UDC 004.4
DOI: 10.25140/2411-5363-2018-3(13)-82-88

Michal Kelemen

MACHINE MOTION OPTIMIZATION

Urgency of the research. *Inspection of pipe systems are needed, because of prevention of damages and disasters. Also repairing and cleaning can be done without any earth works.*

Target setting. *Pipe machine is suitable to move inside gas pipe, water gas, oil gas, waste water pipes, chemical pipes, steam generator pipes, boiler pipes etc.*

Actual scientific researches and issues analysis. *Wheeled or tracked machines are currently used for motion inside pipes. Wheeled type tends to slipping when wall is dirty or rudiments are exposed on inner side of pipe wall.*

Uninvestigated parts of general matters defining. *The question of the design of adaptable pipe machines are uninvestigated, because the next research will be focused to this are.*

The research objective. *The main aim is to optimize structure of machine for improving the overall properties as motion velocity and traction force. Cary items are bristles, which has any structural and material properties.*

The statement of basic materials. *Montage angle and initial displacement and also bristle length can be identified for setting the machine. Bristles are placed at angle on machine body in two groups (front and back). Linear actuator is placed between these groups of bristles. Periodical actuator stroke generates forward motion inside pipe.*

Conclusions. *Phenomenon of friction difference is a key factor for motion of machine inside pipe. Beside of it, a contact phenomenon between bristles and pipe wall is important for analysis in design process of this machine. Real bristles have a limitation of their deflection. In every case, deformation should be in flexible area of loading.*

These bristles flexibility is used as device for compensation of pipe wall irregularities during the machine motion inside pipe.

Keywords: *machine; optimization; pipe; friction; motion.*

Fig.: 8. References: 17.

Introduction. Machine for motion inside pipe has various purpose. It can be used for pipe inspection, also pipe repairing and also there are several application for cables installation into underground pipe.

There are several solution of machines (fig. 1) able to move inside pipe. Several of them uses wheels, tracks, legs, inchworm-style etc. [1-10].

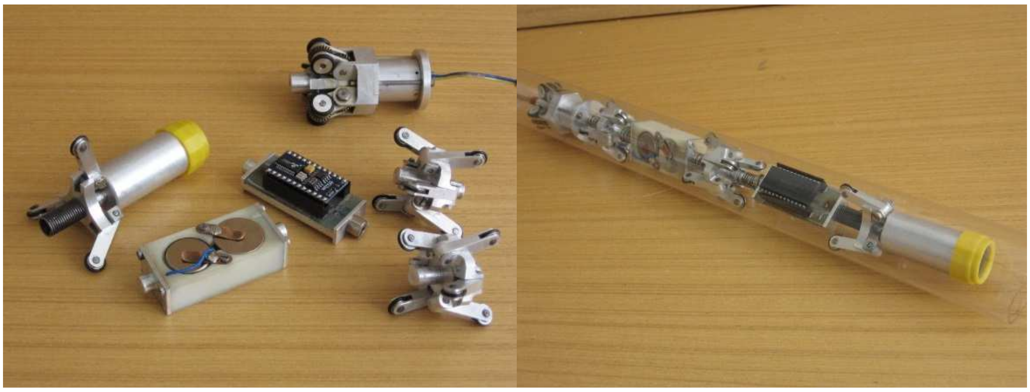

Fig. 1. Wheeled machine for motion inside pipe

Next possible application is machine for motion inside pipe with helical motion of wheels. It has better motion, but still it tends to slipping when wall is dirty (fig. 2).

Described machine (fig. 3) uses thin bristle for contact with pipe wall instead of wheels or tracks. The motion is affected by dirties inside pipe, geometrical deviations and deformation of pipe wall. Bristles are cantilever beams in front and back of machine body. Drive actuator is placed between the front and back bristles. Actuator generates the periodical change of distance between bristle groups. These periodical change of distance are transferred to groups of bristles. It causes that bristles vibrates in both directions (in front and back direction). Bristles are bonded at angle and this way causes the different friction force in front and back directions. This effect is raised with large elastic deformation of bristles. One of the most important key factor is elastic and geometric properties of bristles (length, preloading, angle of slope). These properties is the target of optimization. The deformation should be only elastic, because plastic deformation will decrease the normal friction to wall of pipe.

