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EXPERIMENTAL VERIFICATION OF THE IMPACT OF A TECHNICAL GAS-USING PNEUMATIC COUPLING ON TORSIONAL OSCILLATION

Summary. The field of reducing torsional vibration of mechanical systems has seen the emergence of new flexible coupling designs. Our attention is focused on flexible pneumatic couplings. The flexible member of this coupling design is a pneumatic bag. The typical basic feature of such couplings is that the pneumatic bag allows for a change in air pressure. In the course of developing pneumatic couplings, we have experimented with the use of technical gases other than air for filling pneumatic bags. The aim has been to verify the impact of pneumatic couplings filled with other technical gases on the magnitude of torsional vibration in the mechanical system. For verification itself, two different gases have been used: helium, whose density is lower than air density, and propane butane, whose density is higher than air density. Experimental verification was performed under laboratory conditions on a mechanical system where torsion vibration was produced by a piston compressor.
Keywords: technical gases; torsional vibration; pneumatic flexible coupling; mechanical system

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1. INTRODUCTION

Any joint alignment of machines transmitting mechanical motion may be considered as mechanical system. The motion transmitted by the mechanical system may be continuous or variable. In particular, it is often the case that the variable motion is the source of excessive strain. In technical practice, variable motion is the source of vibration. If the variable motion is transmitted by a mechanical system that rotates, the vibrations that are generated are known torsional vibrations [1].

Vibrations are therefore an indispensable part of every mechanical system; they cannot be removed, but it is possible to reduce their impact [2-7]. The most critical are vibrations that originate in the form of resonance or in the system's vicinity [8]. These conditions must be avoided as they cause breakdowns, such as the breakage of shafts and cog wheels, defects in connecting components, and impressions on springs and grooved shafts.

Several effective ways of avoiding resonance or reducing the impact of vibrations are currently available. In the area of torsional vibrations, a flexible coupling is recommended for use in the mechanical system [9].

Extensive innovation is currently underway, targeting mechanical systems suffering from torsional vibration. In addition to upgrading technical systems, attention needs to be paid to their reliability [10-12].

Considerable progress has been noted in the area of flexible coupling design as well [13,14]. The couplings need to meet the high demands placed on them, as they have to be able to transmit large torques, while sufficiently reducing the magnitude of torsional vibrations at the same time [15,16].

Various additional elements are starting to be used in flexible coupling design to increase their functionality and usability. For this purpose, elements such as shock absorbers, torsional vibration eliminators, planetary gears, springs with different degrees of stiffness and flexible discs are applied therein [17-19]. A special group of flexible couplings is represented by pneumatic flexible couplings, which are characterized by the fact that, as flexible elements, pneumatic bags are incorporated into their design. It is possible to vary the air pressure in pneumatic bags and thus change the coupling characteristics. Therefore, it is possible to talk about a typical load-applying fields rather than about the coupling loading characteristics [20]. Thus, if a pneumatic coupling has a load-applying field of characteristics, it also has a range of degrees of torsional stiffness. An undeniable advantage is the possibility to change this torsional stiffness continuously during the operating mode of the mechanical system.

The use of technical gases for the filling of pneumatic bags of the flexible coupling also has innovative and research potential. Technical gases are easily available common gases used in industrial technological applications. Technical gases can change their pressure [21,22]. They have different properties than air and therefore it is to be expected that, when applied in pneumatic flexible couplings, they will have a different effect on the magnitude of torsional vibration in the mechanical system. We have examined the applicability of selected technical gases in pneumatic couplings under our own laboratory conditions. We found that they had an effect on the change in some of the features of the pneumatic couplings. We decided to experimentally verify the application of a pneumatic flexible coupling using technical gases in a mechanical system impacted by torsional vibration.

Our aim was therefore to experimentally verify the change in the magnitude of torsional vibration in the mechanical system, in which the pneumatic flexible coupling would be filled with different technical gases.

2. MATERIAL AND METHODS

We used three gases to verify the influence of technical gases on the magnitude of torsional vibration. The first gas was air. At the same time, we used air as the reference gas. We chose helium and propane butane as the two other gases to be compared with air. These gases were chosen on the basis that they are commonly available. Furthermore, one of them has a lower density and the other a higher density.

