



Volume 103

2019

p-ISSN: 0209-3324

e-ISSN: 2450-1549

DOI: <https://doi.org/10.20858/sjsutst.2019.103.14>



Journal homepage: <http://sjsutst.polsl.pl>

Article citation information:

Urbanský, M., Kaššay, P., Vojtková, J. New design solutions of tangential pneumatic torsional vibration tuners. *Scientific Journal of Silesian University of Technology. Series Transport*. 2019, **103**, 183-191. ISSN: 0209-3324.

DOI: <https://doi.org/10.20858/sjsutst.2019.103.14>.

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NEW DESIGN SOLUTIONS OF TANGENTIAL PNEUMATIC TORSIONAL VIBRATION TUNERS

Summary. The optimal tuning of a mechanical system in terms of torsional dynamics is a very important function of the flexible shaft coupling, built in the system. Therefore, a flexible coupling with suitable dynamic properties has to be carefully chosen for each specific application. The main advantage of the pneumatic flexible shaft couplings, that is, torsional vibration tuners, developed at our department, is that we can easily regulate their dynamic properties, particularly their dynamic torsional stiffness during the operation of a mechanical system. In order to improve our pneumatic tuners in terms of better utilisation of their pneumatic flexible elements and achieving specific operational properties, two new pneumatic tuners with tangential arrangement of their pneumatic flexible elements were designed. The aim of this article was to introduce these new pneumatic tuners, protected by means of utility models, namely a tangential pneumatic flexible shaft coupling with axially deformed flexible elements and tangential pneumatic flexible shaft coupling with serial arranged flexible elements. Due to the fact that both mentioned pneumatic tuners are not yet

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manufactured, this article deals mainly with the principles and expected advantages of the pneumatic tuners.

Keywords: tangential pneumatic torsional vibration tuners, new design solutions, utility models, properties

1. INTRODUCTION

Nowadays, the reduction of vibration and noise of machines is a very important task, mainly in terms of human health, comfort and the lifetime and safety of machines, for example [6, 9, 14, 12]. Great emphasis is placed on the use of modern progressive technologies in order to improve electric and combustion engines for efficiency, better emissions and dynamics, for example [4, 5, 10]. Flexible shaft couplings are the most utilised machine parts for the flexible transmission of load torque in machines with rotary power transmission. A flexible coupling with suitable dynamic properties, particularly dynamic torsional stiffness, has to be carefully chosen for each specific application, otherwise dangerous torsional vibration can occur in a mechanical system, for example [1, 7].

Flexible elements of flexible shaft couplings are made of various materials, mainly of rubber, plastic and metal. During the operation of mechanical systems, it is subjected to fatigue, ageing of rubber and plastic flexible elements and ageing and wearing down of the metal flexible elements of applied flexible coupling, for example [2, 8]. Consequently, the applied flexible coupling loses its original dynamic properties and thus, the ability to carry out its important functions in a torsionally oscillating mechanical system, mainly, the tuning of a mechanical system in terms of torsional dynamics. The disadvantages of the mentioned flexible elements can be eliminated using pneumatic flexible elements (air-springs). The flexible transmission of torque is ensured by a compressed gaseous medium, which does not suffer from fatigue or ageing. The main advantage of pneumatic flexible shaft couplings (for example, couplings according to granted patents: SK 288455 B6, SK 288344 B6, SK 288341 B6, SK 278750 B6, SK 278653 B6, SK 278152 B6) is the possibility to change their torsional stiffness which depends on the gaseous medium pressure value in its pneumatic flexible elements. This makes it possible to suitably adapt the dynamic torsional stiffness of a pneumatic coupling to the actual operating mode of the mechanical system.

At our department, we dealt with the development, research and application of pneumatic flexible shaft couplings into mechanical systems. We focused mainly on continuous tuning of mechanical systems during their operation in terms of torsional dynamics using pneumatic flexible shaft couplings as active torsional vibration tuners. For continuous tuning, we use electronic control systems developed by us. Our extensive research in the field of pneumatic torsional vibration tuners and torsional dynamics led to improvements in our pneumatic tuners and control systems. In order to improve the tuners for better utilisation of their pneumatic flexible elements and achieving specific operational properties, two new pneumatic tuners with tangential arrangement of their pneumatic flexible elements were designed. The aim of this article was to introduce these new pneumatic tuners, protected by means of utility models, namely:

1. Tangential pneumatic flexible shaft coupling with axially deformed flexible elements⁴.
2. Tangential pneumatic flexible shaft coupling with serial arranged flexible elements⁵.

