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Piston pneumatic flexible shaft coupling suitable for mechanical power transmission

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Abstract The paper presents a newly developed Piston pneumatic flexible shaft coupling, which is applicable for mechanical power transmission for example in the automotive industry as a dual-mass flywheel. Its design is focused on creating the high-flexible coupling, which means flexible coupling with very low value of relative torsional stiffness. Basic characteristic properties of the coupling and its high-flexibility characteristics are theoretically determined. The coupling is protected by means of a patent.

Keywords pneumatic flexible shaft coupling, mechanical power transmission, high-flexibility characteristics, dual-mass flywheel

1. INTRODUCTION

Nowadays, the optimization of machine parts, mechanical systems and machinery is the research scope of many researchers, e.g. [1 – 48]. One of very important tasks mainly in terms of human health and lifetime and safety of machines is the reduction of vibration and noise in machinery, e.g. [1 – 7], [17 – 24].

Flexible shaft couplings are the most used machine parts for the flexible transmission of load torque and mechanical energy in mechanical systems. Their another very important function is the dynamic tuning of mechanical systems in terms of torsional vibration magnitude. Therefore, a flexible coupling with suitable dynamic properties, particularly dynamic torsional stiffness, has to be carefully chosen for each specific application so that dangerous torsional vibrations (near or at resonance areas) do not occur in a mechanical system. From the point of view of mentioned dynamic tuning, the development and utilization of high-flexible couplings is very advantageous and it is the most noticeable in automotive industry nowadays (dual mass flywheels). A high-flexible coupling possesses a very low relative torsional stiffness. Common flexible couplings have the relative torsional stiffness value in the range of $10 \div 30$ rad^{-1} [7]. Shaft couplings marked as high-flexible have the relative torsional stiffness value lower than 10 rad^{-1}. By the application of a high-flexible coupling in a mechanical system (coupling 2 in Fig.1), 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 low speed area far enough under idle operating speed n_V. This low speed area can be quickly run across at the start-up of a mechanical system, as shows the Campbell's diagram of a mechanical system (Fig.1), where i stands for the order of the harmonic component of a torsional vibration excitation.

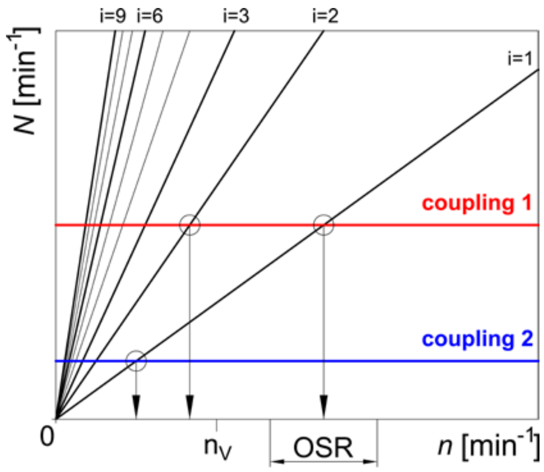

Fig. 1 Campbell's diagram of a mechanical system

Flexible elements of flexible shaft couplings are made of various materials. During the operation of mechanical systems, it comes particularly to the fatigue and ageing of rubber and plastic flexible elements and to the ageing and wearing down of the metal flexible elements of applied flexible coupling [7]. Consequently, the applied flexible coupling loses its original dynamic properties and thus its ability to carry out important functions in a torsional oscillating mechanical system. Flexible shaft couplings from pneumatic flexible shaft couplings group, where belong 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 are able to ensure the flexible transmission of mechanical energy without the loss of their characteristic properties, because the gaseous medium in the compression volume of couplings do not suffer from fatigue or ageing. The main advantage of pneumatic couplings is the possibility to change their torsional stiffness which depends on the pressure value of the gaseous media. On the mentioned grounds, the development of flexible couplings with the advantages of both pneumatic and high-flexible couplings is very advantageous.

From the point of view of physics, a flexible coupling with a low torsional stiffness must have a large twist angle in order to transmit a high load torque. This is the next prerequisite for creating a high-flexible coupling.

Therefore, the aim of this article is to introduce a piston pneumatic flexible shaft coupling, which was developed to improve the properties of pneumatic flexible couplings, especially the maximum angle of twist, in order to create high-flexible pneumatic coupling. Due to the reason that the pneumatic coupling is not manufactured yet, this article deals mainly with principles and expected advantages of the coupling.

2. PROPOSED PISTON PNEUMATIC FLEXIBLE SHAFT COUPLING

The piston pneumatic flexible shaft coupling (Fig.2) is made up of a driving flange (1), driven flange (2), pneumatic flexible elements (4), curved hollow cases (5), curved piston bodies (3), fastening flanges (6) and valves (7).