The occurrence of helium on earth is very rare. Due to its extremely low weight, it is only found in higher layers of the earth's atmosphere. Smaller quantities thereof are also found in natural gas from which it is obtained by freeze-drying. Occasionally, helium also rises from cracks in the earth. Due to its extremely low density and inert behaviour, helium is used to fill balloons and airships as a replacement for flammable hydrogen. A significant disadvantage is its relatively high price. In addition, the helium atom is of a very small diameter, enabling the helium to diffuse easily through solids, which translates into its losses [23-25]. For the purpose of our measurements, HE-4.6 helium was used. The technical gas contained 99.996% helium.

The propane butane used in the experiment consisted of 50% propane and 50% butane. Under normal conditions, propane butane is gaseous, but it can be converted into its liquid form relatively easily by cooling or compression. In its liquid state, it only takes up a 260th of its gaseous volume. The density of this gas is higher than that of the air; it is also flammable. Tab. 1 shows the basic properties of the technical gases used.

Tab. 1.
Basic physical properties of individual gases

	Helium He	Air	Propane-butane $C_3H_8+C_4H_{10}$
Specific gas constant r [J kg-1 K-1]	2,079	287.04	163.39
Gas density [kg.m-3] (15°C)	0.176	1.276	2.145
Molecular weight [kg kmol-1]	4.003	28.966	50.102

Tab. 1 makes it apparent that the gas density of helium is seven times lower than that of air, while the density of propane butane is twice as high as air density. Furthermore, the situation is similar when it comes to the molecular weight of the gases. The greatest value is that of propane butane, while the smallest is that of helium. The change is obvious when we look at the specific gas constant, where helium has the highest value and propane butane has the lowest. When compared to air, these value ratios are similar to gas density ratios.

The experimental gases were used to fill in a pneumatic coupling of the 4-2/70 T-C type (see Fig. 1).

Fig. 1. 4-2/70 T-C pneumatic flexible coupling

Pneumatic coupling transmits the torque via four flexible double-corrugated pneumatic bags evenly distributed over the circumference, which serve as flexible chambers. The flexible chamber's radius is 83.5 mm from the coupling axis. The height of the elastic bags in neutral position is 90 mm and the diameter is 70 mm. The maximum permissible deformation of the elastic bags is 25 mm in both directions of rotation, determining the maximum coupling twist of 11.5°. The elastic bags are interconnected and attached to steel discs.

3. PREPARATION FOR LABORATORY EXPERIMENT

The experiments designed to verify the torsional vibration change induced by the use of technical gases were performed under laboratory conditions in our workplace. The mechanical system employed in the experiments is shown in Fig. 2.

