring is deformation part used for normal force measurement between driven wheels and inner pipe wall. The change of the normal force is caused via change of the inner pipe diameter and it will make spring deformation. Consequently, it is necessary to measure spring deformation through the distance sensor.

Spring deformation is measured through the hall sensor (13) (placed on part 3a) and permanent magnet (14) (placed on part 3b). The microcomputer will evaluate the change of distance between the part (3a) and (3b). After that, microcomputer can affect to actuator for opening and closing of the arms. This is a way how to control normal force between the driven wheels and inner pipe wall [2, 3].

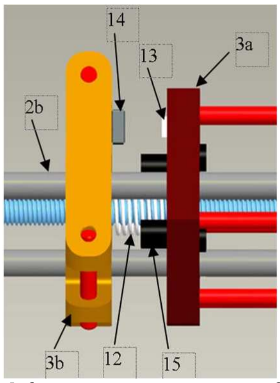

Figure 16 Spring deformation measurement of wheeled machine with adjustable wheels CEREVKA

Actuator has to rotate with screw rod (2a) in suitable direction for controlling of the arm opening and closing. This is a way how to react to the changed conditions inside the pipe. Final design of the adaptable in-pipe machine is shown on (Figure 17).

- Overall machine weight: 0,628 kg

Basic dimensions:

- Opening of the arms (range of the inner pipe diameters):

Min.:98 mm; Max.: 204mm

- Length (for 100 mm pipe): 186 mm
- Length (for 200 mm pipe): 134mm
- Maximum locomotion speed in horizontal pipe 0,082m/s.

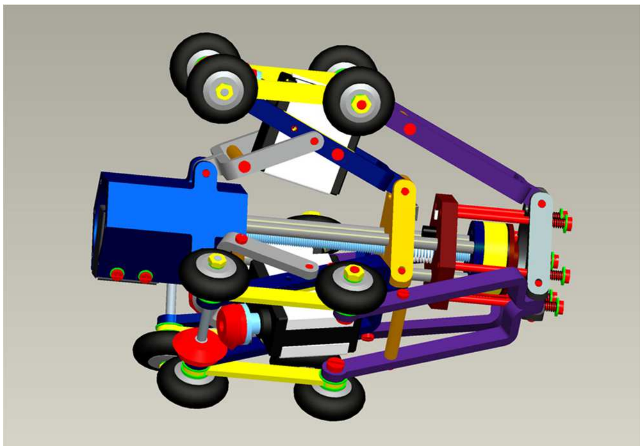
Figure 17 Final design of wheeled machine with adjustable wheels CEREVKA

The overall in-pipe machine will consist of several these modules (Figure 18) arranged one after another. These modules will connect through the suitable controlled joints. This articulated structure looks like snake will be able to locomote inside curved pipes like elbow, reduction of diameter, double branch joint etc [18-21].

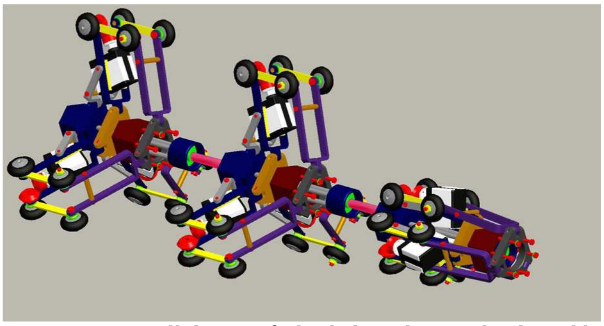

Figure 18 Overall design of wheeled machine with adjustable wheels CEREVKA

4 Conclusion

This mechatronic concept is one of the possible solutions for elimination of above mentioned weakness. It provides to obtain better designed in-pipe machine performance and other properties than in-pipe machine used before. The controlling of the value of the normal force also causes the improving of the energy balance and decreasing of loses [18-23].

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