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CONTROLLING TORSIONAL VIBRATION OF MECHANICAL SYSTEMS BY APPLICATION OF PNEUMATIC FLEXIBLE SHAFT COUPLINGS

Summary. For achievement of the goal to decrease, eventually eliminate the dangerous torsional oscillations, it is necessary any torsionally oscillating mechanical system to preliminary tune. The expression "tuning of mechanical system" means a suitable adjustment of dynamic properties, especially of dynamic torsional stiffness of flexible shaft clutch to dynamic of given system. Via application of pneumatic tuners of torsional oscillations developed by us it is possible to realize a change of their dynamic stiffness by a change of a pressure of a gaseous medium either during non-working or during working regime of given mechanical systems. Based on this, a two ways of tuning of torsionally oscillating mechanical systems are suggested:

- tuning of the torsionally oscillating mechanical systems in non-working regime,
- tuning of the torsionally oscillating mechanical systems in stabile state.

The aim of the submitted paper is to present of both ways of mechanical systems tuning, via application of the pneumatic tuners of torsional oscillations.

KONTROLOWANIE DRGAŃ SKRĘTNYCH W SYSTEMACH MECHANICZNYCH PRZEZ WPROWADZENIE ELASTYCZNEGO SPRZĘGŁA PNEUMATYCZNEGO

Streszczenie. Aby osiągnąć cel, którym jest zmniejszenie, a w efekcie końcowym eliminacja niebezpiecznych oscylacji skrętnych, konieczne jest ustawienie wstępne każdego drgającego skrętnie systemu mechanicznego. Poprzez „ustawienie mechanicznego systemu" rozumie się odpowiednie dostosowanie dynamicznych właściwości, szczególnie dynamicznej sztywności skrętnej elastycznego sprzęgła, do dynamiki danego systemu.

Poprzez zastosowanie pneumatycznych tunerów drgań skrętnych opracowanych przez nas możliwa jest realizacja zmian w sztywności dynamicznej za pomocą zmiany ciśnienia czynnika gazowego albo podczas stanu spoczynku lub stanu pracy urządzenia dla danego systemu mechanicznego. Na tej podstawie sugeruje się dwa sposoby tuningu drgających skrętnie systemów mechanicznych:

- tuning drgających skrętnie systemów mechanicznych w stanie spoczynku urządzeń,
- tuning w stanie stabilnym.

Celem przedłożonej pracy jest prezentacja obu sposobów tuningu mechanicznych systemów z użyciem pneumatycznych tunerów dla drgań skrętnych.

1. INTRODUCTION

Torsionally oscillating mechanical system (TOMS) from a dynamic point of view can be characterized as the most common operating system in the supercritical region with a relatively fast transient dejom for starting and stopping. In terms of regulation we can add to the group managed systems with incomplete information. Incomplete information is seen in the pre-contingency (random) effects of failure. Among the most common trouble spot in the TOMS impacts include the effects of piston machines themselves.

Based on the above it can be concluded that the special piston machines bring to the increase of the torsional vibration system. It should be emphasized that the yield increases torsional vibration when a fault occurs piston machine itself [1, 2].

Therefore, applying a growing need to control dangerous torsional oscillations of mechanical systems. Proved to be dangerous torsional oscillation can be reduced to an acceptable rate or tweak. tuning TKMS flexible shaft couplings. Below the tuning system understand appropriate adaptation especially stiffness parameters of flexible coupling dynamics of the system so that during operation mode TOMS avoid a dangerous torsional oscillation.

In the appropriate tuning TOMS currently used flexible shaft couplings with linear or nonlinear (progressive) characteristics [3].

In the workplace, our department is dealing with, inter alia, long-term research and development of pneumatic flexible shaft couplings. Especially, we focus on the capabilities of the clutches of the torsionally oscillating mechanical systems with a view to their optimum tuning in terms of minimizing the torsional oscillation, or its removal. The existence of new types of flexible couplings creates the possibility of implementing new ways of tuning torsionally oscillating mechanical systems. Therefore, this contribution is to present new ways of tuning of the system, it is through the application of pneumatic flexible shaft coupling.