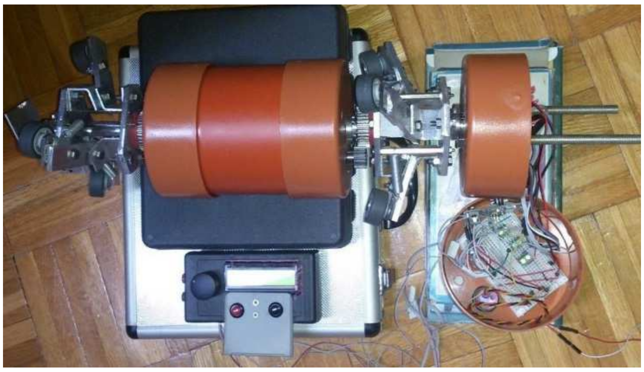

Fig. 2. Wheeled machine with helical motion inside pipe

Actuator has rectilinear motion output and it is possible to select arbitrary type according the needed output force and stroke. Our solution has been proposed with piezostack actuator and also with linear electromagnetic actuator.

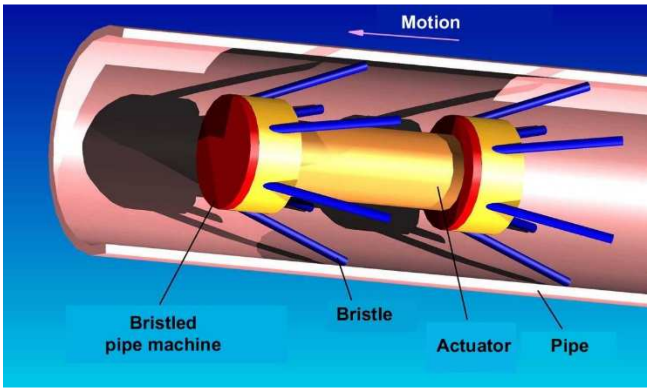

Fig. 3. Solved machine for motion inside pipe with bristles

1. Machine model and optimization of its properties. Analysis and previous experiments shows the large effect of the bristle properties to machine motion. The followed parameters are steady state velocity and traction force of machine. The traction force depends on normal force F_N and friction forces between pipe wall and bristles F_{T1} a F_{T2} and also depends on actuator excitation force F_A. Velocity v of the machine also affect the traction force:

$$F = f\left(F_N, F_A, F_{T1}, F_{T2}, v\right). \quad (1)$$

Velocity of machine is analogically as function of normal force F_N, of actuator force F_A, of friction forces F_{T1} and F_{T2} and of traction force F. Also it depends on velocity of actuator stroke v_A:

$$v = g\left(F_N, F_{T1}, F_{T2}, F, v_A\right). \quad (2)$$

Equation (1) and equation (2) composes the overall math model of machine from the viewpoint of optimization of motion efficiency. It results from this model, that interaction of bristle and wall of pipe has key impact to machine behaviour. Friction forces have significant role for this studied effects.

The aim of machine optimization is to obtain the maximum of difference between the friction forces for motion to front or back. Previous experiences shows that geometry of bristles directly also influences to this difference. Another point is reaching of insensitivity to pipe geometrical deviations and pipe sediments.

$$F_{T2} - F_{T1} \Rightarrow \max, \quad (3)$$

Optimization can be executed via using of mapping of phase space. The main advantage of this method is that it enables to find all possible solutions in selected interval of input variables values. Input variables for optimization are:

- angle of montage of bristles α_1,
- span of the free bristles Δ_R,
- length of bristles L.

