TRANSPORT PROBLEMS 2017 Volume 12 Issue 4
PROBLEMY TRANSPORTU DOI: 10.20858/tp.2017.12.4.5

Keywords: batcher, spring vibration, transverse vibrations, vibration waves, vibration frequency

Vytenis NAGINEVIČIUS, Dalius KALISINSKAS*, Skirmantas ADOMAVIČIUS
Kaunas Technical University of Applied Sciences
Tvirtovės al. 35, LT-50155, Kaunas, Lithuania
**Corresponding author*. E-mail: dalius.kalisinskas@edu.ktk.lt

SPRING-LOADED BATCHER

Summary. On the base of the analysis of the application of vibration mechanisms in the motor transport vehicles, considering the possibilities of fuel injection systems, the study presents survey of possibilities the usage of the devices micro-dosing and spraying apparatus, the construction and the principle of the operation of vibration-assisted spring-loaded batcher, the necessary for its functioning vibration operation forms and the dependences of measured fuel amount on the leakage chamber width and how it is related to vibration frequency and amplitude. The results of mathematical modeling and experimental analysis based on laser holographic interferometry are presented.

1. INTRODUCTION

Motor transport companies constantly face the problem of fuel dosage in fuel injection systems, which is due to complex constructions and their control. As a result, the speed and reliability suffer. A part of the problems is solved in some studies [5, 2].

We would like to offer the new spring-loaded batcher adapted for fuel injection in motor transport systems.

The aim of this study is to investigate the possibilities of spring-loaded batcher for fuel injection in correct doses.

The following tasks are solved to achieve this goal:
to survey the possibilities of usage of the device for fuel injection,
to present the construction and operation principles of vibratory spring-loaded butcher,
to present the theoretical evidence of the system functioning, and
to experimentally analyze the characteristics of the vibration spring.

The study presents the construction of vibration-assisted spring-loaded batcher, describes its principle of operation, and introduces the spring-loaded batcher transverse vibration forms and the dependence of the vibration frequency and the amplitude on the dosed liquid.

1.1. The survey of devices for fuel injection

In Fig. 1 - 4 the injector schemes of indirect and direct gasoline injection are presented [3, 8, 1, 7].

In Fig. 1, a structure of low-pressure injector with electromagnetic control is presented [3], which has a relatively large length of delay, called a solenoid response time.

High-pressure piezo injectors, shown in Fig. 4, have greater accuracy and faster reaction [7]. They are smaller than electromagnetic injectors and have fewer moving parts; therefore, they break down less often. But in practice, they break down as often as electromagnetic injectors and are not recommended.

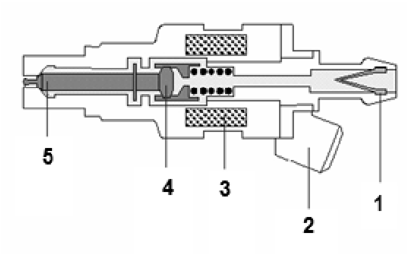


Fig. 1. Fuel injector: 1 - filter; 2 - connection; 3 - electromagnetic coil; 4 - electromagnetic solenoids; 5 - needle valve

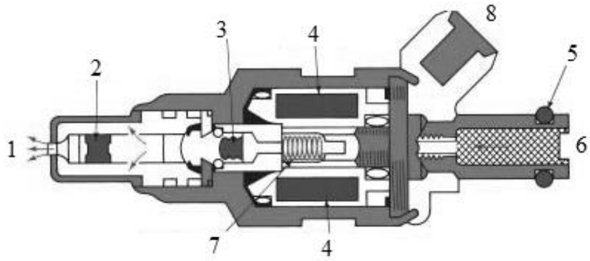


Fig. 2. GDI injector nozzle: 1 - injection; 2 - needle valve; 3 - plunger; 4 - coil windings, 5 - ring seal; 6 - inlet, 7 - plunger spring; 8 - wiring terminal

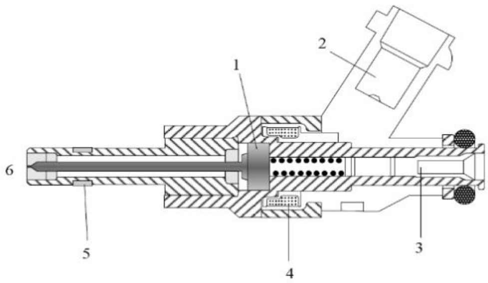


Fig. 3. High-pressure nozzle: 1 - armature; 2 - electrical connection; 3 - fuel inlet; 4 - coil; 5 - ring seal; 6 - injection

Direct injection injectors are high-pressure injectors (Fig. 2, 3) [8]. They have short injection duration, thus allowing injection of fuel into cylinder more than once during a power stroke.