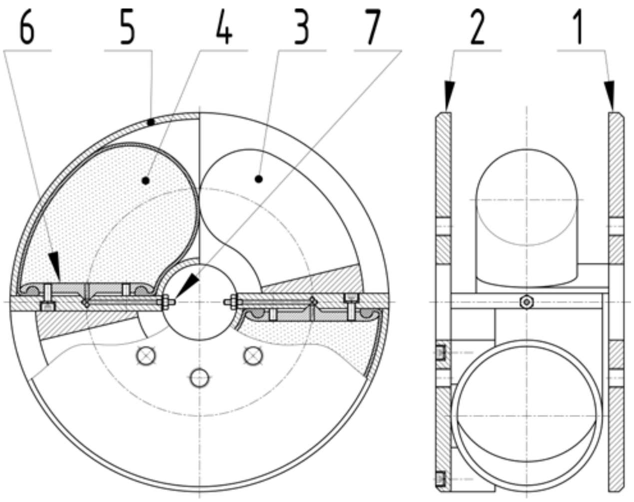

Fig. 2 The piston pneumatic flexible shaft coupling type 2-1/110-P-C in unloaded state

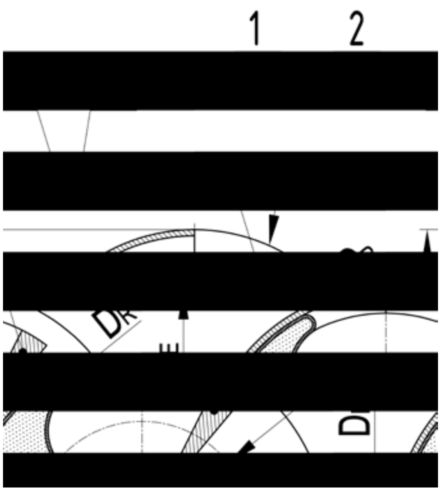

Fig. 3 The piston pneumatic flexible shaft coupling type 2-1/110-P-C in partially loaded state

The compression volume of the coupling is created of two pneumatic flexible elements (4), which are placed motionlessly in the hollow cases (5), which are attached to the driven flange (2). The piston bodies (3) are attached to the driving flange (1). The pneumatic flexible elements (4) are inflated to required overpressure of gaseous media through the valves (7) and the basic position of the piston bodies and the driving flange (1) in relation to the driven flange (2) is herewith defined (Fig.2).

The transmission of a load torque causes the twist of the driving flange (1) in relation to the driven flange (2) and the piston bodies (3) are therefore pushed into the pneumatic flexible elements (4) so that the piston bodies (3) are coated with the pneumatic flexible elements (4) (Fig.3).

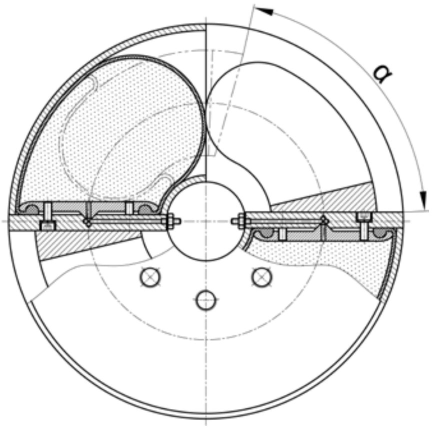

Fig. 4 The maximum twist angle of the piston pneumatic flexible shaft coupling type 2-1/110-P-C

The design of the coupling allows its maximum angle of twist of $\alpha = 75$ degrees (Fig.4). This design of the coupling allows to transmit a load torque flexibly only in one direction.

3. DETERMINING BASIC CHRACTERISTIC PROPERTIES OF THE COUPLING

Following characteristics are determined for the pitch diameter of the coupling D_R = 180 mm and the diameter D_E = 110 mm (Fig.3).

A. Dependence of pressure in the pneumatic coupling on its twist angle

As for pneumatic flexible shaft couplings, a load torque is transmitted flexibly from the driving flange to the driven flange by pneumatic flexible elements. The transmission of load torque causes the twist of the driving flange in relation to the driven flange and therefore the compression volume of a pneumatic coupling is compressed.

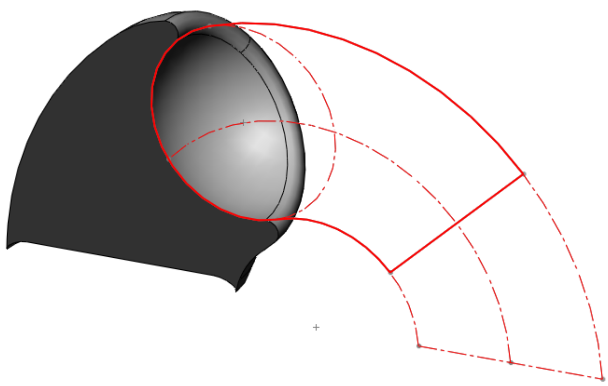

Fig. 5 The principle of modelling the air volume deformation caused by the piston body, in sectional view

The compression of gaseous media in the pneumatic flexible elements is proportional to the load.