⁴ Kaššay Peter, Grega Robert. 2018. *Tangential pneumatic flexible shaft coupling with axially deformed flexible elements*. Utility model No. SK 8250 Y1. Banská Bystrica: ÚPV SR. 7 p. Patent application form No. 78-2017.

Because both mentioned pneumatic tuners are not yet manufactured, this article deals mainly with the principles and expected advantages of pneumatic tuners. We are going to manufacture and research given pneumatic tuners within our next grant project.

2. NEW PNEUMATIC TORSIONAL VIBRATION TUNERS

2.1. Tangential pneumatic flexible shaft coupling with axially deformed flexible elements

Proposed tangential pneumatic flexible shaft coupling with axially deformed elements (Fig. 1) is made up of a driving (1) and a driven hub (2), flexibly connected by pneumatic flexible elements (3). The pneumatic flexible elements are attached to support bodies (4), which are rotatably mounted on pins (5). These pins are solidly connected to the corresponding hub. The axes of the pneumatic flexible elements are perpendicular to the axes of the pins. The support bodies (4) are fixed to the pins with washers (6) and split pins (7). The rubber shells (8) of the flexible elements are firmly connected to the support bodies with flanges (9).

A compressed gaseous medium (most commonly air) is fed into the fuel space of the coupling via a filling valve (12). The compression space of the coupling consists of inner spaces of the pneumatic flexible elements, mutually interconnected with the inner spaces of the support bodies. The pressure of the gaseous medium holds the unloaded coupling in neutral position (Fig. 1). Under load by torque, it comes to angular deflection between the driving and driven hub and consequently to axial deformation of pneumatic flexible elements (Fig. 2).

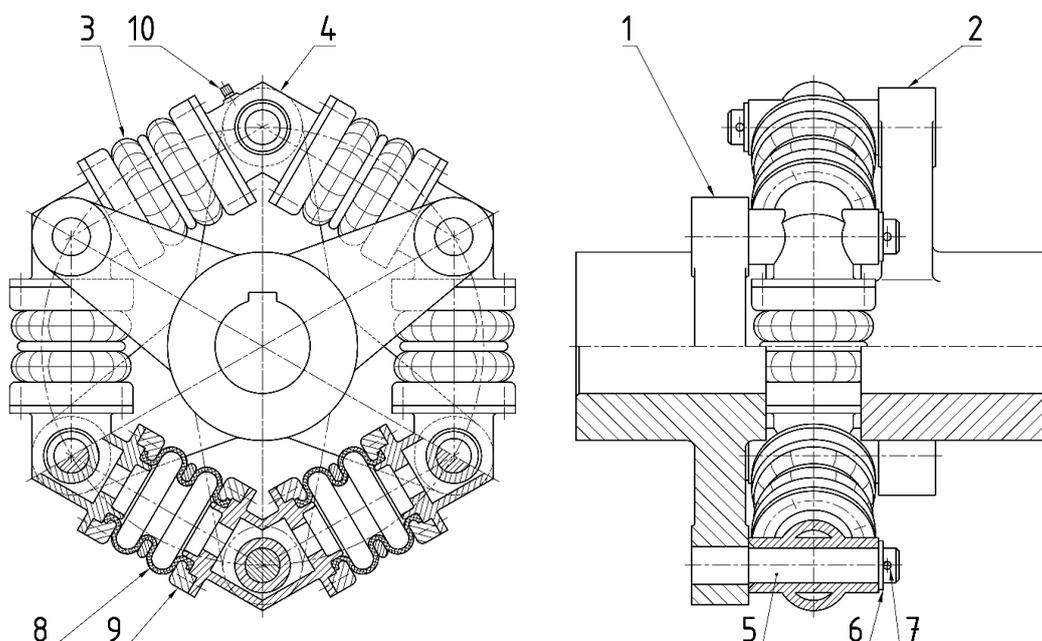


Fig. 1. The tangential pneumatic flexible shaft coupling with axially deformed flexible elements in unloaded state (neutral position)

⁵ Urbanský Matej. 2018. *Tangential pneumatic flexible shaft coupling with serial arranged flexible elements*. Utility model No. SK 8183 Y1. Banská Bystrica: ÚPV SR. 8 p. Patent application form No. 73-2017.