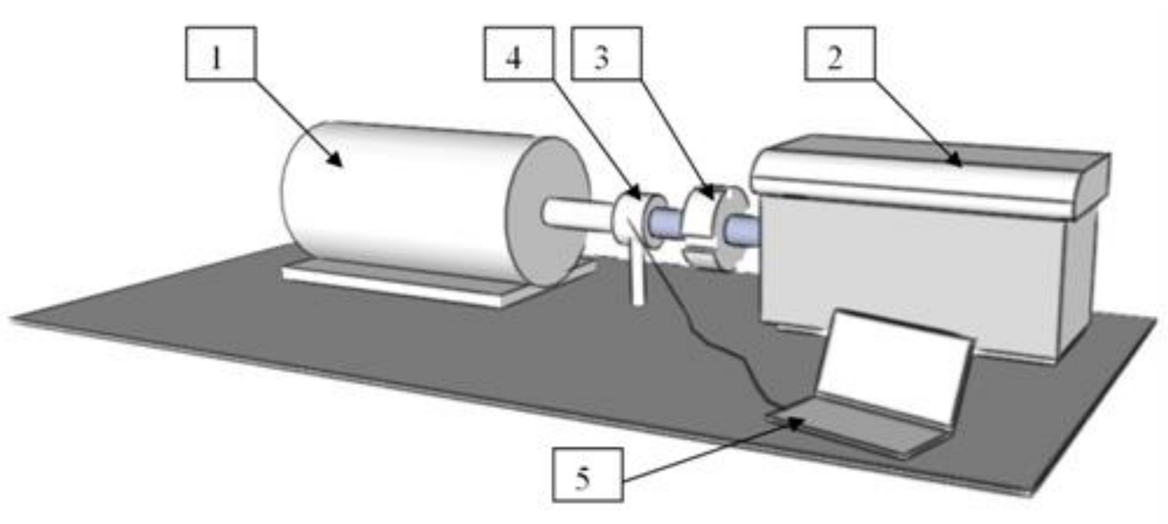

Fig. 2. Scheme of the experimental mechanical system

The mechanical system is designed with an incorporated source of torsional vibration, as well as to allow different speed modes. As a source of torsional vibration, a three-cylinder air compressor (2), of the ORLIK 3JSK-75 type, with the output of 50 m3.h-1, was used. The compressor had a cylinder diameter of 82 mm, a piston stroke of 70 mm and a maximum working pressure of 10 bars. The compressor was driven by a three-phase asynchronous electric motor (1), whose speed was continuously variable with a frequency converter from Siemens, with vector control. The nominal output of the electric motor was 11 kW and the nominal speed was 1,470 min^{-1}. The above-described pneumatic coupling of the 4-2/70 T-C (3) type and a torque sensor (4) were placed between the compressor and the electric motor. The torque sensor was manufactured by MOM Kalibergyár, Type 7934s, with the measuring range: 0 ÷ 500 Nm, with the accuracy of 0.5 N.m. The torque sensor was further connected to the measuring and evaluation apparatus (5). The apparatus was of a universal type: Quantum MX 840 with eight individual measurement channels and individual sample rates up to 40 kS/s per channel.

Using this measuring chain, time domain signals were mapped. Signal analysis can also be used appropriately for transition states, while total torsional vibrations can be conveniently determined from the time signal. Our effort was to determine the effective speed value, known as RMS, from the time signal. This parameter appropriately reflects the energy that is converted to vibrations and therefore a trusted indicator of the state of the machine in terms of vibration magnitude. This parameter is also a suitable parameter for vibration comparisons. The effective vibration value was sought for an operating speed from 200 to 1,500 min^{-1}. Experimental measurements were performed with a step change in revolutions after 100 min^{-1}. Subsequently, the RMS vibration values measured for each revolution were translated into the envelope curve. The measurements were performed for all gases under examination. The gas pressure in the pneumatic coupling varied between 100 and 600 kPa stepwise every 100 kPa. RMS vibration values were detected and recorded for all technical gases pressures.

4. RESULTS AND DISCUSSION OF EXPERIMENTS

With the help of experimental measurements, we wanted to identify the impact of technical gases in the pneumatic coupling on the magnitude of torsional vibration. Dependencies were made using the values obtained in individual measurements; see Figs. 3-8. For the sake of chart clarity, the dependencies found in the measurements on the pressure of the technical gases at 200, 400 and 600 kPa are provided.

The experimental measurements and the evaluated records show that dynamic proportions of the whole mechanical system can be affected by the flexible pneumatic coupling and the varying pressure of all investigated gases.

Figs. 3-5 show the dependence of torque vibration on operating speed. As evident from all the figures, changing the pressure of the studied gases translates into a change in the resonance area. For all three gases, the resonant area of the mechanical system shifts to the lower speed range with decreasing pressures in the pneumatic coupling. The displacement in the resonant area is the same for all three gases and, as indicated by the measurements, depends only on the gas pressure in the pneumatic coupling. By comparing the dependencies, it can be observed that, in the case of air and helium, the torsional vibration value increases with increasing pressure, whereas, in the case of propane butane, the torsional vibration value increases up to 400 kPa. When this value is exceeded, however, the torsional vibrations decrease with increasing pressures.