In Fig.6 we can see the dependences of air overpressure p_{pS} in the compression volume of the pneumatic coupling on its angle of twist

φ. Initial air overpressure values (at $\varphi = 0°$) in the coupling were $p_{pS0} = 100 \div 600$ kPa. The dependences in Fig.6 were computed as follows:

1. the dependence of the air volume V on the twist angle φ was found out using a 3D CAD software (Fig.5),
2. the dependence of the air overpressure p_{pS} in the pneumatic coupling on the twist angle φ was found out considering isothermal compression:

$$p_{pS(\varphi=x)} = \left(p_a + p_{pS0}\right) \cdot \left(\frac{V_{(\varphi=0)}}{V_{(\varphi=x)}}\right) - p_a; \; x \in (0, \varphi_{\max}\rangle, \tag{1}$$

where p_a is the atmospheric pressure (p_a = 101325 Pa).

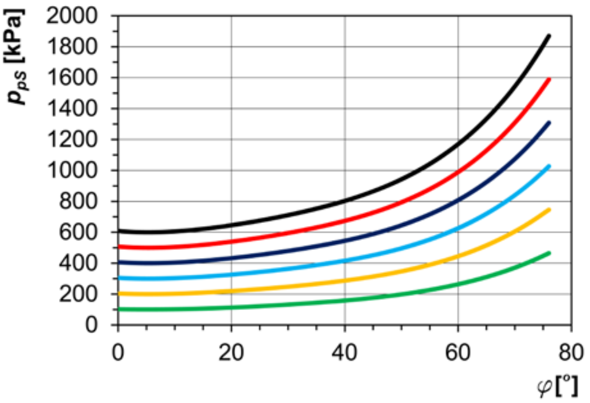

Fig. 6 The air overpressure p_{pS} in the coupling dependent on the twist angle φ at various values of p_{pS0}

B. Static load characteristics

According to the STN 011413:1992, a static load characteristic of a flexible coupling is the dependence of the coupling twist on load torque at slow change of the load torque. The coupling should be loaded up to the maximum static load torque M_{Smax}, which can be defined for example according to the maximum twist angle of a flexible coupling. The condition is not to damage the coupling.

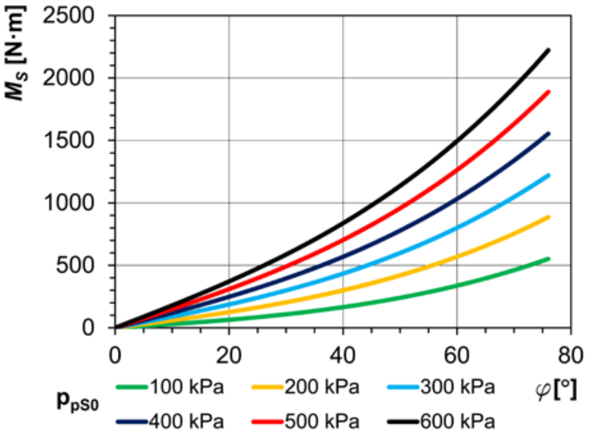

Fig. 7 The static load characteristics at various values of p_{pS0}

In Fig.7 we can see the static characteristics of the pneumatic coupling at initial air overpressure values in its compression volume $p_{pS0} = 100 \div 600$ kPa, which were computed from the equality of the works of gaseous media and torque:

$$p_{pS} \cdot dV = M_S \cdot d\varphi \Rightarrow M_S = p_{pS} \cdot \frac{dV}{d\varphi} \tag{2}$$

We can see that the static load characteristics of the pneumatic coupling are slightly non-linear.

According to the STN 011413:1992, the nominal torque M_N of a flexible coupling can be determined as the third of its maximum static load torque M_{Smax}. In Fig.8 we can see the M_{Smax} and M_N dependences on initial air overpressure p_{pS0} for the piston pneumatic flexible coupling.

