

Mobile Mini-mechanism for Moving in Pipe with Small Diameter

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Abstract The paper deals with a mobile miniature mechanism which was moved inside glass pipe. The mobile miniature mechanism consists of driving and driven body, which is moved by magnetic force. In the theoretical analysis of miniature mechanism movement its mean velocity on the base of two elastic masses impact model is examined. In experimental part dependencies of attractive force and repulsive force on distance are examined.

Keywords: mobile robot, In Pipe Mechanism, Analysis of Movement, impact

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1. Introduction

For several years in the world the considerable effort is aimed on research and development of miniature mechanisms able to move in tubes for inspection and maintenance. According to which category in terms of the geometric dimensions of a mobile machine we propose to divide pipes into two groups: macro pipes and micro pipes. In micro pipes can move machines which are from category of micro machines. In term of micro machines we can understand machines, which as a whole due to its dimensions are usable in micro area, and also assembled machines which were created from extremely small functional parts about 1 mm. All types of pipe micro machines have their own specific problems, concretely such as traction forces problem [1].

The above categorization is clear from the experience of the authors, and also from the inspiration of animal movements. Other ways of motion can be also realized by modifying these basic movements, or a combination thereof, but also is possible discovering new ways of motion. Thus, this division is not closed and this is subject to further research and development. In case of tubes with small diameter the minimal size of conventional drives used as an actuators limit the miniaturization. In addition the conventional wheel or caterpillar drive inclines to slipping, when inside wall is choked by dust. This study deals with mobile miniature mechanism, which utilizes energy released during crash of two masses. The diameter of realized miniature mechanism is 11 mm and its length is 35 mm. The impact force in moving direction is bigger than friction force between artificial hair and the tube wall. In inverse function the impact force is smaller than friction force [1,2,3].

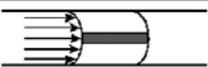
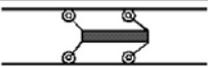
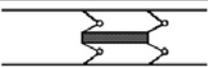
Pressure of fluid	
Wheeled	
Crawled	
Legged	
Inchworm	
Vibrations	
Travelling wave	

Figure 1. Possibilities of in pipes moving

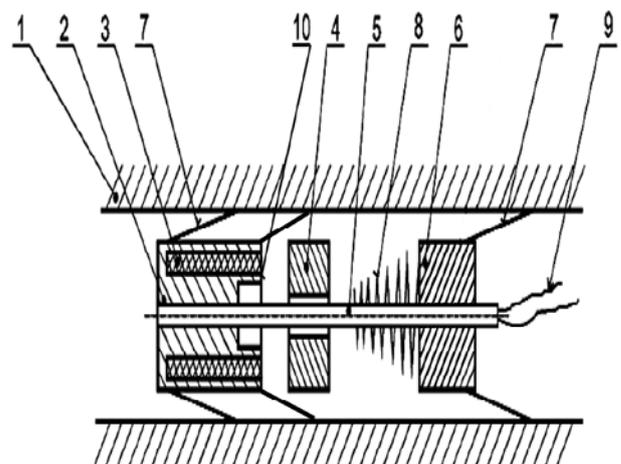


Figure 2. Global arrangement of miniature mechanism

2. Mechanism Movement

Driving body of mobile mechanism in Figure 2 consist of permanent magnet 4, magnetically circuit 2, 10. Driven body of mobile mechanism consist of electromagnet 3, adjusting module 6, recoil spring 8, guide rod 5, guide artificial hairs 7, power supply and sensing in moment of crash 9, contact wall of pipe 1. Cylindrically shaped permanent magnet 4 with longitudinal whole moves on guide rod 5 between electromagnet 3 and adjusting module 6. During crash of permanent magnet 4 and electromagnet 3 movement of mini-mechanism is created.

The movement analysis has been done on the simplifying model in Figure 3 [4].