The angular twist causes the gaseous medium compression so the load torque can be transmitted flexibly. The support bodies of the proposed coupling are automatically turned to the equilibrium position so that only axial deformation of the elastic elements occurs. In Fig. 3, we can see that in the case of conventional tangential pneumatic flexible shaft couplings (with fixed support bodies), the flanges of the elements are tilted during twisting.

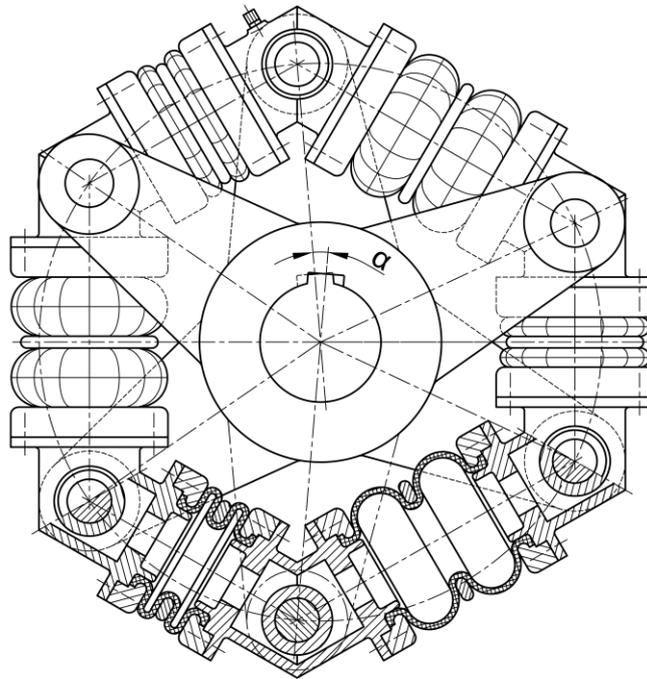


Fig. 2. The tangential pneumatic flexible shaft coupling with axially deformed flexible elements in fully loaded state (at maximum twist angle α)

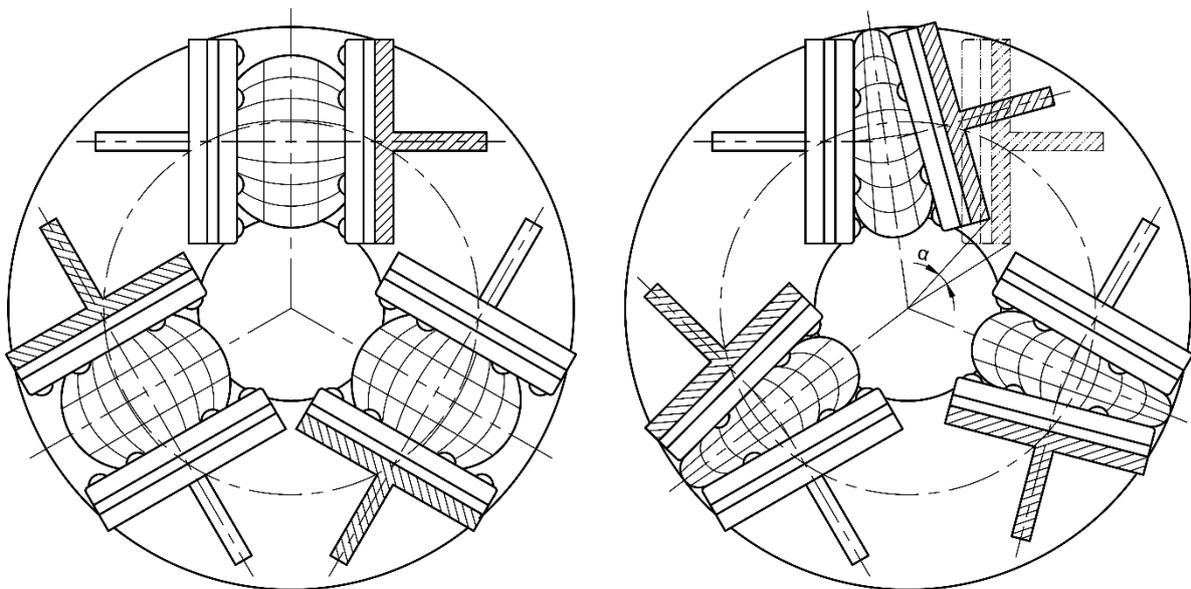


Fig. 3. A tangential pneumatic flexible shaft coupling
a) in basic position, b) in fully loaded state (at maximum twist angle α)

Since the flanges of the pneumatic flexible elements are parallel in the full extent of the coupling's twist, it is possible to fully utilise the stroke of the pneumatic elements given by their manufacturers, for example [2, 110]. Therefore, the pneumatic flexible elements are deformed in the most suitable way with respect to their design and lifetime. Another advantage of this type of coupling is that the entire assembly of flexible elements connected by the support bodies can be easily withdrawn from the pins, which allows easy and quick assembling and disassembling of the whole coupling.

