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Design of the mobile minimachine capable of motion inside small pipes

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ABSTRACT
` **This paper deals with utilization possibility of a kinematical couple of screw-matrix in minimachine mechatronic concept which is assigned to move within the pipes having less than 25 mm of the inner diameter. The principle of the movement for a straightforward motion consists in transformation of the actuator rotary movement through a screw and a nut to the linear motion. It causes a change of distance between the front and rear parts of the minimachine modules. Due to minimization of the dimensions, the electrical control and power supply components are placed outside of the minimachine operating area. The control module is based on a programmable integrated circuit (PIC).**

Keywords - **control, minimachine , motion, pipe**

1. Introduction

Nowadays the mobile machines for motion within thin pipes represent a promising area of research. Their utilization is oriented towards detection of defects on the inner pipe surface, the repair of localized defects, monitoring and maintenance of pipes and last, but not least, their utilization is oriented towards drawing new cables through old and unused pipe systems.

The utilization of motion principles by means of classic wheel and crawling traction for design of in-pipe minimachine is limited by a small pipe inner diameter. For this reason for positioning and motion of the minimachine, there are used bristles in the form of flexible beams. They are strained towards the pipe inner surface under a precise angle that causes friction difference between the bristle and pipe wall.

At the minimachines realization, the actuators that are designed and manufactured with different approach are used [1, 2]. The used principle for motion is determined by the pipe inner diameter because of the efficiency of generated forces needed for the initiation of the minimachine motion decreases with dimensions.

Motion of the designed in-pipe minimachine is based on inchworm principle known from biology. Next chapters deal with concept, electrical equipment, and control of such a machine.

2. Concept of Minimachine

The in-pipe minimachine as shown in Fig. 1 consists of three modules, where the outer modules (the front and back ones) consist of rotary electromagnetic actuators to provide strain of the bristles, then a screw,

Fig. 1 3D model of the in-pipe minimachine.

nut and bristles. The middle module developing the own movement has a rotary electromagnetic actuator, screw and nut. The principle of the movement is based on transforming the actuator rotary movement through the screw and nut into the straight motion.

This motion causes change of distance between the minimachine front and back modules. The direction of the minimachine movement within a pipe depends on pressing the concerned bristles and their pressing to the inner wall of the pipe is ensured by a screw and nut.

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The direction of the minimachine movement within a pipe depends on pressing the concerned bristles in the outer modules to the pipe wall (Fig. 2). Pushing forward the bristles and their pressing to the inner wall of the pipe is ensured by a screw and nut (Fig. 3).

The control system of the minimachine ensures its cyclic repeating of the change in direction of the linear movement [1, 3].

