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Pneumatic capsule transport

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Abstract

The main advantages of the pneumatic capsule transport are: the high speed, ecological safety and the possibility to fully automate the movement. The objective of the work is to analyze the possibility to use the pneumatic capsule transport for transportation of different cargoes. The theoretical method of capsule pneumatic transport characteristics, depending on the tube material, includes the mathematical model with different types of friction. This model is based on Newton's second law of motion. The experimental device consists of a t-piece that is connected to the tube and vacuum pump through three-way valves. The capsule passes by one of the ultrasonic detector and starts the timer. The timer goes off when the capsule passes by the second detector. Specially designed program gives the opportunity to check the differential pressure in real-time mode and to get the data about the time movement of the capsule. The experimental research showed that the theoretical model can be used to calculate different types of the pneumatic capsule transport; the experimental model can be used to get kinematic data of the capsule movement and to determine the friction coefficient; the device and the software gives the opportunity to continue the research of the possibility to use the capsule pneumatic transport for transportation of different cargoes.

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Keywords: pneumatic capsule transport; friction coefficient; mathematical simulation

1. Introduction

The great Italian physicist E. Torricelli once said: "We live submerged at the bottom of an ocean of air". This "ocean" is a very convenient working medium, which is used in vacuum and compressor technology. One of them is pneumatic transport, where compressed air and vacuum technologies are used. The aim of project is the search for new opportunities for the development of capsule pneumatic transport to convey people and various cargoes.

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One of the types of capsule tube transport is evacuated tube transport with magnetic levitation train “Maglev” [1, 2] (Fig. 1). The disadvantages of projects are the high cost of creating and maintaining the tube vacuum and the track.

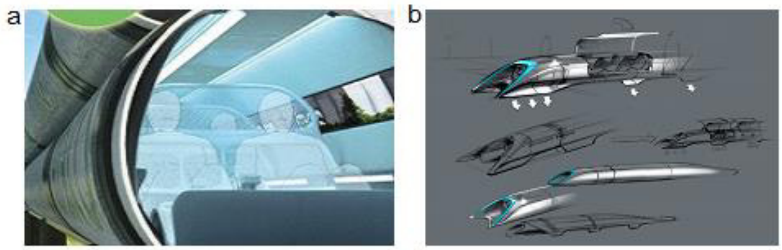

Fig.1. Daryl Oster’s (a) and Elon Musk’s (b) projects of evacuated tube transport.

Modern pneumatic container transport (Fig. 2a, b) takes its history from the idea of light (Fig. 2a) and heavy-duty (Fig. 2b) “air-mail” from 18th century [3]. The main advantages of pneumatic capsule transport are high speed, environmental safety, and the ability to fully automate the movement.

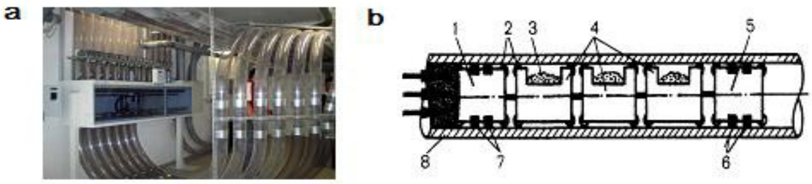

Fig. 2. Compact capsule transport (a) and large capacity transport (b): 1, 5 – pneumatic engine; 2 – wheels; 3 – cargo; 4 – carriage; 6, 7 – gland packing; 8 – duct.

To further develop the pneumatic transportation, it is necessary to study the possibility of moving goods by creating a differential pressure data for the properties of the materials used in friction pairs and pairs of bearings. The first part of research is theoretical investigation.

2. Theoretical investigation

Mathematical model of compact capsule transport (Fig. 3a) and large capacity transport (Fig. 3b) with different friction forces is based on the II-nd Newton’s Law.

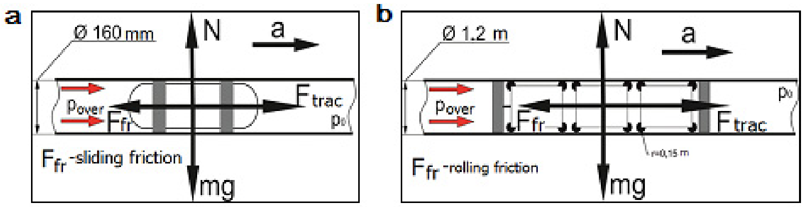

Fig. 3. Compact capsule transport scheme (a) and large capacity transport scheme (b).