2. METHODS OF CONTROLLING TORSIONAL VIBRATION OF MECHANICAL SYSTEMS BY APPLICATION OF PNEUMATIC COUPLINGS

Under pneumatic clutch tuning TOMS understand appropriate adaptation of basic dynamic properties (dynamic torsional stiffness and damping coefficient) pneumatic clutch system dynamics. The adjustment is made inflated space compression coupling to a suitable value of the pressure gaseous medium. Change in pressure gaseous medium and a change in the torsional stiffness of the pneumatic clutch can be carried out or during the operation of mechanical systems. This leads to two proposed ways of tuning torsionally oscillating mechanical systems application of pneumatic couplings:

- tuning torsionally oscillating mechanical systems out of service, ensuring so. condition of the tuning system,
- tuning torsionally oscillating mechanical systems during steady state operation, ensuring so. condition of continuous tuning of the system.

2.1 Brief description of the pneumatic tuner of torsional oscillations

Pneumatic coupling, see fig. 1 consists of the driving part (*1*) and the driven part (*2*), between them is a compression space filled with a gaseous medium. The compression space consists of three circumferentially dislocated, differential components, connected each other with the pipes (*5*). Every differential element has the compressed (*3*) and the pulled (*4*) pneumatic-flexible element.

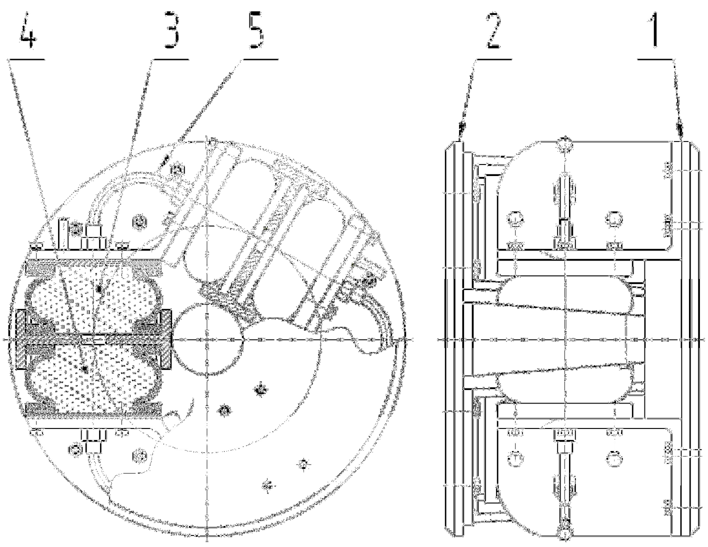

Fig. 1. Real assembly of the pneumatic flexible differential shaft coupling
Rys. 1. Rzeczywisty montaż elastycznego mechanizmu różnicowego sprzęgła pneumatycznego

The change of gaseous medium overpressure (p) in the compression space at the required level during the system standstill, i.e. out of operation, enables coupling functioning with always other characteristics (fig. 2), as well as with always other characteristic mechanical features (torsional rigidity and dumping coefficient). By means of dynamic torsional rigidity (fig. 3) there is changed or accommodated also the natural system frequency $\Omega = \sqrt{k / I_{red}}$ with regard to the exciting angular frequency (ω), so that it can be eliminated a resonance phenomenon ($\Omega = \omega$) in the operational range of system and in this way can be eliminated also the dangerous torsional oscillation of system. This fact is described as a tuning of the TOMS out of its operation. The tuning is performed by means of gaseous medium overpressure value (p), which is determined in advance according to the detailed dynamic calculation.

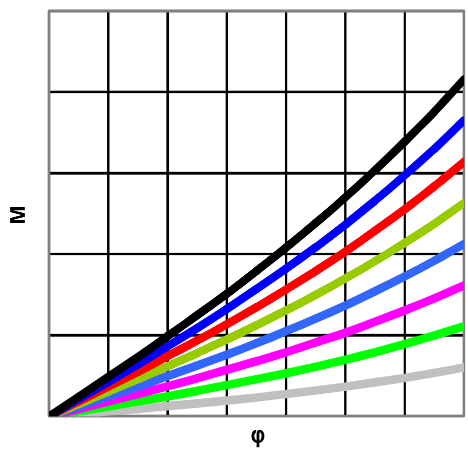

Fig. 2. Behaviours of static characteristics of pneumatic differential coupling for pressures of gaseous medium *p = 100 – 800 kPa*
Rys. 2. Zachowania statycznych charakterystyk pneumatycznego mechanizmu różnicowego sprzęgła dla ciśnienia czynnika gazowego *p = 100 – 800 kPa*

The second possibility is changing of gaseous medium overpressure value (p) in the compression space during operation of mechanical system (during its operational regime). It is tuning of the TOMS during its operation in the steady state, i.e. it is a continuous tuning of the given system. The main purpose of this developed continuous tuning of any TOMS is to avoid resonance or near-resonance state in the operational range of system.