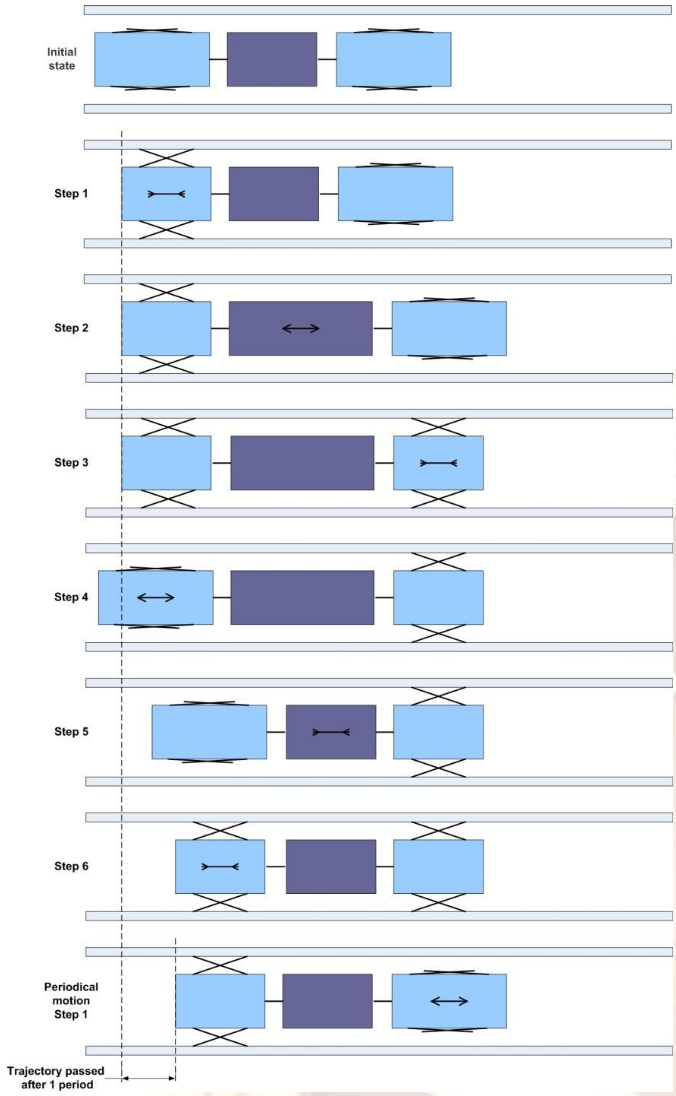

Fig. 2 Motion sequence of the minimachine

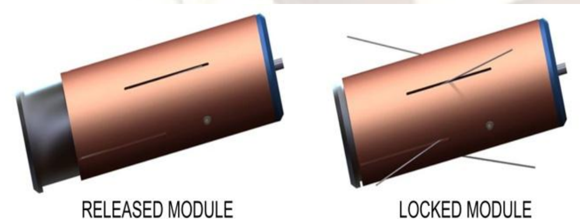

Fig. 3 Model of the front (back) in-pipe minimachine module

3. Forces Acting on Minimachine Bristle

The motion in the pipe is caused by friction forces acting between bristles of the minimachine and pipe wall [4]. For design of minimachine construction, it is necessary to define dependence between minimachine dimensions and its force action on pipe wall (Fig. 4). That is a function of bristle deflection.

$$d = a + L.\sin\alpha - r \quad (1)$$

where:
L – bristle length
Decomposition of the forces for the minimachine forward motion is shown in Fig. 5.
Forces during motion of the minimachine:

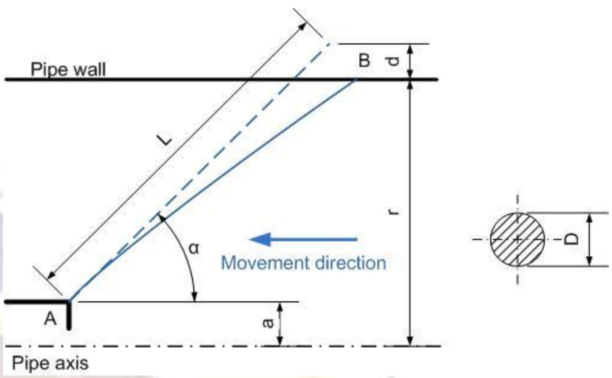

Fig. 4 Dimensions of minimachine bristle.

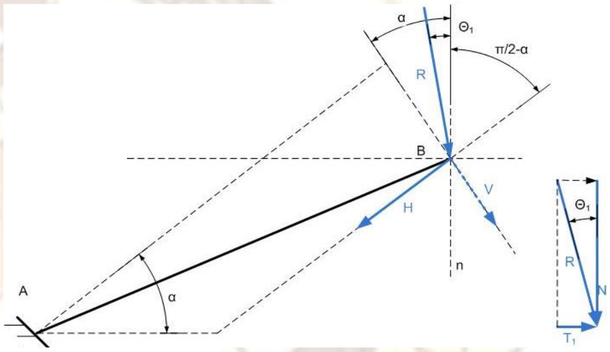

Fig. 5 Acting forces at forward motion.

$$T_1 = f_1.N \quad (2)$$

$$V = R.\cos(\alpha - \theta_1) = R.\cos\gamma_1 \quad (3)$$

where:
R – reaction of the pipe wall
θ – friction angle;
$\tan\theta = f_1$ – kinetic coefficient of friction

$$V = R.\sin(\gamma_1 - \theta_1) = R.\sin\gamma_1 \quad (4)$$

$$y_1 = \alpha - \theta_1 \quad (5)$$

Decomposition of the forces during bracing (i.e., when the bristles are strained to the wall) is shown in Fig. 6.
For standstill (when the relative velocity of the bristle towards pipe wall is equal to zero) there is valid:

$$T \le N.f_0 \quad (6)$$

where f0 ... is the static friction coefficient.
Value of tangential reaction T results from balance conditions, can be at most:

$$T_{max} \le N.f_0 \quad (7)$$

For maximal value of the force T there is valid:

$$V = R.\cos\gamma \quad (8)$$
$$H = R.\sin\gamma \quad (9)$$
$$\gamma = \alpha + \theta \quad (10)$$

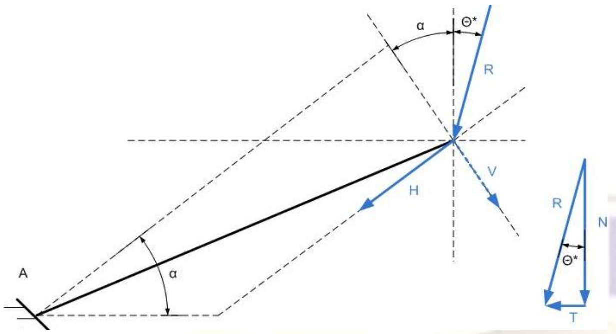

Fig. 6 Acting forces at bracing.

4. Control of the Minimachine

In the in-pipe minimachine body there is not enough free space for embedded control electronics which would require to increase the minimachine dimensions. The building-in limit switches of actuating units in the marginal positions of its trajectories needs also some space and this significantly influences the construction and dimensions of the minimachine. Therefore, the electrical control and power supply components are situated outside of the minimachine.