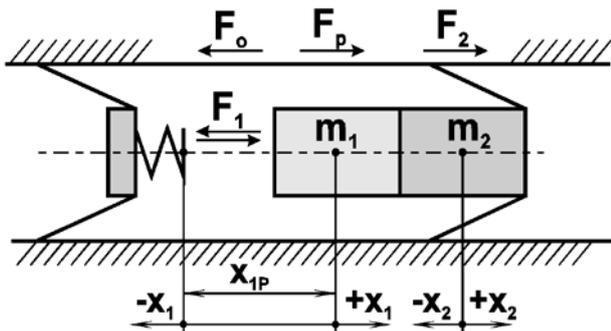


Figure 3. Simplified model of the crash of drive and driven body

According to theoretical analysis it is convenient to divide the miniature mechanism function into the three cycles, which interlock: 1. Preparing cycle, 2. Active cycle, 3. Regenerative cycle.

On the Figure 3 is x_1 – trajectory, v_1 – speed and m_1 – mass of drive body, and x_2 – trajectory, v_2 – speed and m_2 – mass of driven body. Also x_{1p} – distance between a centroid of drive body and spring of adjusting module if drive body is in contact with active surface, m_t – total mass of miniature mechanism, m_r – reduced mass of miniature mechanism, F_1 – friction force between drive body and sliding drive, F_2 – friction force between artificial hairs and tube wall, F_p – attractive force of drive body to the active surface of miniature mechanism, F_0 – repulsive force between drive body and active surface of miniature mechanism, F_h – drive force of miniature mechanism, T – time of miniature mechanism cycle, k – constant of the spring, which represents a deformation of drive and driven body during the crash on active surface.

According to nonlinearity of movement equations we have divided the analysis into the three phases. In every phase the friction is represented by Coulomb friction with absolute valve F_{r0} [5,6]

2.1. Phase A

At the beginning of this phase the drive body is in the contact with miniature mechanism active surface in consequence of attractive force F_p . By the voltage impulse in the coil of electromagnet in time $t = t_p$ the repulsive force F_0 is activated $|F_0| > |F_p|$ and consequently the drive body is moving toward to the adjusting module. Duration of the repulsive force is till the moment of contact of drive body with spring on adjusting module. In this moment $t = t_b$ the Phase A is finished and Phase B begins [5].

2.2. Phase B

This phase begins in moment of contact of drive body with spring on adjusting module in moment $t = t_b$ and ends in moment of end of this this contact in time $t = t_c$. In this phase only attractive force F_p influences on drive body. The absolute value of deformation force created as a result of impact between drive body with spring of adjusting module is smaller than absolute value of friction force F_2 during this phase. It means, that miniature mechanism do not move.

2.3. Phase C

At the moment of end of contact of drive body in the Phase B in time $t = t_c$ the Phase C begins. During this phase the drive body is accelerated by attractive force F_p toward to the active surface of the miniature mechanism. In the moment of the contact with this surface in time $t = t_d$ this phase is finished and the Phase D of active cycle begins.

2.4. Phase D

This one begins in the moment of contact of drive and driven body on the active surface. Phase D is an immediate continuing of preparing cycle. Its duration begins by time of impact between drive and driven body in time $t = t_d$ and ends when drive impact force F_h is equal to the friction force F_2 in time $t = t_e$. It means that driven body of miniature mechanism does not move in this phase yet.

2.5. Phase E

Beginning of this phase is in time $t = t_e$ when $F_h = F_2$, and begins in time $t = t_f$ when drive force $F_h = 0$. During all this phase miniature mechanism moves.

2.6. Phase F

This phase follows immediately after the impact of drive and driven body on active force in time $t = t_f$ and ends in moment of miniature mechanism stopping in time $t = t_g$, when the regenerative cycle begins.