2. Optimization of machine. Followed output variables are friction forces. Mapping of this forces has been executed for defined input intervals of them.

Dependence of friction force for motion to front is shown in fig. 4. It is computed for round cross-section of bristle. Friction force raises up when bristle length is decreased. Minimal values of friction forces are still on angle 1.5 rad. Decreasing of bristle length (fig. 5) rapidly influences to normal force and also friction force for movement to front.

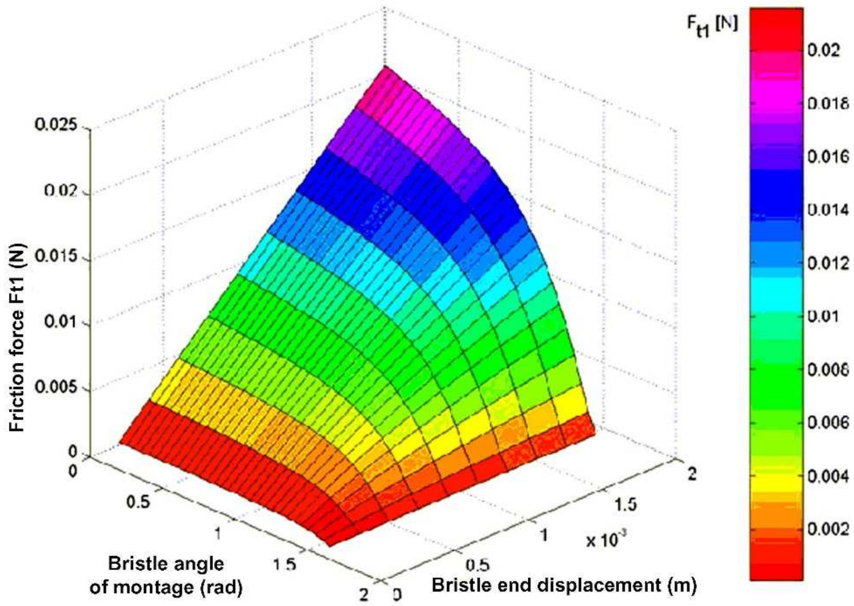

Fig. 4. Friction force for motion to front of machine body

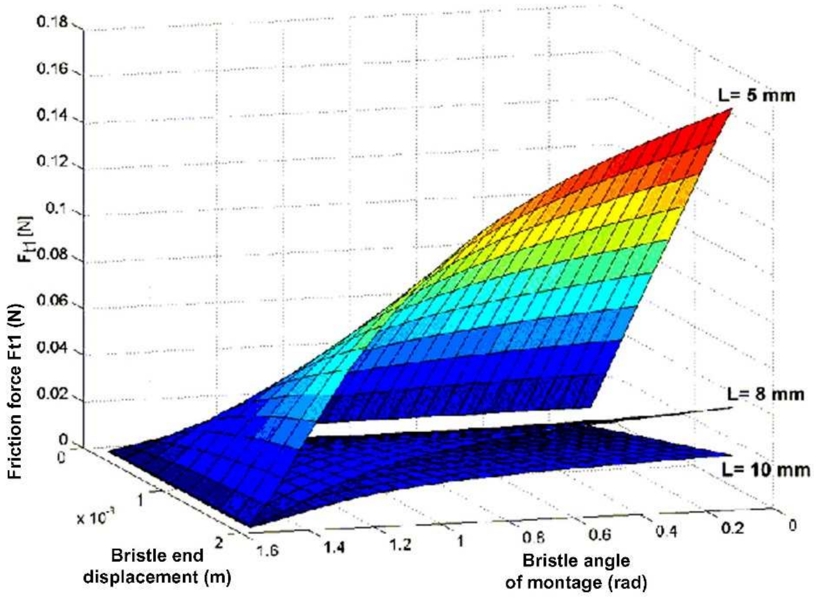

Fig. 5. Friction force for movement to front for various bristle length

Friction force for movement to back has different character (fig. 6). There is area of discontinuity shown as extremely rapid raising up of friction force to positive values and immediately falling down to negative values. In real the friction values for specified values raises to infinity and machine with bristles is blocked against the motion to back direction. If we will smooth the mapping mesh then the values will raises up very fast.