2.2. Tangential pneumatic flexible shaft coupling with serial arranged flexible elements

Proposed tangential pneumatic flexible shaft coupling with serial arranged flexible elements (Fig. 4) contains a driving flange (1) and a driven flange (2). Between the flanges, the compression space of the coupling is situated. The compression space of the coupling is comprised of pneumatic flexible elements (3), (4), (5), which are arranged in a circle so that they are connected and create a "flexible chain". The flanges of the pneumatic flexible elements (3) are fixed to rigid parts (6) of the driving flange and to support bodies (7). The flanges of the pneumatic flexible elements (4) are fixed only to the support bodies (7). The flanges of the pneumatic flexible elements (5) are fixed to rigid parts (8) of the driven flange and to the support bodies (7). The support bodies are fastened to rotatable floating bodies (9) by pins (10). The rotatable floating bodies are rotatably mounted on a pin (11). The pin (11) is coaxially embodied in the driven flange (2).

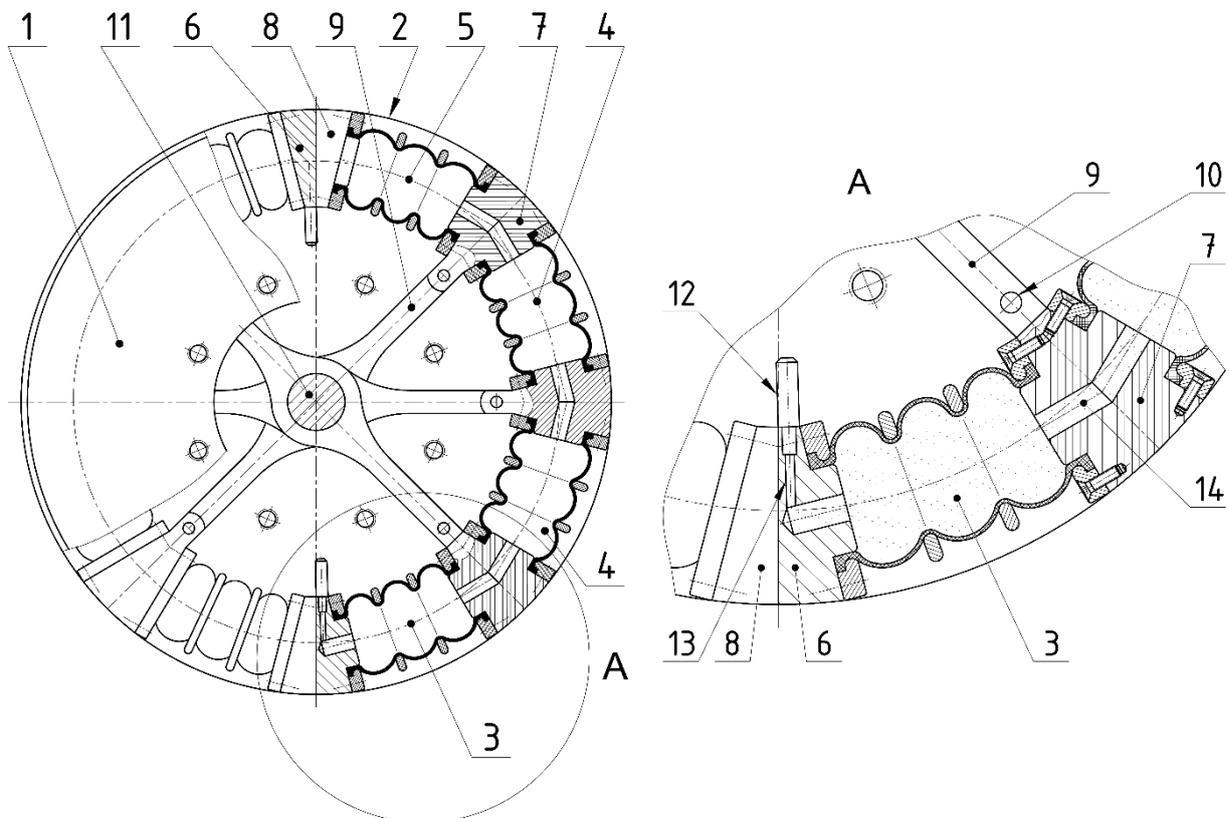


Fig. 4. The tangential pneumatic flexible shaft coupling with serial arranged flexible elements in unloaded state