3. Regenerative Cycle

The cycle has only one phase marked as G. Its duration $t_h - t_g$ is given by allowed operation temperature of miniature mechanism, which is created in conclusion of Joule loss in the coil of electromagnet [9,10]. Time dependencies of speed v_2 and trajectory x_2 during active tact obtained by simulation are shown by Figure 4 and Figure 5. Parameters of miniature mechanism was chosen as follows: $m_1 = 0,001 \text{ kg}$, $m_2 = 0,009 \text{ kg}$, $k = 10^8 \text{ Nm}^{-1}$,

$F_2 = 2,5 \text{ N}$, $v_{1Dd} = 0,5 \text{ ms}^{-1}$. According to fact that Phase D is very short, and it is impossible to show it separately, the Phases D and E are marked together. Duration of Phase D is only $5 \cdot 10^{-8} \text{ s}$ [7,8].

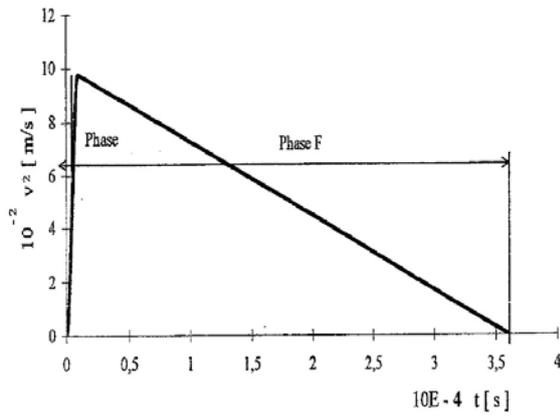


Figure 4. Time course of speed v_2 of driven body during active tact

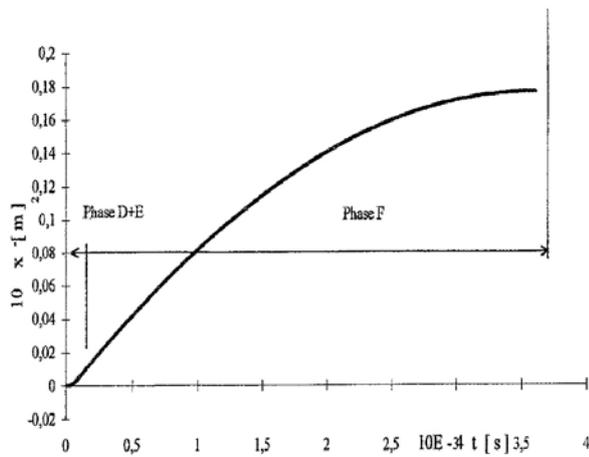


Figure 5. Time course of trajectory x_2 of driven body during active tact

From analysis of miniature mechanism movement, which has been accomplished for simplified model on Fig. 3, driven body in every three phases of active cycle is described by motional equation:

$$m_2 \ddot{x}_2(t) = 2m_r v_{1Dd} \delta(t - t_d) - F_2 \quad (1)$$

By solving and modification of Equation 1 for speed of driven body we should obtain a relation:

$$v_2(t) = \frac{2m_r v_{1Dd}}{m_2} 1(t - t_d) - \frac{F_2}{m_2} (t - t_d) \quad (2)$$

$$v_2(t) = \frac{2m_1 v_{1Dd}}{m_t} 1(t - t_d) - \frac{F_2}{m_2} (t - t_d) \quad (3)$$

which after omitting of friction force F_2 represents a known relation for direct impact of two elastic spheres, $1(t)$ is the Heaviside function. From Equation (2, 3) results, that time, in which the driven body is stopped, i.e. $v_2 = 0$, is

$$t_g = \frac{2m_r v_{1Dd}}{F_2} + t_d \quad (4)$$

For mean speed of miniature mechanism v_{2str} we should write:

$$v_{2str} = \frac{1}{T} \int_{t_a}^{t_g} v_2(t) dt = \frac{2m_r^2 v_{1Dd}^2}{m_2 T F_2} \quad (5)$$

where T is time of miniature mechanism cycle:

$$T > \frac{2m_r v_{1Dd}}{F_2} \quad (6)$$

4. Experimental Results

Because analytical expression of attractive and repulsive force dependence on distance l could be found analytically only for simple magnetic circuits, we examined them experimentally. The attractive force has been examined by spring force sensor in following way: for given distance l , we measured force, which could separate the drive body from electromagnet. The current through the coil was equal to zero. The measured data and regression dependence are shown on Figure 6 [7,8].