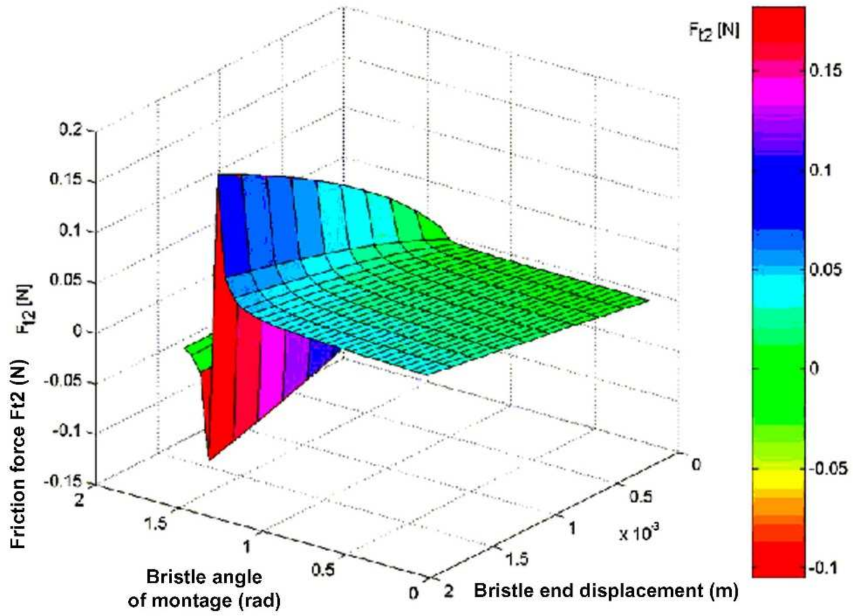

Fig. 6. Dependence of friction force for movement to back

For movement to back, also it is necessary to know influence of bristle length to friction force for this case (fig. 7). For smaller bristle length is situation similar as before. The value of friction force is raised up for decreased length of bristle. Decreasing of bristle length also causes the increasing of normal force and also friction force for this case of movement.