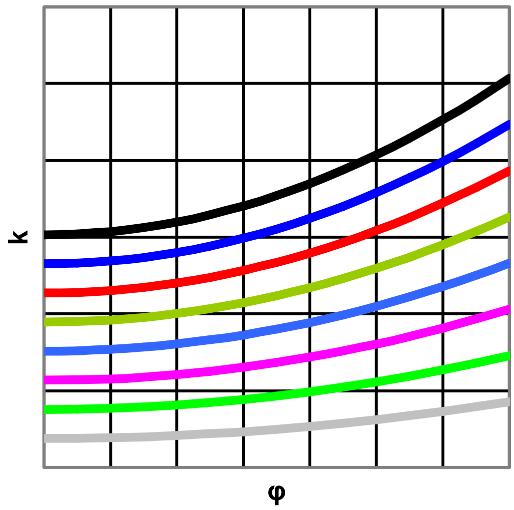

Fig. 3. Behaviours of torsional rigidity k of pneumatic differential coupling for pressures of gaseous medium *p = 100 – 800 kPa*

Rys. 3. Zachowanie skrętnej sztywności k pneumatycznego mechanizmu różnicowego sprzęgła dla ciśnienia czynnika gazowego *p = 100 – 800 kPa*

Application of continuous tuning, according to the invention [11], requires also new application of another kind of coupling. It is coupling, i.e. the air tuner torsional oscillations (PToTO), which is able to change its basic characteristics, like torsional rigidity and damping coefficient. This requirement is fulfilled in the case of pneumatic differential coupling, which is developed newly by us and which is able to operate in the function of torsional oscillations tuner (fig. 4).

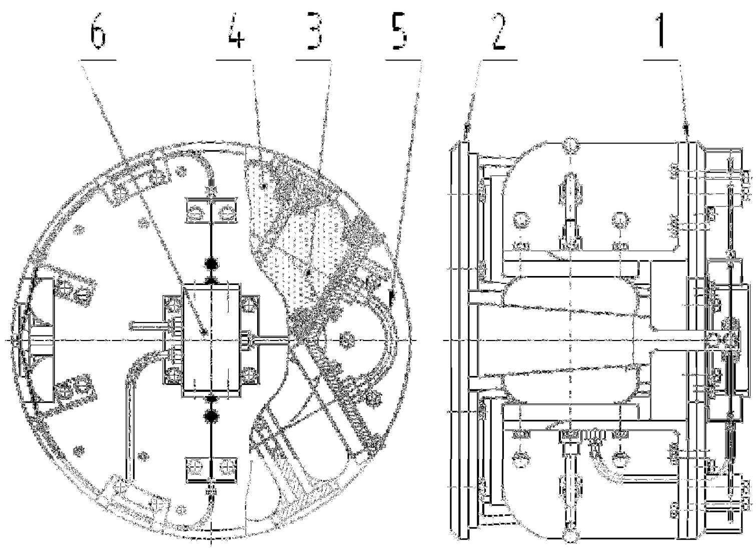

Fig. 4. Pneumatic tuner of torsional oscillations

Rys. 4. Tuner pneumatyczny drgań skrętnych

Pneumatic tuner of torsional oscillations (fig. 4), protected by two patents for an invention [4, 5], is similar to the pneumatic differential coupling. The main difference consists in regulator (*6*), which enables to keep constant angle of twist in the coupling. The basic principle of the PToTO is the self-regulation ability of the angular twisting, caused due to actual change of loading torque, into the given constant angular value φ_k. This self-regulation of gaseous medium pressure in the compression space in the tuner has an immediate influence onto the characteristic of pneumatic tuner (fig. 2) and, of course, onto the torsional rigidity *k* (fig. 4). In this way it can be changed the natural frequency of the system.

There are presented behaviours of torsional rigidity of the PToTO on the fig. 5 in dependence on the loading torque. To each of the calculated constant angles of twist $\varphi_{k\,1}$, $\varphi_{k\,2}$, $\varphi_{k\,3}$ and $\varphi_{k\,4}$ belongs one behaviour of torsional rigidity *a*, *b*, *c*, *d*.

