Investigation of temperature change for two flexible pneumatic elements dynamically loaded

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Abstract. Pneumatic flexible elements are used in pneumatic shaft couplings. These flexible elements are connected in different ways, and they are pressurized with a certain pressure. The article examines temperature changes of two connected elastic elements. It also describes measuring devices, and it examines the stresses of these elements. The article describes the measuring device constructed and designed in our laboratory. We describe its main parts and its working mode. The main aim was to find out the effect of the number of connecting holes on temperatures, the number of which we can change. Also, the aim of this article is to determine the temperature changes of flexible elements with different interconnections. We are investigating 2 flexible pneumatic elements. We measured the temperature of the air in the flexible element, the temperature of the outer and inner surface of the flexible element. In conclusion, we state the effect of the number of connecting holes on all three temperatures under investigation.

Keywords: Couplings, Measuring, Flexible elements, Element temperature.

1 Introduction

Nowadays, every industry uses various mechanical devices consisting of a drive device and a driven device. Such a composition of these devices is called a mechanical system in mechanical engineering. One of the important parts of the mechanical system is the shaft coupling that connects a drive and a driven device. According to several authors, the best way to control dangerous torsional oscillations is using an appropriately chosen shaft coupling [1, 2, 3, 5, 6]. We have been developing and researching such flexible shaft couplings for many years at our KKaDI department at the Faculty of Mechanical Engineering in Kosice [1, 4, 7, 8]. We focus on the development and research of flexible shaft couplings in more details. These flexible couplings can be used in various devices where the main emphasis is put on safety [9, 10, 11].

The aim of this article is to determine the temperature changes of flexible elements with different interconnections. In our laboratory, we interconnected 2 flexible pneumatic elements and investigated three different temperatures. The temperature of the air in the flexible element, the temperature of the external and internal surface of the

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flexible element. The main aim was to find out what effect the number of connecting holes on temperatures.

Flexible elements are used in these flexible shaft couplings. [2, 14]. These flexible elements are made of rubber that is pressurized with a certain gas pressure, and due to dynamic stress, they are capable to heat up. In these pneumatic elements, which are placed in the pneumatic shaft coupling, the air is compressed, and this causes a certain increase in temperature. In some shaft couplings, pairs of these elements are interconnected. In order to ensure the quality properties of the rubber and these elements at the same time, their temperature should not exceed 70°C. We will examine this temperature of two connected elements during their dynamic stress.

2 Materials and methods

2.1 Pneumatic elements

Flexible pneumatic elements are used in our newly developed flexible pneumatic couplings [2, 12, 13] (**Chyba! Nenalezen zdroj odkazů.**). An example of such coupling is shown in fig. 1. In this coupling, 4 double flexible elements are used, and they are evenly distributed around the perimeter and connected by one connecting hole. If necessary, we can increase the number of connecting holes as needed. Fig. 2 shows a such double elastic element. In practice, we can also increase the number of connecting holes as needed.

Fig. 1. Flexible pneumatic shaft coupling with double flexible elements and 1 connecting hole [2].

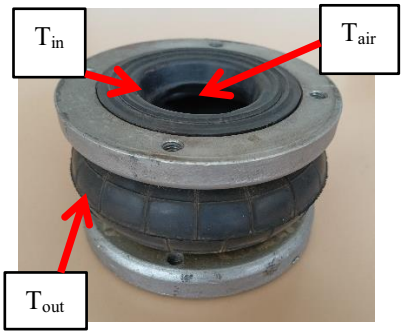

Fig. 2. The examined elastic element with a representation of places where the temperature is measured [2].

2.2 Connecting flange

During an examination of the temperature, the number of connecting holes (1 to 6 holes) will be changed. We will ensure the mutual connection of the holes with the help of the connecting flange, which can be seen in Fig. 3.