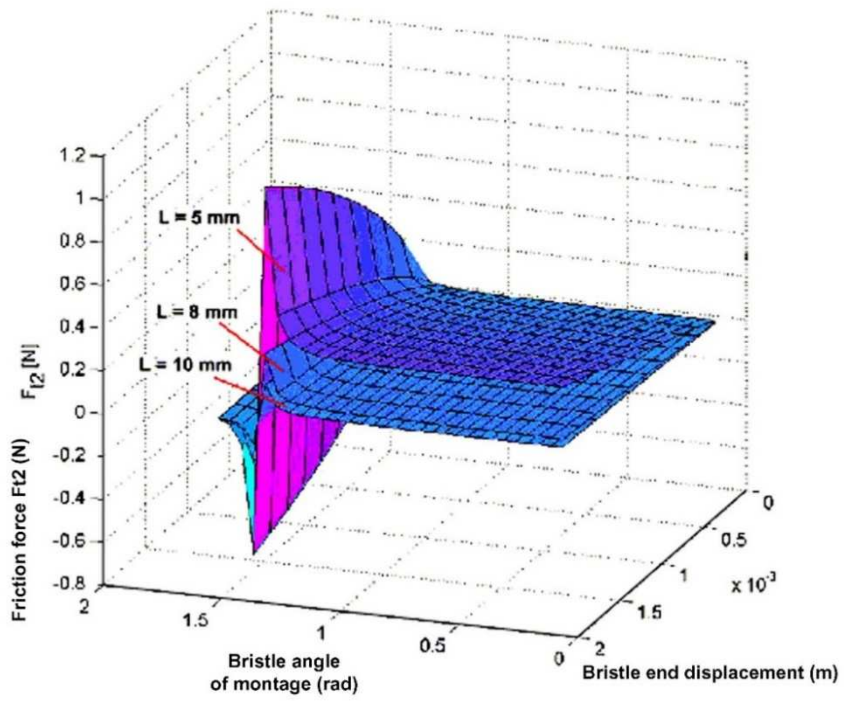

Fig. 7. Friction force for movement to back

Selection of bristle length also should be make in accordance with space possibility inside pipe. Length of bristle directly influenced bristle stiffness and also normal force against the pipe wall. There is an effort to make the bristle more elastic with low stiffness for ability to adapt to the pipe wall irregularities. It is necessary to make any compromise. The flexibility of bristle helps compensate wall deviations and sediments, which can complicate the motion of machine inside pipe. Efficiency of machine motion is also affected by difference between the friction forces for movement to front and back. Montage angle is another factor, which also affects these friction forces.

Figure 8 shows the dependence of friction force difference for movement to front and back on changed montage angle of bristle, radial position of bristle end.

Limit value for montage angle is value where friction force obtain extreme value. Optimal parameters of bristle is in case where is a maximum difference between friction forces.

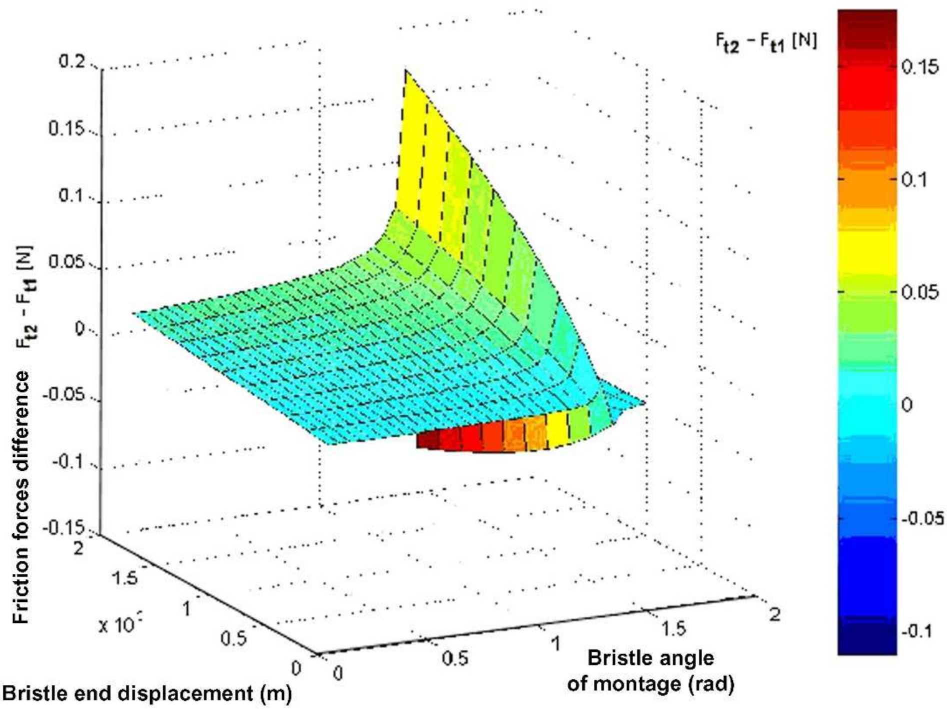

Fig. 8. Difference of friction forces for machine movement

Conclusion. Phenomenon of friction difference is a key factor for motion of machine inside pipe. Beside of it, a contact phenomenon between bristles and pipe wall is important for analysis in design process of this machine. Real bristles have a limitation of their deflection. In every case, deformation should be in flexible area of loading.