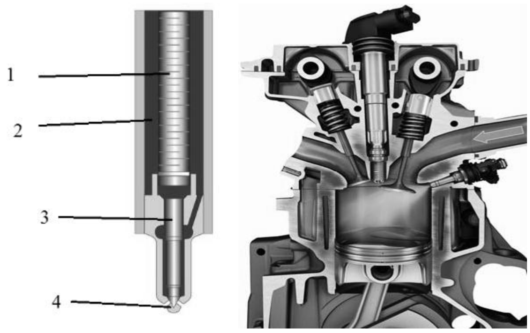


Fig. 4. Piezo-ceramic high-pressure nozzle: 1 - piezo element; 2 - fuel; 3 - needle valve; 4 - injection

All the above mentioned systems have one structural characteristic in common – fuel injection is injected through holes that are at the end of injector. Therefore, the max debits are limited as the injection is performed through one hole or a single-hole system.

1.2. The survey of micro-dosing and spraying apparatus

Micro-dosing and spraying apparatus, its design optimization, operation principles and research results are presented in various papers [9 - 15]. Its functionality is based on the influence of high-frequency vibrations generated by piezo-actuator to the flow of liquid substances in a micro tube. Such spray systems provide high accuracy of micro-dosing and are applicable in a variety of applications from avionics to medicine. Their disadvantage in solving problems of fast fuel dosage change may be considered the limited possibilities to maximally fast make the changes of fuel flow rate in a wide range.

2. VIBRATION-ASSISTED SPRING-LOADED BATCHER: CONSTRUCTION AND PRINCIPLE OF OPERATION

The spring-loaded batcher is a rigid steel spring made of turns without gaps and is capable of ensuring system tightness in case of fuel supplied under fixed pressure to the sealed spring. The spring-loaded batcher is shown in fig. 5.

The spring-loaded batcher (numbered 1) is measured at the car inlet manifold (numbered 2). Let us suppose that the inlet opening is at the left end of the spring. Another end of the spring (1) is tightened and fixed to transverse vibration vibrator (3).

When the spring is at rest, it does not leak out the fuel between the turns (the close contact between the turns provides the tightness of the spring).

Then, when the transverse vibrations are excited by the help of the vibrator in the form of standing four half-waves in the spring, the spaces between the turns appear, which provide the possibilities for the fuel leak-out. The four half-waves are excited in order to ensure that their amplitude peak phases appeared at the liquid centers of inlet manifold (these openings represent the four-cylinder engine mixture intake channels). The standing vibration waves of the spring are shown in fig. 5.

It is obvious, that when the piston moves down, rarefaction is caused, which intakes the fuel mixture into the ignition chamber.

This is only one of the possibilities to arrange the batcher. The other solution could be to arrange the spring-loaded batcher in each channel and excite transverse vibrations, e.g. in the shape of a single half-wave. This would provide the possibility for a separate batcher to operate independently (Fig. 6).