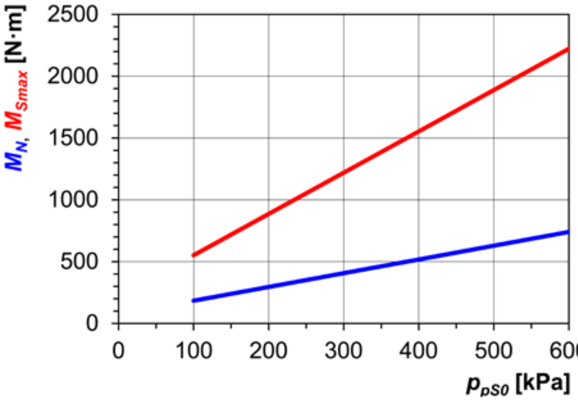

Fig. 8 Maximum static torque M_{Smax} and nominal torque M_N dependent on initial air overpressure p_{pS0}

C. Static torsional stiffness

The dependence of the static torsional stiffness k_S of a flexible coupling on its twist angle φ can be computed by deriving the equation of the static characteristic of a flexible coupling.
In Fig.9 we can see the static torsional stiffness k_S dependent on the twist angle φ of the coupling at initial air overpressure values in the pneumatic coupling $p_{pS0} = 100 \div 600$ kPa.

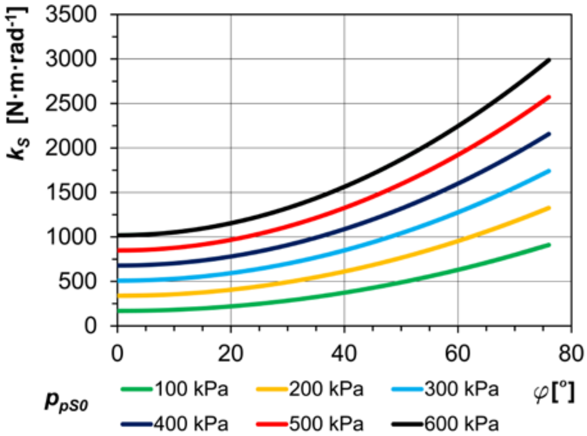

Fig. 9 The dependence of the static torsional stiffness k_S on the twist angle φ at various values of p_{pS0}

D. High-flexibility characteristics

In order to compute the relative torsional stiffness values k_0 of the pneumatic coupling, the values of the dynamic torsional stiffness k_{DN} of the pneumatic coupling at the nominal torque M_N need to be determined. According to the research [15], the k_{DN} values of the pneumatic coupling can be determined using following formula:

$$\frac{k_{DN}}{k_{SN}} = 1{,}05 + 4{,}14.10^{-4}.p_{pS0} \,, \tag{3}$$

where k_{SN} is the value of the static torsional stiffness of the pneumatic coupling at the nominal torque M_N at certain value of initial air overpressure in the pneumatic coupling from the range of $p_{pS0} = 100 \div 600$ kPa.

The relative torsional stiffness k_0 of a flexible coupling is defined as the ratio of the nominal dynamic torsional stiffness of a coupling k_{DN} (at M_N) to the nominal torque M_N of a coupling. In Fig.10 we can see the relative torsional stiffness k_0 dependences on initial air overpressure in the pneumatic couplings p_{pS0} = 100 ÷ 600 kPa.

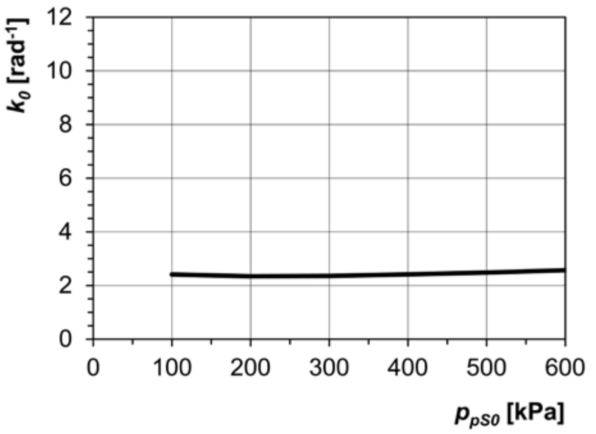

Fig. 10 The relative torsional stiffness k_0 dependent on initial air overpressure p_{pS0}

As we can see from Fig.10, the piston pneumatic flexible coupling type 2-1/110-P-C meets the requirements for high-flexibility in whole range of the initial air overpressure p_{pS0} in its compression volume.

4. CONCLUSION

The piston pneumatic flexible shaft coupling can be applied in systems of mechanical drives. It allows flexible torque transmission and thanks to the ability to change its torsional stiffness, ensure the tuning of these systems at various operating conditions. The design of the piston pneumatic flexible shaft coupling is focused on creating the high-flexible coupling. The current trend in the field of flexible shaft couplings, the most noticeable in automotive industry, is just the development and utilization of high-flexible couplings as dual mass flywheels. Because gaseous media throughout its lifetime is not subject to ageing, resulting that pneumatic couplings do not lose their initial positive dynamic properties, it seems to be very advantageous to develop flexible couplings with the advantages of both pneumatic and high-flexible couplings.

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