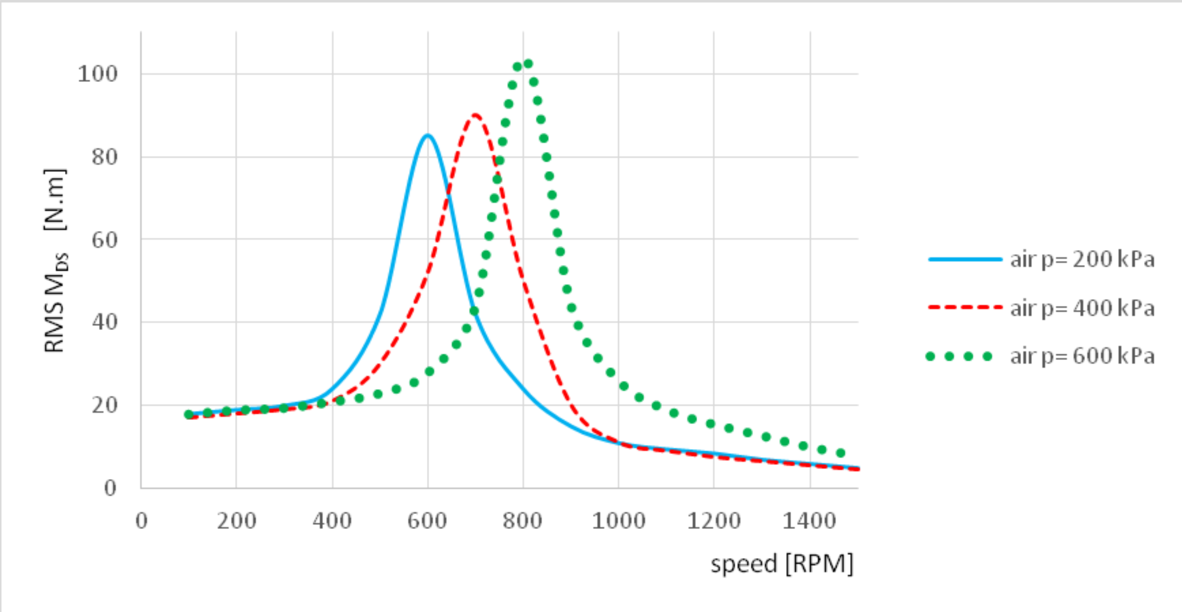

Fig. 3. Envelope curve of RMS values for the torsional vibration in the mechanical system with a pneumatic flexible coupling filled with air at p=200 kPa, p=400 kPa, p=600 kPa

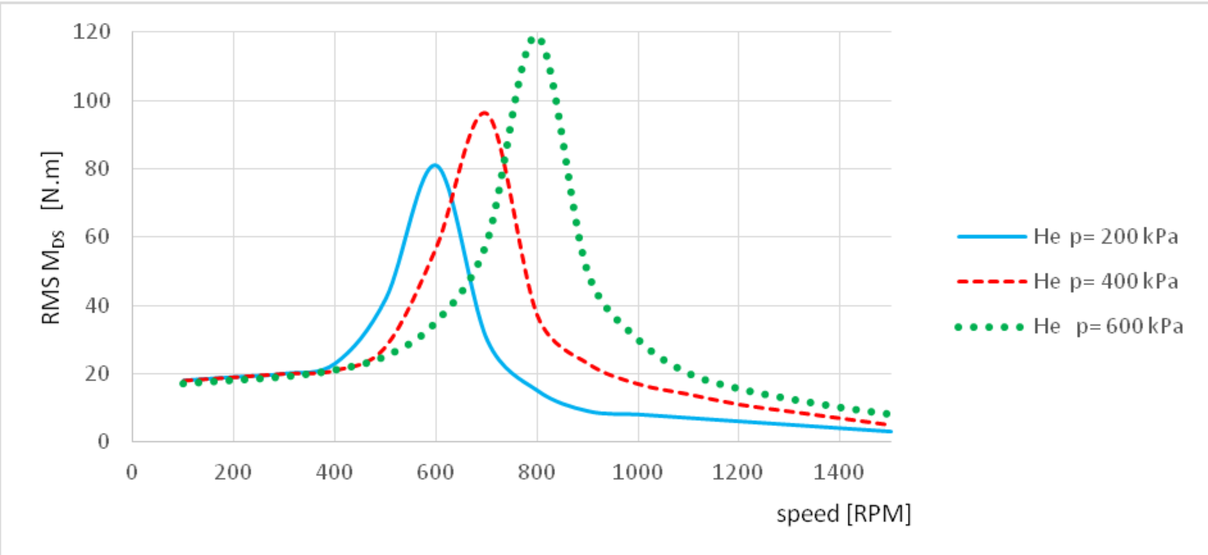

Fig. 4. Envelope curve of RMS values for the torsional vibration in the mechanical system with a pneumatic flexible coupling filled with helium at p=200 kPa, p=400 kPa, p=600 kPa