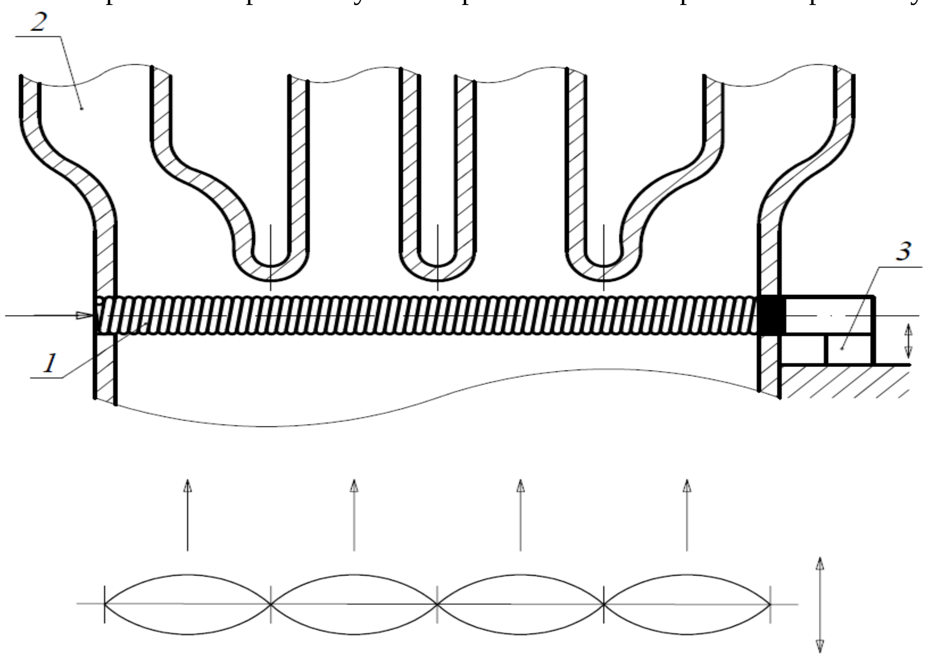


Fig. 5. Spring-loaded batcher

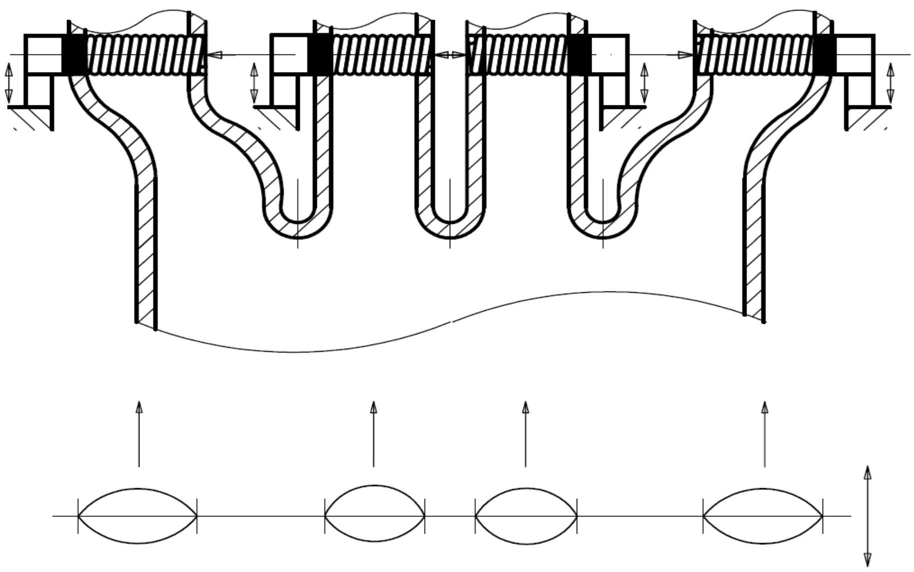


Fig. 6. Spring-loaded batcher in each channel

3. THEORETICAL SUBSTANTIATION OF POSSIBILITIES FOR THE BATCHER FUNCTIONING

The rigid coiled spring could be considered as a duct.

Let us suppose, that within the range of spring strains analyzed, the material elasticity is constant, therefore, dependence on the strain amount from the applied force is directly proportional.

If the spring is affected by the axis strength force, the existing winding area will be proportional to the spring elongation.

The increased surface of elongated spring will be determined, when it is coiled into the arc. The calculation scheme is presented in Fig. 7.

In the inner part of bended spring, the turns touch each other tightly.

The inner arc curvature range is ρ_0. It is equal to the following:

$$\rho_0 = \frac{L}{\pi} \tag{1}$$

The length of the arc L is equal to the following:

$$L = \frac{2\pi\rho_0}{2} = \pi\rho_0 \tag{2}$$

The outer part of the arc between the turns will have the gap δ, which being in the shape of a spiral, decreases to 0 in the inner part of the arc. Thus, the gap of spiral shifting width gap is produced.