These bristles flexibility is used as device for compensation of pipe wall irregularities during the machine motion inside pipe.

The paper shows the typical case for design of mechatronic product, where optimization of mechanical parts are necessary for obtaining of best properties. Only best prepared mechanical design allows to reach optimal synergistic combination of mechanics, electronics and controlling [11-17].

Acknowledgement. *The authors would like to thank to Slovak Grant Agency – project KEGA 018TUKE-4/2018, and FGV/2016 supported by Faculty of Mech. Eng. at Technical University of Kosice.*

References

1. AOSHIMA, S. et al. (1993). A miniature mobile robot using piezo vibration for mobility in a thin tube. *ASME J. Dynam. Syst., Meas., Contr.*, 115, 270–278.

2. IDOGAKI, T.et al. (1995). *Characteristics of piezoelectric locomotive mechanism for an in-pipe micro inspection machine*. Proc. IEEE 6th Int. Symp. Micro Machine and Human Sciences, 193–198.

3. SUN, L., SUN, P., QIN, X., WANG, C. (1998) *Micro Robot in Small Pipe with Electromagnetic Actuator*. Micromechatronics and Human Science, MHS '98. Proceedings of the 1998 International Symposium on, 243-248.

4. MATSUMOTO, T.et al. (1994). *A prototype model of micro mobile machine with piezoelectric driving force actuator*. Proc. IEEE 5th Int. Symp. Micro Machine and Human Sciences, 47–54.

5. FUKUDA, T., HOSOKAI, H., & UEMURA, M. (1989) *Rubber gas actuator driven by hydrogen storage alloy for in-pipe inspection mobile robot with flexible structure*. Proc. IEEE Int. Conf. Robotics, Automation, 3, 1847–1852.

6. IWASHITA, S., HAYASHI, I., IWATSUKI, N., & K. NAKAMURA. (1994). *Development of in-pipe operation micro robots*. Proc. IEEE 5th Int. Symp. Micro Machine and Human Sciences, 41–45.

7. DEGANI A., FENG S., CHOSET H., and MASON M. T. (2010). *Minimalistic, Dynamic, Tube Climbing Robot*. Proc. of 2010 IEEE Int. Conf. on Robotics and Automation Anchorage Convention District, May 3-8, 2010, Anchorage, Alaska, USA, 1100-1101.

8. GMITERKO, A., DOVICA, M. (1997). *Dependence of the Body Sensitivity Function on Geometrical Size for the Mechatronic System*. International Conference Mechatronics and Robotics' 97. 29.9.-2. 10. 1997, Brno, Czech Republic, 27-30.

9. GMITERKO, A., KELEMEN, M., DOVICA, M., CAPÁK, M. (1999). *Miniature mobile robot for moving in a tube with small diameter*. Proceedings of the 2nd International Conference Mechatronics and Robotics ’99, Brno, Czech Rep., 1999, 67-70, ISBN 80-214-0604-6.

10. KELEMEN, M., GMITERKO, A., GÓTS, I. (2001). Mechatronic concept of bristled in-pipe machine. *ATP Plus.* 2001, 48-52

11. VITKO, A., JURIŠICA, L., BABINEC, A., DUCHOŇ, F., KĽÚČIK, M. (2010). *Some Didactic Problems of Teaching Robotics*. Proceedings of the 1st International Conference Robotics in Education 2010. Bratislava, 16.-17. 9. 2010, Bratislava, Slovak University of Technology in Bratislava, ISBN 978-80-227-3353-3, 27-30.

12. KONIAR, D., HARGAS, L., SIMONOVA, A. et al. (2014). *Virtual Instrumentation for Visual Inspection in Mechatronic Applications*. 6th Conference on Modelling of Mechanical and Mechatronic Systems (MMaMS) Location: Vysoke Tatry, SLOVAKIA Date: NOV 25-27, 227-234.