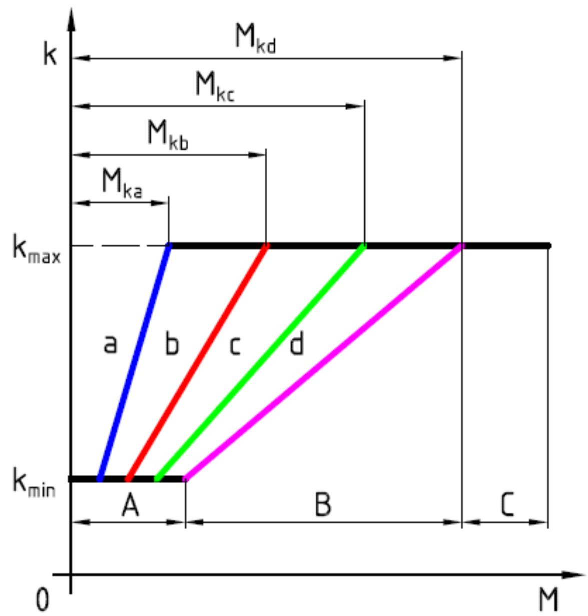

Fig. 5. Behaviour of torsional rigidity *k* of pneumatic tuner of torsional oscillations in dependence on loading torque *M*

Rys. 5. Zachowanie sztywności skrętnej *k* tunera pneumatycznego dla drgań skrętnych w zależności od obciążenia momentu obrotowego *M*

The above-mentioned behaviours are limited with minimum and maximum values of torsional rigidity k_{min} and k_{max} according to the pressures of gaseous medium from interval p_{min} and p_{max} in compression space of the PToTO. There are also presented behaviours illustrated by a fractional line, which consists of three areas: pre-regulation – *A*, regulation – *B* and over-regulation – *C* area. From this illustration it is evident that change of $\varphi_{k\,i}$ influences interval of pre-regulation and regulation area, but it influences mainly the value of pneumatic tuner torsional rigidity during operational regime of the system. There are also influenced values of loading torque M_1, M_2, M_3 and M_4 with regard to the maximum value k_{max} of torsional rigidity. The pneumatic tuner with an increasing value of constant angle of twist, during a certain loading torque, has a declining torsional rigidity. In the case of the PToTO with the maximum angle of twist value φ_{kmax}, from the relatively hard pneumatic coupling (behaviour *a*) becomes a high flexible pneumatic coupling (behaviour *d*), which is able to operate with considerably higher value of loading torque M_d at maximum value of dynamic torsional rigidity.

2.2 Characteristics of torsionally oscillating mechanical systems tuning out of service

Under the most of your torsionally oscillating mechanical system pneumatic tuning out of service means the inflated space compression knob to a suitable value of the pressure gaseous medium before starting the system in action. For a given pressure, the work of mechanical systems implemented throughout its operations. Appropriate value of the pressure gaseous medium, and hence the appropriate value of the dynamic torsional stiffness tuner determined by pre-dynamic calculations carried out by the system in terms of torsional dynamics.

The suggested method of tuning the mechanical systems can be characterized as tuning torsionally oscillating mechanical system, which is only suitable for the system operating with constant operating speed.

When investigating any suitable tuning TOMS working with constant operating speed start from Campbell diagram (fig. 6).

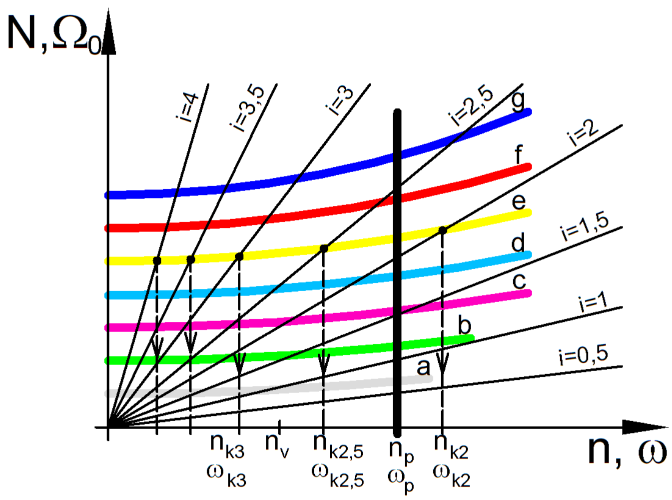

Fig. 6. Campbell diagram of TOMS illustrated in the general view
Rys. 6. Diagram Campbella TOMS widok ogólny

In fig.6 is a general view given Campbell diagram for pneumatic tuning system tuning. SPEED Custom frequencies are shown by horizontal curves *a, b, c, d, e, f, g* for the whole range of pneumatic pressure gaseous media tuner. The positions of the critical speed curves are characterized by their own points of intersection with the frequency of speed lines (rays) charakterized harmonic compo-nents ($i = 0.5 - 4$) load torque. The figure clearly shows that constant pressure is suitable in terms of static (characterized by a moderate potential for transfer torque M_N) and a dynamic perspective (most of your system appropriately characterized in terms of major and minor harmonics harmonics [5, 8, 9, 12]) for the working speed n_p the mechanical system.