The outer arc radius $\rho_{iš}$ is equal the following:

$$\rho_{iš} = \rho_0 + 2(R + r) \tag{3}$$

The outer arc length $L_{iš}$ is the following:

$$L_{iš} = \pi\rho_{iš} = \pi[\rho_0 + 2(R + r)] = \pi(\rho_0 + \sigma) \tag{4}$$

where, σ - spring-duct diameter. It is equal to the following:

$$\sigma = 2(R + r) \tag{5}$$

Thus, the outer arc length $L_{iš}$ is the following:

$$L_{iš} = \pi\left(\frac{L}{\pi} + \sigma\right) = L + \pi\sigma \tag{6}$$

Outer arc elongation ΔL is equal to the following:

$$\Delta L = L_{iš} - L = L + \pi\sigma - L = \pi\sigma \tag{7}$$

Thus average elongation of the spring ΔL_{vid} is equal to the following:

$$\Delta L_{vid} = \frac{\Delta L}{2} = \pi(8 + r) \tag{8}$$

Increased surface of average elongated spring ΔS_{vid} will be equal to the following:

$$\Delta S_{vid} = 2\pi R \Delta L_{vid} = 2\pi^2 R(R + r) \tag{9}$$

This is the space for the leak out of the part of fuel.

Let us analyze the case, when the spring-duct axis is in the shape of curve, which is presented in Fig. 8.

In general case between $f(a)$ and $f(b)$:

$$l = \int_a^b \sqrt{1 + [f'(x)]^2} \tag{10}$$

If the excited vibrations are in the shape of sine, the half of its length L_p will be as follows (Fig.9):

$$L_p = \int_0^{1/4} \sqrt{1 + [\sin' x]^2} = \int_0^{1/4} \sqrt{1 + \cos^2 x} \tag{11}$$

The spring-duct elongation half-waves ΔL_p will be the following:

$$\Delta L_p = L_p - \frac{l}{4} \tag{12}$$

This elongation of the spring affects the increase of its inner surface:

$$\Delta S_{vid} = 2\pi R \Delta L \tag{13}$$

Thus, the outer surface S area change could be expressed as follows:

$$S = A_0 \cos\left(\frac{2\pi}{\lambda} x\right) \sin(2\omega t) \tag{14}$$

$$\omega = 2\pi f \tag{15}$$

where A_0 - maximum amplitude of standing waves; x – spring-duct coordinate along axis; λ - length of wave; f - frequency, Hz.

Thus, we could confirm, that the higher the amplitude of spring vibration, the wider the space between the spring turns and more fuel will leak out between them.

4. EXPERIMENTAL ANALYSIS OF THE SPRING

The amplitudes of vibration of the structure are determined using the methodology presented in papers [4, 6]. Fig. 10 presents the structural diagram of a setup for experimental analysis of the spring vibration. The stand contains a spring that is harmonically excited by the high-frequency signal generator (2) and the amplifier (3). The signal frequency is monitored by the frequency meter (4), and the voltage amplitude of the power supply is monitored by the voltmeter (5). The optical circuit of the stand includes a holographic installation with a helium-neon laser which serves as a source of coherent radiation. The beam from the laser (6) splits into two mutually coherent beams passing through the beam splitter (7). The object beam, reflected from the mirror (8), is split by the lens (10) and illuminates the surface of the tubular working tube (1) and, after reflecting from it, impinges on the photographic plate (12). The reference beam, reflected by the mirror (9), and expanded by the lens (11), illuminates the holographic plate (12) where the interference structure is recorded.