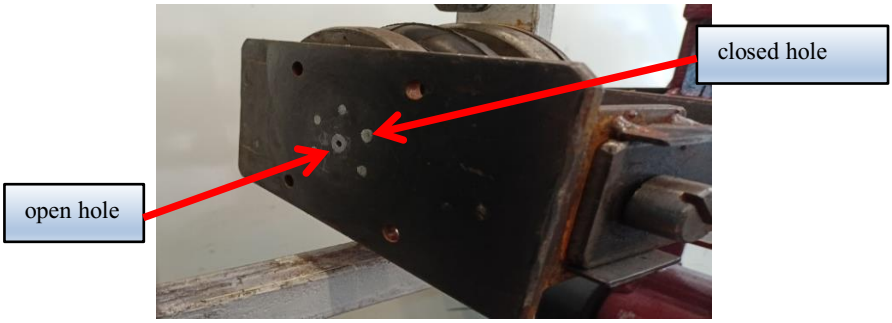

Fig. 3. Connecting flange with connection holes.

This flange consists of 6 drilled holes which we can gradually close at a certain pressure and revolutions. Figure 3 illustrates the case of one middle open hole and the other ones are closed. The disadvantage of this solution is that every time of changing the number of connecting holes, we have to disassemble the measuring device and reassemble it. It cannot be processed during the running time. The diameters of the holes are 2.5 mm, and they are drilled on a 40 mm pitched circle. We will measure the temperature of the outer surface, the temperature of the inner surface of the flexible element and the temperature of the air inside the element. During measuring we use flexible pneumatic elements with a diameter of 120 mm and a neutral height of 75 mm, as a Fig. 2 shows.

The working pressure is limited by the maximum working pressure which is 800kPa. Normal operating temperature is in the range of -40 °C to 70 °C. For special cases, the manufacturer can provide another material working in the temperature range of -20 °C to 115 °C.

2.3 Test device for temperature measuring

Test rig is precisely described and shown in fig. 4. It consists of electric motor (1) which drives the crank mechanism (2) through the belt transmission (3). The flexible pneumatic elements (4) are fixed in the fixed frame (5), which are connected by means of a connecting flange (6).

We use the SM 160L DC electric motor (1) with an output of 16 kW with an additional thyristor speed controller of the IRO type with a possibility of a continuous speed change from 0 – 2000 min^{-1}. For sensing of air temperature inside the flexible member T_{air} and the temperature of the inner surface of the flexible member T_{in}, we used two digital multimeters M-3870D METEX with temperature probe ETP–003, and measurement range −50 °C to +250 ° C.

Temperature probes were set up in three measured locations. The following temperatures were measured:

- Air temperature inside the flexible member T_{air},
- Temperature of the inner surface of the flexible member T_{in},
- Temperature of the outer surface of the flexible member T_{out}.

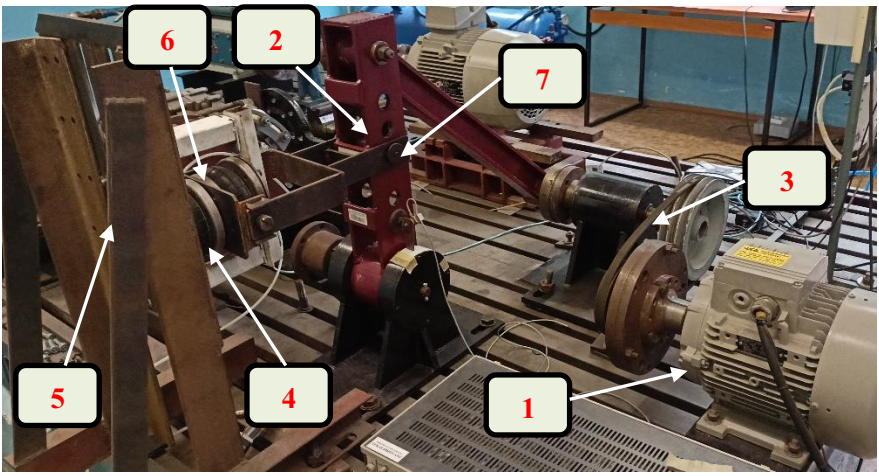

Fig. 4. Test device for measuring the temperature of 2 interconnected flexible pneumatic elements.