Mutual interconnections of the pneumatic flexible elements (3), (4), (5) are done by ducts (14), which are created in the support bodies (7). The compression space of the coupling can be filled with gaseous medium through valves (12) and valve ducts (13). If there is overpressure of the gaseous medium in the pneumatic flexible elements (compared to the atmospheric pressure) then the rigid parts (6) of the driving flange and the rigid parts (8) of the driven flange are in contact, then the unloaded coupling is in basic position (Fig. 4). Under load by torque, it comes to an angular deflection between the driving and driven hub and consequently to a deformation of the pneumatic flexible elements of the pneumatic coupling. The angular twist causes the gaseous medium compression and then the load torque can be transmitted flexibly in mechanical systems (Fig. 5). The shape of the support bodies (Position 7 in Fig. 4) can be adjusted so that the bearing surfaces of the pneumatic flexible elements flanges are parallel at the maximum twist angle α of the coupling (Fig. 5), in order to maximise the effective area of the compression space of the coupling and hence increase the maximum load torque of the coupling.

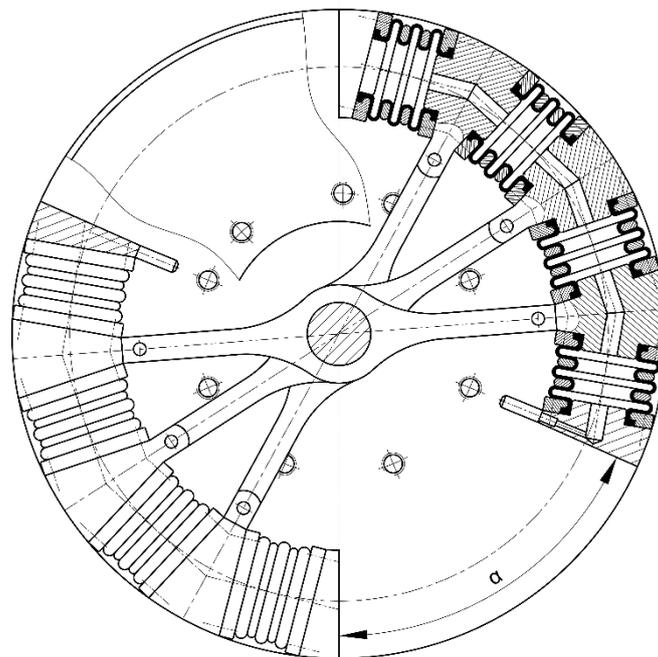


Fig. 5. The tangential pneumatic flexible shaft coupling with serial arranged flexible elements in fully loaded state (at maximum twist angle α)

The function of the support bodies (7) in connection with the rotatable floating bodies (9) (Fig. 4) is to ensure the stability of the “flexible chain” of pneumatic flexible elements in the radial and axial direction (referred to the axis of rotation of the coupling) when the coupling is twisted. In this way, much higher values of the maximum twist angle α of the coupling (Fig. 5) can be achieved (for example, compared to the tangential pneumatic flexible shaft coupling shown in Fig. 3).

The high value of the maximum twist angle of the coupling is one of the prerequisites for creating a high-flexible coupling, which means flexible coupling with very low value of relative torsional stiffness k_0 , can be expressed as follows:

$$k_0 = \frac{k_{DN}}{M_N} [\text{rad}^{-1}]. \quad (1)$$

The k_0 is defined as the ratio of the nominal dynamic torsional stiffness of a flexible coupling k_{DN} (at M_N) to the nominal torque M_N of the coupling. Common flexible couplings have the relative torsional stiffness value in the range of $10 \div 30 \text{ rad}^{-1}$. Shaft couplings marked as high-flexible have the relative torsional stiffness value lower than 10 rad^{-1} . Therefore, with respect to physical principles, a flexible coupling with a low torsional stiffness must have a large twist angle in order to transmit high load torque.