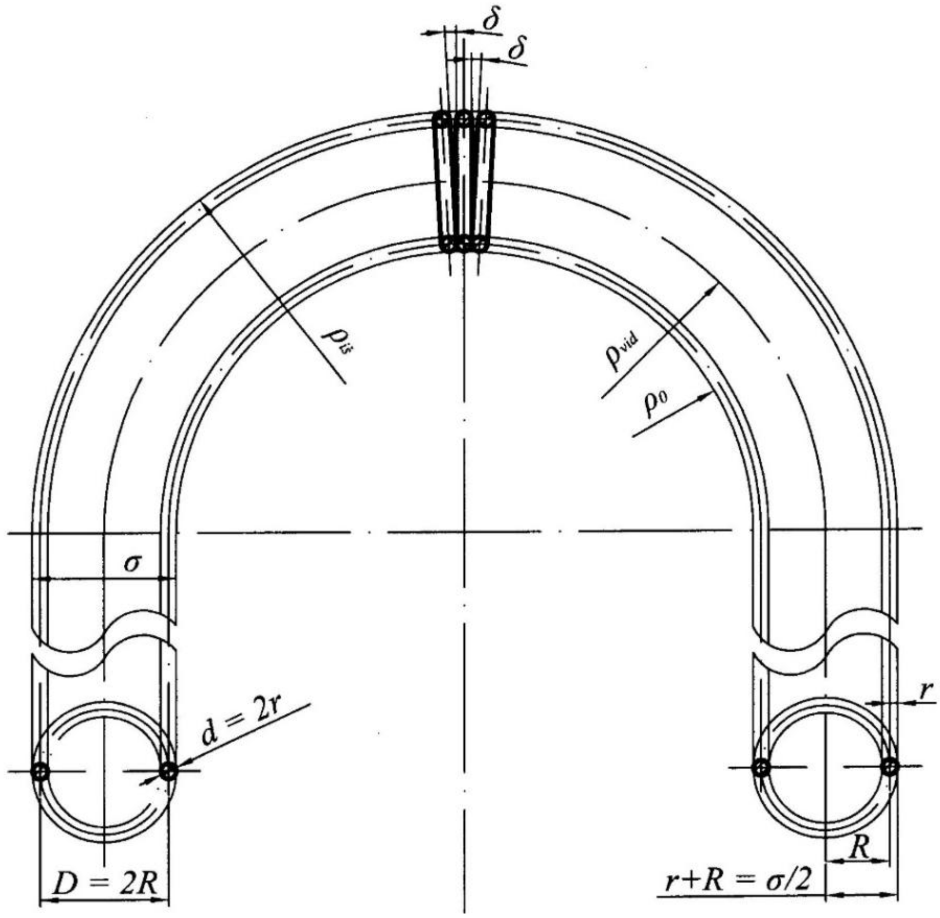


Fig. 7. Calculation scheme of the spring elongation

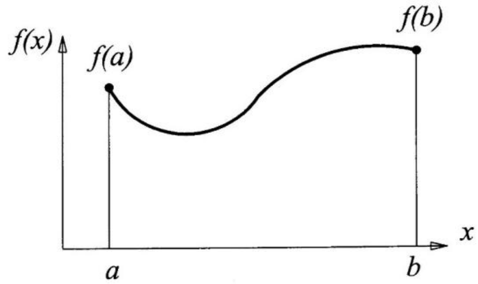


Fig. 8. Spring axis as curve

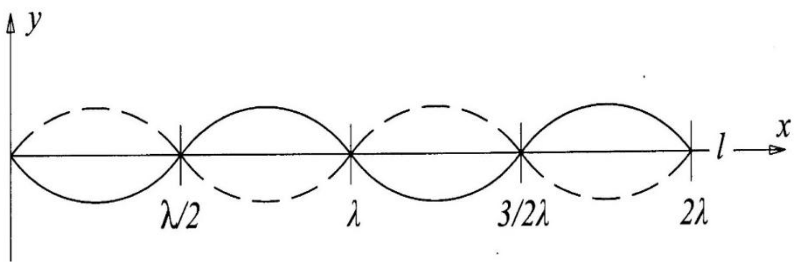


Fig. 9. Transverse vibrations of spring-loaded batcher

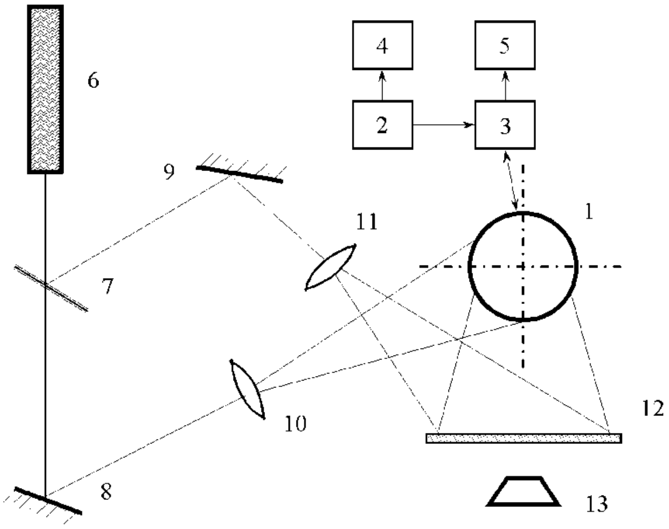


Fig. 10. The schematic drawing of the laser holographic interferometry system: 1 - tubular working tube; 2 - high-frequency signal generator, 3 - amplifier; 4 - frequency meter; 5 - voltmeter, 6 - laser; 7 - beam splitter; 8, 9 - mirror; 10, 11 - lens; 12 - photographic plate; 13 - recorder