By changing the connecting holes on the crank mechanism shown by position 7, we can change the size of the oscillation amplitude, which was set to a value of 7.7 mm during our measurements. The ambient temperature at which we performed the measurements is constant, namely T=22°C.

3 Reynolds number value

The answer to the question of laminarity in air flow through the connecting hole is given by the well-known characteristic - Reynolds number Re. The relation for its calculation has the form:

$$\mathrm{Re} = \frac{2uR\rho}{\eta} \tag{1}$$

where ρ is the air density,
u – the air flow in the connecting hole,
R – its radius (radius of connecting holes R=1,25mm),
$\eta = 17{,}6 \cdot 10^{-6}\ \mathrm{Nsm^{-2}}$ is the dynamic air viscosity.

If we assume that the air flow in the connecting hole is laminar, the maximum flow velocity can be calculated as:

$$u_{max} = \frac{\Delta p}{4\eta L}. \tag{2}$$

By numerical substitution of current values for us (p_0 = 100 – 700 kPa, L = 6 mm, η = 17,1·10^{-6} Nsm^{-2}, ρ = 1,2 kgm^{-3}, amplitude of oscillations A = 7,7 mm, revolutions in the range n = 100 – 1000 min^{-1} and R = 0,1 – 4 mm) we get Reynolds number values ranging from 6600 to several million. However, we consider the flow to be laminar only until Re < 2300 (considering turbulation from value of 10,000). Obviously, in our case it is turbulent prudence. Therefore, we will not mathematically express the temperatures in the flexible element, but we will only show the results of experimental measurements, which can be used to create a mathematical model later.

4 Results of experimental measurements

During performing the measurements in our department laboratories, we observed temperature changes in connection of two flexible elements with various number of connecting holes (from 1 to 6).

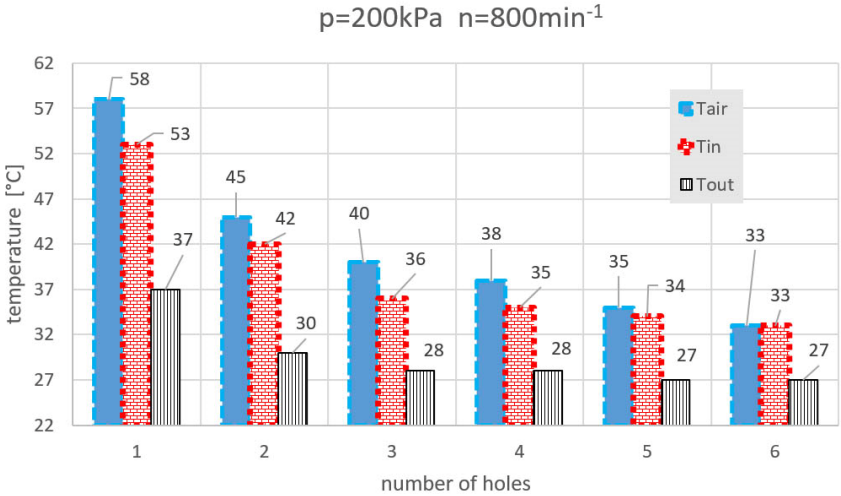

Fig. 5. Course of measured temperatures depending on the number of connecting holes, at initial pressure p=200 kPa and revolutions 800 min^{-1}.

Fig. 5 shows the change in temperatures depending on the number of connecting holes of two flexible elements. The pressure in the flexible element is 200 kPa and the speed is 800 min^{-1}.

During measurement, we increased the speed to 800 min^{-1} at the pressure in the flexible element 200kPa. The temperature of the outer surface T_{out} reached the lowest temperature of 27°C with the maximum number of connection holes, namely six. In measurement with the one connecting hole, the value of temperature is 37°C, which

is not a significant change. The temperature of the inner surface T_{in} reached greater values than T_{out}. It varies in the range of 33°C with six holes to 53°C with one connecting hole. Similarly, the air temperature inside the flexible elements reached the highest temperature, and it varies from 33°C with six openings to 58°C with one connecting opening.