13. DUCHOŇ, F., HUBINSKÝ, P., HANZEL, J., BABINEC, A., & TÖLGYESSY, M. (2012). Intelligent Vehicles as the Robotic Applications. *Procedia Engineering*, 48 (2012), 105–114. doi.org/ 10.1016/j.proeng.2012.09.492.

14. KONIAR, D., HARGAŠ, L., & ŠTOFAN, S. (2012). Segmentation of Motion Regions for Biomechanical Systems. *Procedia Engineering*, 48 (2012), 304–311. doi.org/10.1016/j.proeng.2012.09.518.

15. TURYGIN, Y., & BOŽEK, P. (2013). Mechatronic systems maintenance and repair management system. *Transfer of innovations*, 26 (2013). 3-5.

16. SPANIKOVA, G., SPANIK, P., FRIVALDSKY, M. et al. (2017). Electric model of liver tissue for investigation of electrosurgical impacts. *Electrical Engineering*, 99 (4), 1185-1194. doi.org/ 10.1007/s00202-017-0625-0

17. KARAVAEV, Y. L., & KILIN, A. A. (2016). *Nonholonomic dynamics and control of a spherical robot with an internal omniwheel platform: Theory and experiments*. Proceedings of the Steklov Institute of Mathematics, 295 (1), 1 November 2016, 158-167.

УДК 004.4

Міхал Келемен

ОПТИМІЗАЦІЯ РУХУ МЕХАНІЗМУ

Актуальність теми дослідження. *Перевірка трубних систем необхідна для запобігання ушкоджень та аварій. Також їх ремонт і очищення можуть виконуватися без будь-яких земляних робіт.*

Постановка проблеми. *Трубні механізми придатні для переміщення всередині газопроводу, водопроводу, нафтопроводу, трубопроводів для стічних вод, трубопроводів для транспортування хімічних продуктів, парогенераторів, труб котлів тощо.*

Аналіз останніх досліджень і публікацій. *Нині для руху всередині труб використовуються колісні або гусеничні механізми. Коли стіна труби забруднена або на внутрішній стороні стіни труби наявні намули, колісний тип механізму схильний до проковзування.*

Виділення недосліджених частин загальної проблеми. *Питання проектування конструкції адаптивних трубних механізмів залишається невивченим, тому наступне дослідження буде сфокусовано на цьому.*

Постановка завдання. *Основна мета – оптимізувати структуру механізму для поліпшення загальних властивостей як швидкості руху, так і сили тяги. Пересувні блоки являють собою щетинки, які мають різні структурні та матеріальні властивості.*

Виклад основного матеріалу. *Для установки механізму можуть бути визначені монтажний кут і початкове відхилення, а також довжина щетинки. Щетинки розміщуються під кутом на корпусі механізму в дві групи (спереду і ззаду). Лінійний привід розміщується між цими групами щетинок. Періодичний хід виконавчого механізму створює поступальний рух усередині труби.*

Висновки відповідно до статті. *Феномен різниці тертя є ключовим фактором для руху механізму всередині труби. Крім того, для аналізу в процесі проектування цього механізму важливим є явище контакту між щетинками і стінкою труби. Реальні щетинки мають обмеження в їх вигині. У кожному випадку деформація повинна бути в гнучкій області навантаження.*

Гнучкість щетинок використовується як засіб для компенсації нерівностей стінки труби під час руху механізму всередині труби.

Ключові слова: *механізм; оптимізація; труба; тертя; рух.*

Рис.: 8. Бібл.: 17.

Kelemen Michal – Prof. Ing., PhD., Faculty of Mechanical Engineering, Technical University of Kosice (Letna 9, 04200 Kosice, Slovakia).

E-mail: michal.kelemen@tuke.sk

Researcher ID: J-2845-2013

Scopus Author ID: 8396804800

Kelemen, M. (2018). Machine motion optimization. *Technical sciences and technologies*, *3* (13), 82–88.