The characteristic function defining the complex amplitude of the laser beam M_T in the plane of the hologram formed by the time averaging holography techniques takes the following form:

$$M_T = \lim_{T\to\infty} \frac{1}{T} \int_0^T \exp\left(i \left(\frac{4\pi}{\lambda} \right) Z(x) \sin \omega t \right) dt = J_0 \left(\left(\frac{4\pi}{\lambda} \right) Z(x) \right) \quad (16)$$

where T – the exposure time of the hologram, ($T >> 1/\omega$); ω – the frequency of structural vibrations, λ – the laser wavelength; J_0 – zero order Bessel function of the first type.

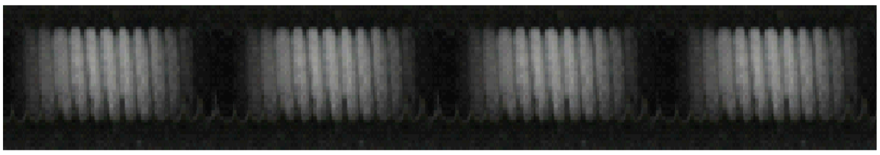
Then, the resulting intensity I of the point (x, y) on the hologram is as follows:

$$I(x, y) = a^2(x, y) |M_T|^2, \quad (17)$$

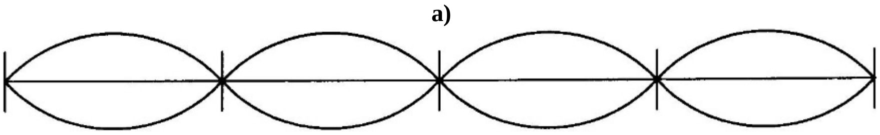
where a(x, y) – the distribution of the amplitude of the incident laser beam. It can be noted that the centers of dark interference bands in the holographic interferogram coincide with such values of $Z(x)$ which turn the Bessel function to zero. The structure of the distribution of the interference bands does not depend on the static deformations of the structure, or on the distance between the structure and the hologram.

The practical problem using the time averaging holographic interferometry is related to the fact that the surface of analyzed object must perform steady state vibration, otherwise the interference band pattern can be hardly interpretable. As the construction elements of the analyzed system oscillate but do not perform translational motion, the application of this convenient holographic analysis turns out to be not very effective.

Results of experimental analysis are presented in Fig. 11.



a)



b)

Fig. 11. Results of experimental analysis: holographic interferogram of vibrating spring at frequency 1,24 kHz (a), distribution amplitude of vibration of spring. (b)

5. THE RESULTS OF THE STUDY

The aspects of particle disperse and flow turbulence analysis are not discussed in the papers.

When forming the theoretical mathematical model, it is assumed that there is direct dependency between the amount of fluid that leaks out through the gap between the spring turns while the spring is bended and the surface between the spring turns.

Analog equation of the spring-duct axis (10) when excited vibrations are in the shape of sine is expressed (14).

Results of experimental analysis are presented by holographic interferogram in Fig. 11.

6. CONCLUSIONS

The vibration-assisted spring-loaded batcher is applied for the fuel metering in the car engine inlet manifolds. Its construction is simple, can be easily and exactly controlled, and achieves proper values of vibration amplitudes.

The main bottleneck of reviewed devices for fuel injection is limited possibilities to maximally fast make the changes of fuel flow rate in a wide range.

The theoretical substantiation of the possibilities of the dispenser functioning is presented by the way out of standing vibrating waves of the spring in the dispenser.

Results of experimental analysis are presented by holographic interferogram of distribution amplitude of vibration of spring at frequency of 1,24 kHz.