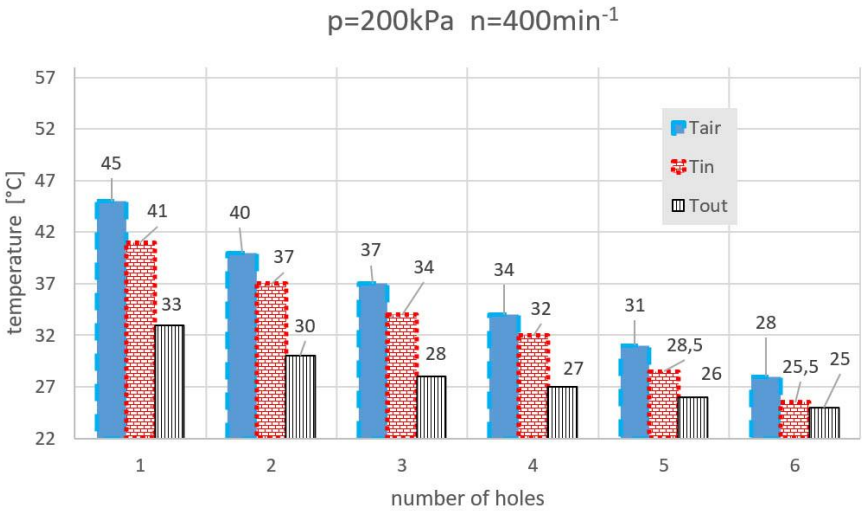

Fig. 6. Course of measured temperatures depending on the number of connecting holes, at initial pressure p=200kPa and revolutions 400 min^{-1}.

In Fig. 6 we can see the change in temperature depending on the number of connecting holes during measurements where the pressure in the flexible element is 200 kPa and the speed is 400 min^{-1}. The temperature of the outer surface T_{out} reached the lowest temperature of 25°C with the maximum number of connection holes, namely six, compared with one connecting hole, the value is 33°C, which is not a significant change. The temperature of the inner surface T_{in} reached greater values than T_{out}. It varies in the range of 25.5°C with six holes to 41°C with one connecting hole. Similarly, the highest temperatures are reached by the air temperature inside the flexible elements, which varies from 28°C with six openings to 45°C with one connecting opening.

In Fig. 7 and Fig. 8, we can observe the temperature changes depending on the different number of connecting holes. The pressure in the flexible element is 500kPa and we increased the speed from 400 min^{-1} to 800min^{-1}. The temperature of the outer surface T_{out} reached the lowest temperature of 24-27°C with the maximum number of connecting holes, namely six. Measurement with one connecting hole, the value is 25-32°C, which is not a significant change. The temperature of the inner surface T_{in} reached greater values than T_{out}. It varies in the range of 26-30°C with six holes up to 29-38°C with one connecting hole. Similarly, the highest temperatures are reached by the air temperature inside the flexible elements, which varies from 26-33°C with six openings to 30-44°C with one connecting opening.