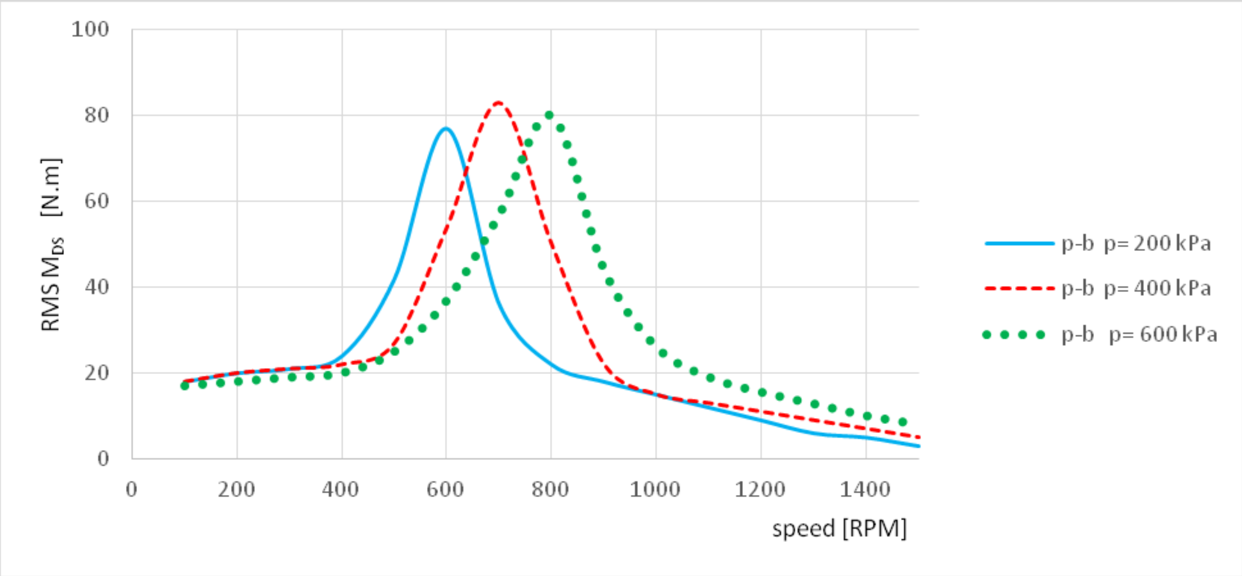

Fig. 5. Envelope curve of RMS values for the torsional vibration in the mechanical system with a pneumatic flexible coupling filled with propane butane at p=200 kPa, p=400 kPa, p=600 kPa