References

1. Bahattin, M. & Çelik, B. Özdalyan. *Gasoline direct injection*. 2010. P. 19. Available at: http://www.intechopen.com/books/fuelinjection/gasoline-direct-injection.
2. Bubulis, A. & Naginevičius, V. & Vasiliauskas, R. & Busilas, A. & Palevičius, A. Experimental investigation of micro spray systems. In: *Vibroengineering 2006: proceedings of the 6th International Conference*, October 12-14, 2006. Kaunas, Lithuania / Lithuanian Academy of Sciences, IFToMM National Committee, Kaunas University of Technology. Kaunas: Technologija, 2006. P. 183-186. ISSN 1822-1262.
3. Enright, N. Basic principles of operation and applications of fuel injection systems in petrol-powered cars. *Department of Mechanical & Automobile engineering Limerick institute of technology*. 25 p.
4. Naginevičius, V. & Ragulskis, M.K. & Palevičius, A. Analysis of the dynamics of the vibratory valve-injector. In: *Mechatronic Systems and Materials: 3rd international conference*, 27-29 September, 2007. Kaunas, Lithuania: abstracts of reviewed papers. Kaunas University of Technology. Vilnius Gediminas Technical University. Lithuanian Academy of Science, Kaunas: Technologija. 2007. 220 p. ISSN 1822-8283.
5. Naginevičius, V. & Speičys, V. & Avotins, J. Vibratory Distribution Nozzle. In: *Transport Means - 2009: proceedings of the 13th international conference*. October 22-23, 2009. Kaunas University of Technology, Lithuania / Kaunas University of Technology, IFToMM National Committee of Lithuania, SAE Lithuanian Branch, The Division of Technical Sciences of Lithuanian Academy of Sciences. Klaipėda University. Vilnius Gediminas Technical University. Kaunas: Technologija. 2010. P. 99-103. ISSN 1822-296X.
6. Ragulskis, M.K & Palevičius, A. Theoretical and experimental studies of tubular valve dynamics. *International Journal of Acoustics and Vibration: a quarterly publication of the International Institute of Acoustics and Vibration.* 2002. Vol. 7. No. 1. P. 53-57. ISSN 1027-5851.
7. Sadegh, D. *Effect of temperature and thermal cycles on PZT ceramic performance in fuel injector applications.* Department of Mechanical and Industrial Engineering University of Toronto. 2012. P. 7-10.

8. Wen-Chang, T. & Peng-Cheng, Yu. Design of the Electrical drive for the high-pressure GDI injector in a 500cc motorbike engine. *International Journal of Engineering and Industries.* 2011. Vol. 2. No. 1. P. 70-83.
9. Polak, J.F. Ultrasound energy and the dissolution of thrombus. *N Engl J Med.* 2004. Vol. 351. P. 2154-2155. Available at: http://dx.doi.org/10.1056.NEJMp048249.
10. Grube, E. & Sutsch. & Lim, V.Y. & Buellesfield, L. & Iakovou, I. & Vitrella, G. High-frequency mechanical vibration to recanalize chronic total occlusions after failure to cross with conventional guidewires. *Journal of Invasive Cardiol*. 2006. Vol. 18. P. 85-91.
11. Dubinsky, T.J. & Cuevas, C & Dighe, M.K & Kolokythas, O. & Hwang, J.H. High frequency focused ultrasound: current potential and oncologic applications. *AJR Am Journal of Roentgenol.* 2008. Vol. 190(1). P. 191-199. Available at: http://dx.doi.org/10.2214/AJR.07.2671.
12. Tzai, T. & Minchenya, V.T. & Vladimirskuya, T & Mrochek, A.G. Progress on research of ultrasound angioplasty. *Journal of Chinese Medicine Research.* 2005. Vol. 5(2). P. 135-136.
13. Palevicius, A. & Bansevičius, R. & Dragasius, E. & Ragulskis, M. Development of smart piezoceramic transducers for detection of solidification in composite materials. In: *Proceedings of SPIE: Smart Structures and Materials 2004: Smart Sensors Technology and Measurement Systems.* Bellingham: SPIE / 15-17 March 2004, San Diego, California, USA. 2004. Vol. 5384. P. 71-79. ISSN 0277-786X.
14. Bansevičius, R. & Dragašius, E. & Palevičius, A. & Daugėla, A. & Ragulskis, M. Development of smart sensors for solidification detection in composite materials. *Mechanika.* 2004. No. 5 (49). P. 50-54. ISSN 1392-1207.
15. Ostasevicius, V. & Palevicius, A. & Daugėla, A. & Ragulskis, M. & Palevicius, R. Holographic Imagining technique for characterization of MEMS switch dynamics. In: *Proceedings of SPIE: Smart Structures and Materials 2004: Smart Electronics, MEMS, BioMEMS, and Nanotechnology.* 15-18 March 2004. San Diego, California, USA. 2004. Vol. 5389. P. 73-84. ISSN 0277-786X.

Received 05.09.2016; accepted in revised form 06.12.2017