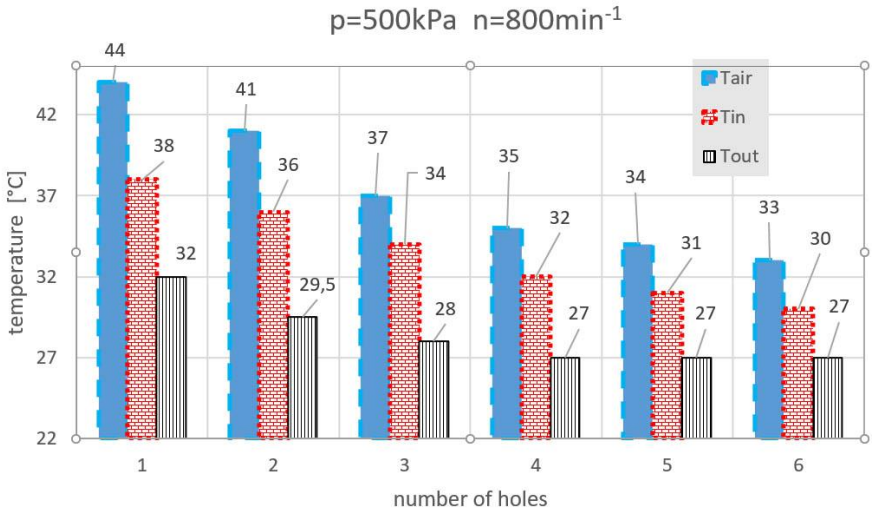

Fig. 7. Course of measured temperatures depending on the number of connecting holes, at initial pressure p=500kPa and revolutions 800 min^{-1}.

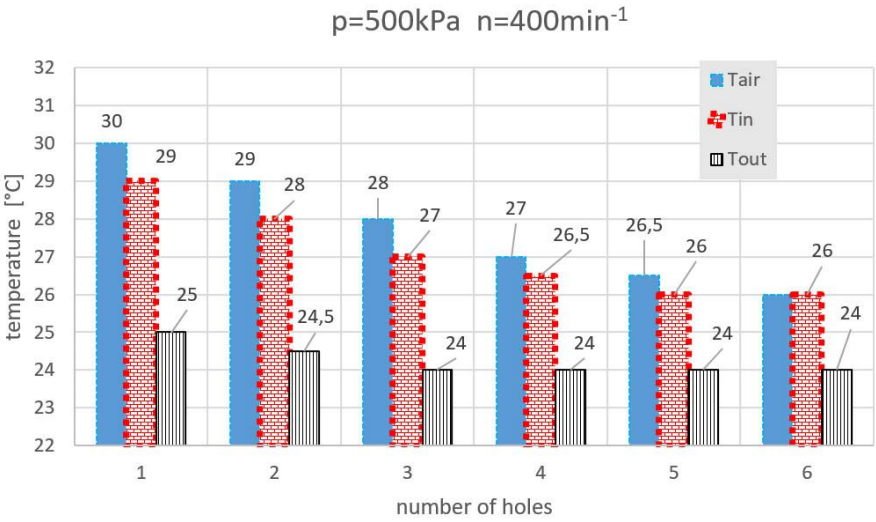

Fig. 8. Course of measured temperatures depending on the number of connecting holes, at initial pressure p=500kPa and revolutions 400 min^{-1}.

5 Conclusion

The aim of the article was to find out how the temperature of two connected flexible elements changes when they are placed in a pneumatic coupling, and they are connected by one or more connecting holes. We designed a measuring device that we used for this purpose. By describing the air flow and using the Reynolds number, we pointed out that a turbulent air flow occurs during the given measurement.

All measured values are recorded after 30 minutes. After this time, no temperature changes significantly. However, we can state that the increased number of openings caused a decrease in all temperatures, which is positive information for us. We can state that the highest temperatures were reached at the lowest pressure of 200 kPa and the highest measured revolutions of 800 min^{-1}.

We can also state that none of the measured temperatures exceeded the critical temperature of 70°C and therefore the pneumatic flexible elements do not lose their properties and they can work with no problems in operation. So, we can say that with these couplings, the influence of temperature does not have any critical condition on the operation and therefore also on the safe operation of the equipment where these couplings are located.

All-important results and measured values in other articles [6,13] are also published. It is important to note that these flexible elements work in pneumatic couplings. These pneumatic shaft couplings can work in different environments in terms of temperature. In laboratory conditions, they were always kept at a constant temperature, but in real conditions, the increased temperature of the workplace can have a significant effect on the temperature of flexible elements, which we did not address in this work. If the couplings will work in operation where the temperature is increased, this can cause an increase in the temperature of the element.

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