Capsule acceleration time up to reference speed is the function of need capsule speed, capsule mass, tube diameter, friction coefficient and pressure drop (pressure difference before and after the capsule):

$$t = \frac{vm}{\pi d^2/4 \cdot \Delta p - \mu mg} \quad (1)$$

Maximum weight of the capsule, subject acceleration time capsule, is the function of a reference speed upon tube diameter d, friction coefficient μ and pressure drop Δp (pressure difference before and after the capsule):

$$m = \frac{\pi d^2 \Delta p}{4(a + \mu g)} \quad (2)$$

3. Dynamic characteristics of friction

When considering the light capsule transport, the friction coefficient μ is defined as the ratio between the friction force F needed to create sliding and the normal force N which presses the two bodies against each other. The static friction coefficient μ_s is measured just before sliding and the dynamic friction coefficient μ_d is measured during sliding. The latter, widely used as a reference, is a useful parameter. In Eq. 1 and 2 we must use the dynamic friction coefficient.

Table 1 presents some values of static friction coefficient μ_s for friction pairs for material which can be used as pipe material and rubber as a capsule seal. Those values are very different, that is why the time or acceleration calculation would be very different. But what can we say about dynamic friction coefficients?

Table 1. Static friction coefficient for different materials of tube and rubber capsule seal.

The tube material	Static friction coefficient
HDPE (High Density Polyethylene)	0.5
PVC (Polyvinyl chloride)	0.2
F-4 (PTFE-4)	0.04

On the other hand, capsule and tube materials are polymers. The friction theory of polymers was developed by Russian scientist Bartenev G.M. [4]. Polymers can exist in four physical states - the crystalline and three amorphous states (glassy, rubbery, and viscous flow). Polymers that exist in the glassy or crystalline state are sometimes called rigid polymers. Each state has its own complex of mechanical properties and its own area of technical application.

The molecular friction theory for polymers yields a binomial expression for the external friction force F as a function of the nominal load N:

$$F = \mu N + \mu p_0 S_0 \quad (3)$$

or

$$F = \mu(N + p_0 S_0) \quad (4)$$

where μ is the true friction coefficient; S_0 is the real contact area; p_0 is the specific adhesion affecting area S_0.

It follows from expression (3) that the force of friction is the sum of two components. One of them, μN, depends on the response of Born forces to the load, the other, $\mu p_0 S_0$, depends on the response of repelling forces to the force of molecular attraction.

The total dynamic friction in the dry systems is drastically increased by the presence of adhesion [5]. The true area of contact plays a vital role for adhesion, decreases for velocity. Also adhesion friction decreases for low velocities. This dependence is different for different friction pairs and may be up to μ≈2.5 [6]. That is why it is very important to explore transient friction coefficient for real pipe-capsule pairs.

4. Experimental investigation

The dynamic friction experimental device is based on the polymer tube and the capsule which can be made from different materials. Device (Fig. 4a) consists of the tree connection, which is connected through three-way ball valves to the pipe and to a vacuum pump. The valves are switched so that one end of the tube is connected to atmosphere and the other directly with a vacuum pump. And it creates the necessary pressure drop for movement of the capsule.

The capsule, passing by one of ultrasonic sensors, starts the timer, stops at the intersection of the second sensor. Special experimental C#-based software [7] allows to measure the differential pressure in real time, to obtain the data of average differential and time of movement. The weight of the capsule, the length and diameter of the pipe can be changed. Using the above data, acceleration of the capsule, maximum and average speed and coefficient of friction are calculated. Besides, this software can determine the error in direct and indirect measurements.

Fig. 4b presents the electronic scheme for sensors and microcontroller connection.