2.3. Tuning characteristics of torsionally oscillating mechanical systems during steady state operation

The essence of tuning torsionally oscillating mechanical system during operation in steady-state results from a suitable adaptation of the basic dynamic characteristics of pneumatic tuner system dynamics. Done incause it is possible to ensure the regulatory system that creates closed-loop feedback. This can vary continuously, so adjust the dynamic characteristics of pneumatic tuner dynamics of mechanical systems in order to work for the system avoid a dangerous torsional oscillation.

Proposed methods of tuning TOMS under regulatory circuits and regulatory systems, which have been granted patent protection [6, 7, 8, 9, 10, 11], and their implementation can be ensured:

- regulatory system to ensure smooth changes in the characteristics of pneumatic couplings [7],
- regulatory system for the implementation of continuous mechanical tuning system [8],
- application of pneumatic couplings with additional regulatory systémom [4, 7],
- static optimization method based on the regulations extremal [4, 7, 8, 9],
- application of pneumatic coupling with autoregulation [7, 9].

Mentioned methods of tuning can be characterized as torsionally oscillating continuous tuning of the mechanical systems at steady state, which is particularly suitable for any operating system with a wide range of working scillating mechanical systems is also inspeeds. Theoretical tuning any torsionally o this case most frequently checked on the basis of the results of Campbell diagram. On fig. 7 is a general view shows the Campbell diagram for torsionally tuned wave mechanical tuning system with pneumatic self-regulation. Working range of the mechanical system is shown bounded by an angular frequency ω1 and ωn. The optimal tuning of the mechanical system is to control dangerous torsional vibration, dynamic stress reduction, and thus ensure trouble-free work within the system working. In other words, optimally tuned mechanical system is to satisfy the requirement to work within the system to avoid any resonance with the lower harmonic components of load torque. From fig. 7 shows that this requirement ensures that only if the conduct of its frequency system will be located between the beam harmonic load torque (curve 1 in fig. 7). Then we can conclude that the mechanical system is optimally tuned in terms of size and torsional vibrations course (1) can be based on the findings of the course called optimal tuning system.

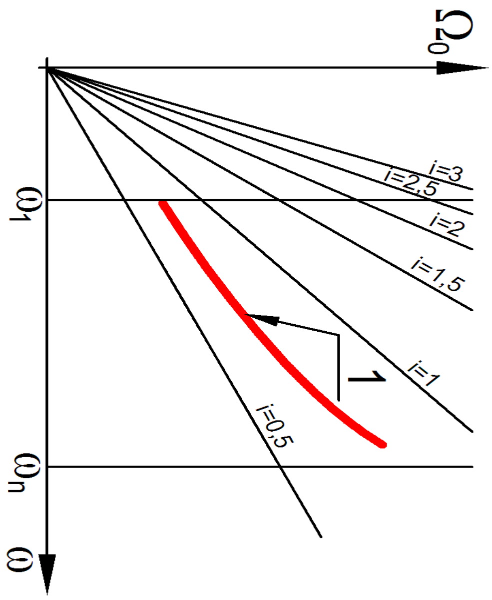

Fig. 7. Campbell diagram of TOMS illustrated in the general view
Rys. 7. Diagram Campbella TOMS widok ogólny

Ensure that the course is subject to change one of the basic characteristics of pneumatic tuner, i.e. torsion [4, 7, 8, 12], during system operation [9].

3. CONCLUSION

Based on the results of experimental verification has shown that by changing the gas pressure in the media space pneumatic compression knob is changed, ie match the dynamic torsional rigidity, which has a decisive impact on the actual frequency of the system. The essence of the principle of tuning torsionally oscillating mechanical system pneumatic tuners is to adapt its own angular frequency of mechanical excitation of the system angular frequency in order to work within the system to avoid the resonance condition and consequently to its dangerous torsional vibrations. Change in pressure gaseous medium in the area of pneumatic compression tuner, and thus change its dynamic torsional rigidity, which has a direct impact on the intrinsic angular frequency of the mechanical system can be carried out or during the operation of the system.

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