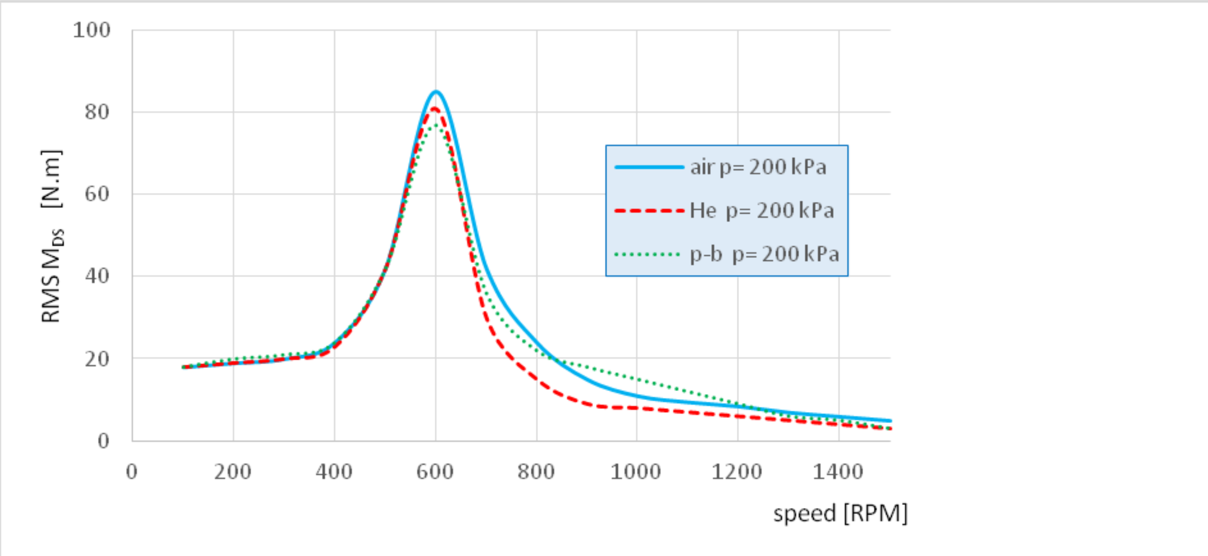

Fig. 6. Envelope curve of RMS values for the vibration in the mechanical system with a flexible pneumatic coupling filled with air, helium and propane butane, respectively, at 200 kPa

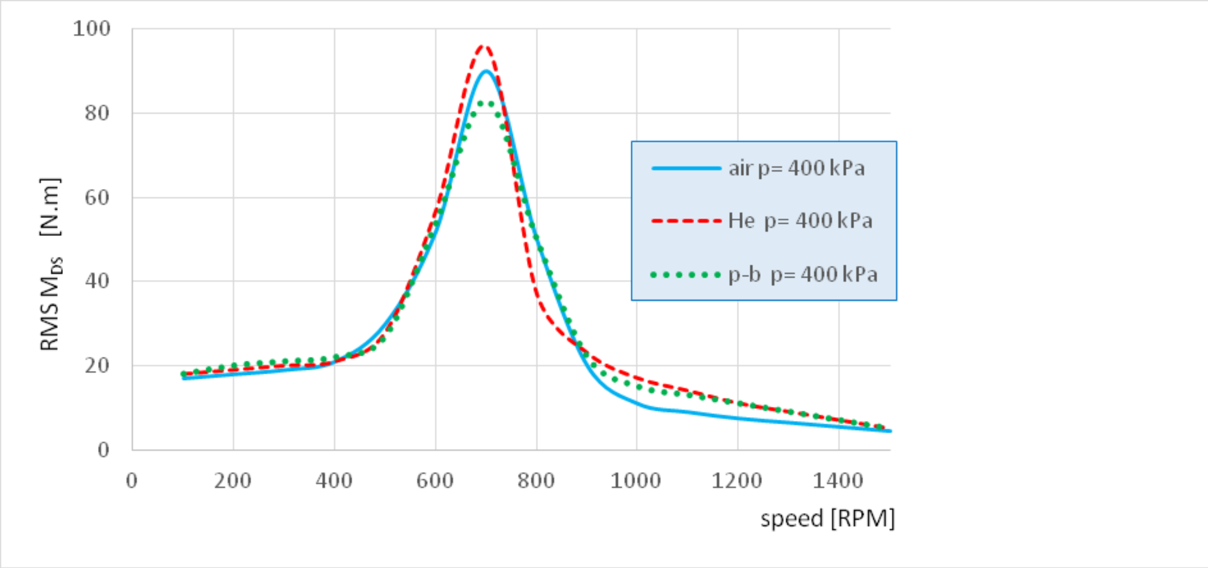

Fig. 7. Envelope curve of RMS values for the torsional vibration in the mechanical system with a flexible pneumatic coupling filled with air, helium and propane butane, respectively, at 400 kPa