It is obvious that the mechanical load, affecting the electric motor output shaft (i.e. a load torque), increases its current consumption. The maximal current consumption rises from a short-term deadlock of the electric motor's output shaft. In the designed in-pipe minimachine the limit switches are replaced by a control module of the actuating units' current consumption. This module compares the current consumption of the particular actuator with the predetermined limiting values of current consumption. If the current achieves the limiting values, the module informs the minimachine control about achieved state. The minimachine actuators are supplied directly through the electric wires (Fig. 7). The power supply, which is the part of the control unit, supplies the in-pipe minimachine and its control by the energy. The control unit monitors the succession of every single step, which altogether creates the final movement of the minimachine. The control module contains a programmable integrated circuit (PIC). The control module of current consumption of its individual actuators informs the control module about achieving the limiting value of the current consumption [5, 6].

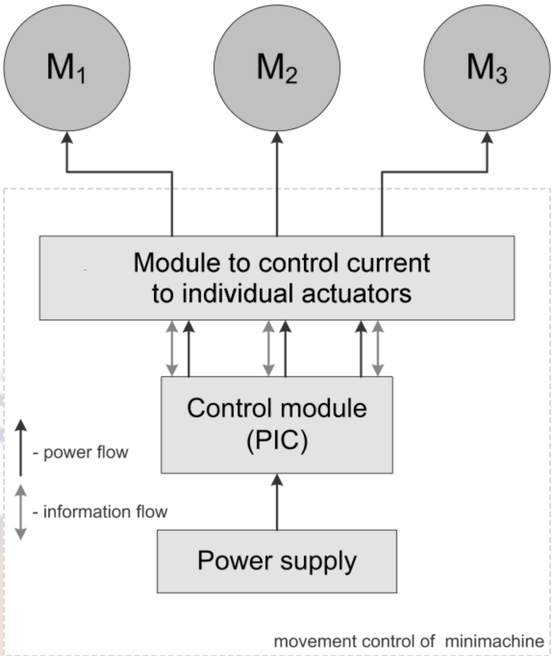

Fig. 7 Control scheme of the in-pipe minimachine

5. Control Program of the Minimachine

The minimachine movement consists of the indivi- dual steps whose performance and succession are con- trolled by the control program in the control module.

To design the control program, it is necessary to define these steps and their sequence during the mini-machine movement. The backward movement of the minimachine consists of the same steps as the forward movement, however, the sequence of these steps is different [7].

The diagram of the program is shown in Fig. 8. The control program includes also a part, which upon the intervals between particular repeated cycles of the movement identifies a possible lockout of the minimachine in the pipe that can be caused by an obstacle on the trajectory of the movement. In the case the lockout would be not detected, an overheating of the actuating units could occur leading to their subsequent permanent damage.

6. Conclusions

The paper describes development of the mechatronics concept of the in-pipe minimachine. The developed minimachine is capable to move within the tubes of diameter about 25 mm. The average speed of movement is up to 120 mm/min. It depends on the quality of the tube surface (smoothness of the walls and friction coefficient between the wall and the bristles) and it can be changed by a control unit (frequency of contractions of the actuator units). In the prototype there were used three micromotors (with rated values U_n=4.5 V DC, I_n=250 mA) with a built-in gear.

The future research will concern a completion of the minimachine by sensors, e.g., by an acceleration sensor [8] and a camera to monitor inner walls of the pipes.

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References

[1] M. Dovica, M. Gorzas, Mechatronics aspects of in-pipe minimachine on screw-nut principle design, *Recent Advances in Mechatronics 3*, 2007, 335-339.
[2] J.G. Zhu, H.W. Lu, Y.G. Guo, Z.W. Lin., Development of electromagnetic linear actuators for micro robots, *Proceedings of the 11th International Conference on Electrical Machines and Systems, vol. 1- 8*, 2008, pp. 3673-3679.
[3] L. Jurišica, Mechatronics Systems, *Komunikácie 9* , 2007, 5-7.
[4] V.G. Chashchukin, Simulation of dynamics and determination of control parameters of inpipe minirobot, *Journal of Computer and Systems Sciences 47 (5)*, 2008, 806-811.
[5] R. Isermann, *Mechatronic systems: Fundamentals*, Springer 2005, p. 624, ISBN-10: 1852339306
[6] J. Skuta, M. Babiuch, Usage of serial interface for communication with MEMS components, *Proceedings of 8th ICCC*, Strbske pleso, Slovak Republic, May 24-27, 2007, pp. 705-709.
[7] G. Carbone, A. Malchikov, M. Ceccarelli, S. Jatsun, Design and simulation of kursk robot for in-pipe inspection, *SYROM 2009*, Netherlands, 2009.
[8] S. Luczak, W. Oleksiuk, M. Bodnicki, Sensing tilt with MEMS accelerometers, *IEEE Sensors Journal 6 (6)*, 2006, 1669-16