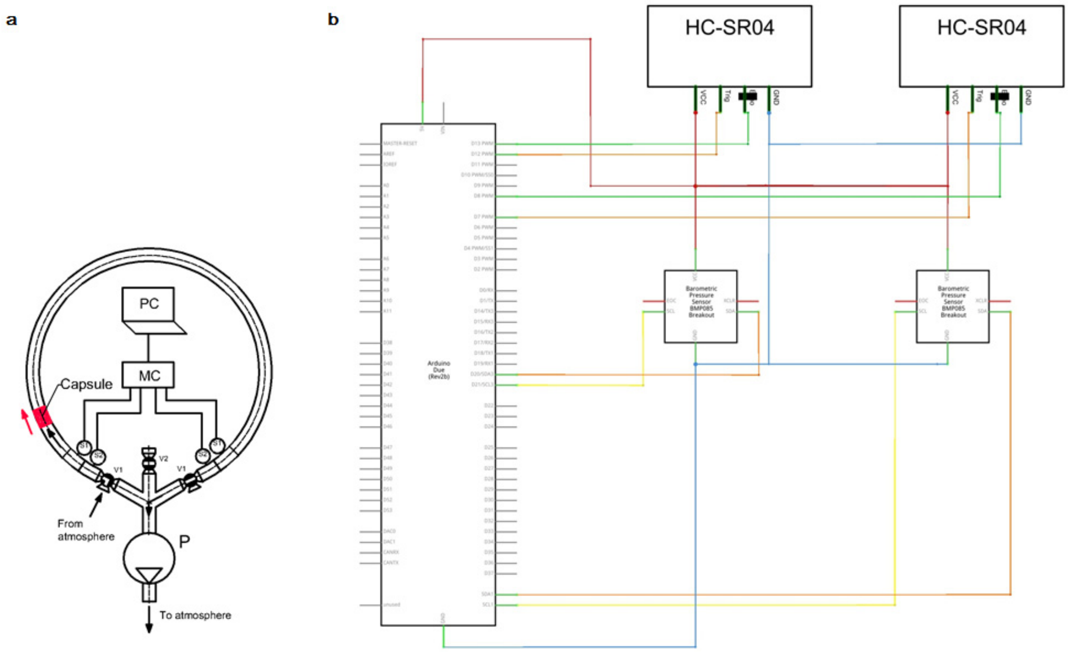

Fig. 4. Scheme of experimental device (a) and electronic scheme of experimental device (b): S1 – ultrasonic range finder HC-SR04; S2 – pressure Sensor BMP085; MC – microcontroller; PC – laptop; P – pump; V1 - three-way valve; V2 - two-way valve.

Table 2 contains constants for use in the experimental investigation. The average dynamic friction coefficient obtained is 1.25. This value can be used for next theoretical investigation of capsule movement in pipeline.

Table 2. Experimental constants.

Parameter	Value	Unit of measure
Pipe material	PVC (Polyvinyl chloride)	-
Capsule mass	202	g
Capsule material	Glass	-
Pipe length	2553	mm
Pipe diameter	50	mm

5. Conclusions

Pneumatic capsule transport has a very actual application: very fast and ecological transportation of small needs, cargo and people. The choice of the material for the pipeline plays an important role when transporting weighting cargoes. The experimental device makes it possible to get the average coefficient of dynamic friction and can be used for the further experimental research of pneumatic transport possibilities.

References

[1] Tubular transportation system for transporting passengers/cargo: Pat. US 5950543. USA: Inv.: Daryl Oster; Assig.: et3.com Inc., Filed 10.10.1997; Publ. 14.09.1999.
[2] Hyperloop Tech. Web-site. (2014) Available at: http://hyperlooptech.com/ (accessed 19 September 2014).
[3] V.I. Levin, The profession of compressed air and vacuum (Professii szatogo vozduha i vakuuma), Moscow: Engineering Publ. [Mashinostroeniye], 1989, 256 p. (in Russian).
[4] G.M. Bartenev, V.V. Lavrentev, Friction and wear of polymers (Trenie I iznos polimerov), Leningrad, Khimia, 1972, 240 c. (in Russian).
[5] D. Besdo, B. Heimann, M. Klüppel, M. Kröger, P. Wriggers, U. Nackenhorst, Elastomere Friction Theory, Experiment and Simulatio. Lecture Notes in Applied and Computational Mechanics. V.51., Series Editors F. Pfeiffer, P. Wriggers. Springer-Verlag. 2010, 256 p. DOI 10.1007/978-3-642-10657-6.
[6] K. Friedrich, A.K. Schlarb, Friction and Wear of Bulk Materials and Coatings. Tribology And Interface Engineering Series, 55. Editor: B.J. Briscoe, Tribology Of Polymeric Nanocomposites. Elsevier, 2008, 568 p.
[7] J. Blum, Exploring Arduino. Tools and Techniques for Engineering Wizardry (Izuchaem Arduino. Instrumenty i metody tekhnicheskogo volshebstva. Moscow, BHV Publ. (BHV), 2015, 336 p. (in Russian).