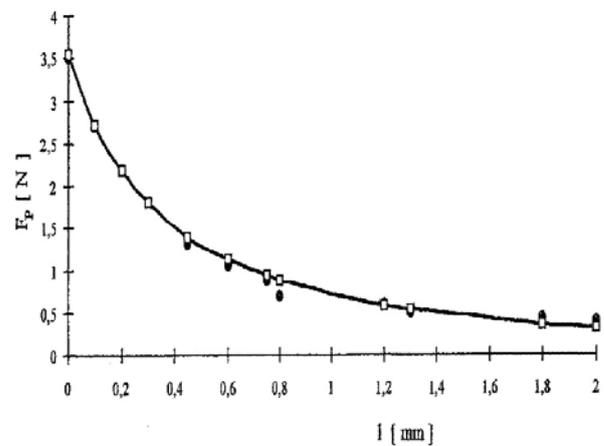


Figure 6. Dependence of the driving-body attractive force on the distance from electromagnet

The dependence of repulsive force on distance l was determined indirectly. According to fact, that attractive force could not be eliminated, we measured difference between attractive and repulsive force for given distance l . The drive body was weighted by known weight, while the current through the coil was constant. Similarly to previous we examined, which weight is able to separate the drive body from electromagnet. The Fig. 7 shows the measured data and regression dependence. Using these attractive and repulsive force dependencies we have made the model of mobile robot according to the Fig. 2. The weight of drive and driven body is 10 g. The speed of mobile robot in glass tube was 2 cm s^{-1} .

From performed analysis of miniature mechanism for moving in tube with small diameter following facts results [6,7]:

- mean and immediate speed of miniature mechanism increases with increasing of momentum of drive body in moment of crash with driven body,
- momentum of drive body increases with increasing of constant J appearing in dependence for repulsive force. This constant depends on current size in coil of electromagnet,
- optimal position of spring depends only on character of repulsive force dependence. This is valid according to assumption that speed of drive body in moment of impact on spring is equal to the speed in moment of its bounce and repulsive force durates only till the impact with spring.

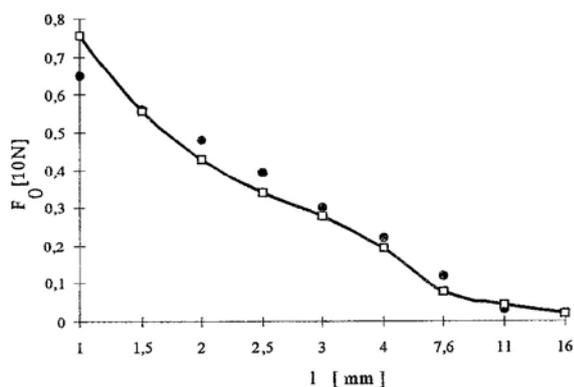


Figure 7. Dependence of the driving-body repulsive force on the distance from electromagnet

5. Conclusion

Micro machine has one negative feature. Each new cycle of micro machine starts from the same initial state. This means that individual cycles do not follow each other, from the dynamic point of view, they are discontinuous. To prevent the return of the movement of the micro machine into the initial state at the end of the cycle (in terms of the state vector) it is necessary to remove the regeneration tact. This is only possible when the repulsive force F_0 is activated in the appropriate point of the Phase E. In terms of dynamics, this appropriate point is the moment when the driving element has a direction of the velocity consistent with the direction of the repulsion. For the future, it is appropriate to proceed to modification of a micro machine and adjust its tact.

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