By the application of a high-flexible coupling in a mechanical system (coupling 2 in Fig. 6), the resonances from the individual harmonic components of a torsional vibration excitation can be moved from the operating speed (n) range (OSR) of the system to the lower speed area far enough under idle operating speed n_V , for example [142]. This lower speed area can be quickly run across at the start-up of a mechanical system, as shown in the general Campbell's diagram of a mechanical system (Fig.6), where i stands for the order of the harmonic component of torsional vibration excitation.

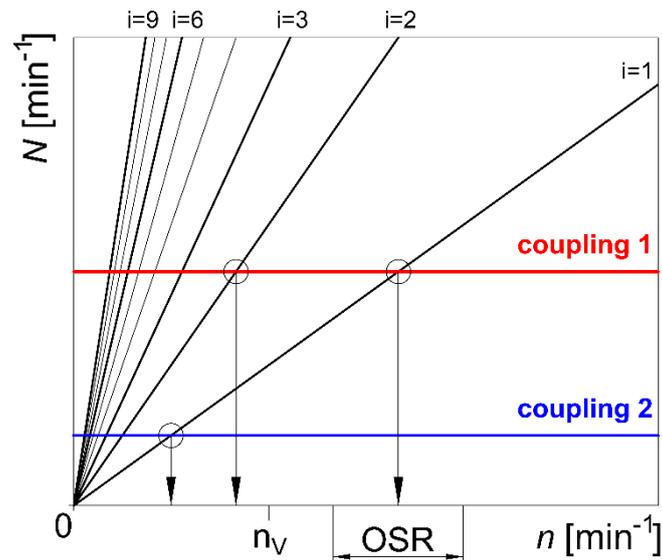


Fig. 6. Campbell's diagram of a mechanical system

3. CONCLUSION

The tangential pneumatic flexible shaft coupling with axially deformed elements and the tangential pneumatic flexible shaft coupling with serial arranged flexible elements can be applied in the systems of mechanical drives. They allow flexible torque transmission and due to the ability to change their torsional stiffness, ensure the tuning of these systems at various operating conditions.

In the case of the tangential pneumatic flexible shaft coupling with axially deformed elements, the pneumatic flexible elements are deformed in the most suitable way in terms of their design and lifetime and the stroke of the pneumatic flexible elements is allowed to be fully utilised.

Regarding the tangential pneumatic flexible shaft coupling with serial arranged flexible elements, the design is focused on creating the high-flexible coupling, which means flexible coupling with very low value of relative torsional stiffness. The current trend in the field of flexible shaft couplings, which is the most noticeable in the automotive industry, is the development and utilisation of high-flexible couplings (dual mass flywheels). Because gaseous media throughout its lifetime is not subject to ageing, resultantly, pneumatic couplings do not lose their initial positive dynamic properties, it would be of better advantage to develop flexible couplings with the advantages of both pneumatic and high-flexible couplings.

On the above-mentioned grounds, we suppose that both proposed pneumatic couplings are able to increase the technical level and reliability of the mechanical systems in which they will be applied. Therefore, we are going to research and manufacture the prototypes of the given pneumatic couplings under the terms of our next grant project. Our research will be focused on the following activities:

- designing and manufacturing of specific prototypes of the pneumatic couplings using the principles of presented utility models,
- measuring static [11] and dynamic operating properties of the prototypes,
- creating the mathematical and physical models of the prototypes,
- applying the prototypes into torsionally oscillating mechanical systems, in order to do a tune and continuous tune the mechanical systems during their operation in terms of torsional dynamics using pneumatic flexible shaft couplings as active torsional vibration tuners and electronic control systems developed by us,
- creating the mathematical models of the torsionally oscillating mechanical systems,
- comparing the results of measurements with results of the simulations of the torsionally oscillating mechanical systems with the applied prototypes,
- improving the mathematical and physical models of the prototypes, if necessary.

Acknowledgement

This paper was written within the framework of the APVV-16-0259 grant project entitled, Research and development of combustion technology based on controlled homogenous charge compression ignition in order to reduce nitrogen oxide emissions of motor vehicles.

This paper was written within the framework of the KEGA 041TUKE-4/2017 grant project entitled, Implementation of new technologies specified for solving questions concerning the emissions of vehicles and their transformation in educational processes in order to improve the quality of education.

This paper was written within the framework of the VEGA 1/0473/17 grant project entitled, Research and development of technology for homogeneous charge self-ignition using compression in order to increase engine efficiency and to reduce vehicle emissions.

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Received 10.02.2019; accepted in revised form 30.04.2019



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