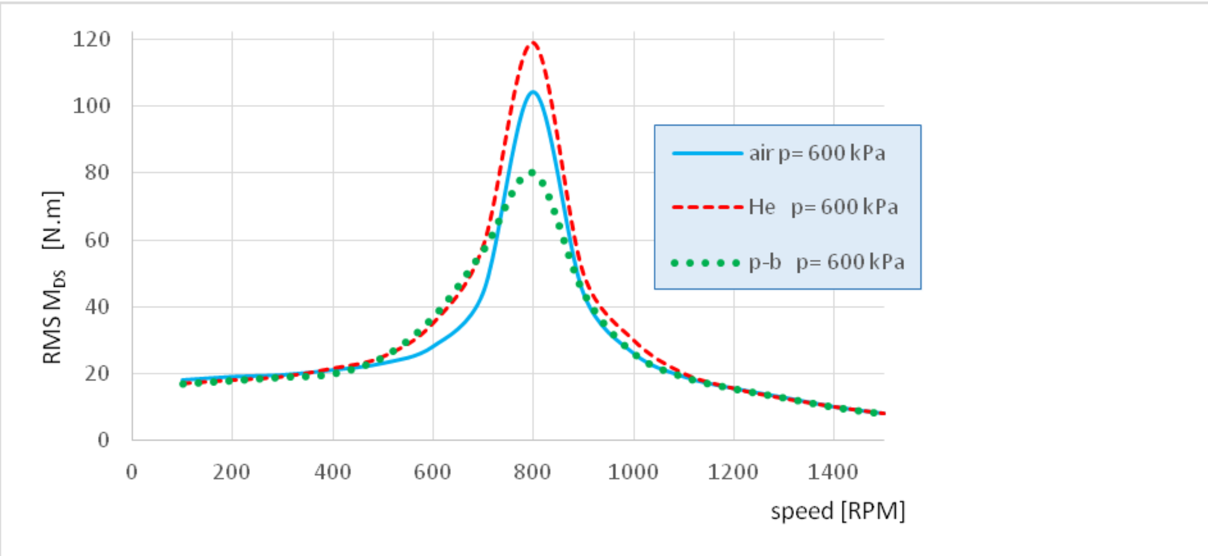

Fig. 8. Envelope curve of RMS values of the torsional vibration in the mechanical system with a flexible pneumatic coupling filled with air, helium and propane butane, respectively, at 600 kPa

In order to compare the impact of the technical gases at the same pressures and speed, we have created dependencies, as shown in Figs. 6-8. It is clear from these dependencies that the most significant reduction in the vibration value in the region of resonance is achieved when the pneumatic coupling is filled with propane butane. This condition applies to all the compared pressures. Interestingly, at lower pressures of up to 200 kPa, the lowest vibration value is shown by the pneumatic coupling filled with helium. Starting with the pressure of 200 kPa and greater, the pneumatic coupling filled with helium has the lowest impact on torsional vibration, and thus achieves significantly higher torsional vibration values than the pneumatic coupling filled with air and propane butane.

In the subresonance area, which is also of interest, the torsional vibration values for all the compared gases are the same. In the area above the resonance level, the torsional vibration values for the individual gases differ by up to 400 kPa; but, at the pressure of 600 kPa, the torsional vibration values are again the same in the area above resonance.

5. CONCLUSION

From the analysis of the courses of the measured magnitude of RMS torsional vibrations, it can be stated that the change in the pressure in all three technical gases in the pneumatic coupling bags also changes the magnitude of torsional vibration in the mechanical system.

The measured values of torsional vibrations show the impact of technical gas pressure on the occurrence of a resonance area. Furthermore, experimental measurements verify that technical gases affect the vibration value in the resonance area. The difference between the resonance values is as much as 30% if the pressure in the pneumatic coupling is 600 kPa. The greatest impact on torsional vibration in terms of resonance concerns propane butane, while the lowest impact involves Helium. Different physical properties of the technical gases affect torsional vibration, especially in the resonance area. Although the difference in the density of the studied gases is more than sevenfold, under increasing pressure in the region of resonance, the torsional vibration difference is 150%. Thus, the difference in gas density does not appear to be proportional to the change in torsional vibrations. Two basic findings can be postulated from the experimental measurements:

1. The type of technical gas in the pneumatic coupling does not affect the location of the resonance area of the mechanical system. Only the value of the technical gas pressure in the pneumatic coupling affects the occurrence of the resonance area in the mechanical system. With increasing pressure, this area shifts to the higher revolution range.
2. If the mechanical system with applied pneumatic coupling is located in the resonance area, the magnitude of the torsional vibration is strongly impacted by the type of technical gas in the pneumatic coupling. If a higher density gas is used, the torsional vibration value will decrease.

The presented results confirm the fact that the use of technical gases other than air in pneumatic couplings can be applied in the field of mechanical protection against torsional vibration. Such use may be especially beneficial to mechanical systems operating close to the resonance area, where it may be efficient to use technical gases of a higher density than air.

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