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INVESTIGATION OF THE CHANGE IN TEMPERATURE INSIDE THE ELASTIC ELEMENT DEPENDING ON THE SPEED AT A CONSTANT PRESSURE IN THE ELEMENT

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Abstract: The article investigates the change in temperature inside the elastic element at three different speeds and a constant pressure of 300 kPa inside the elastic element. These flexible elements are used in flexible pneumatic couplings developed at our workplace. These elements are subjected to dynamic stresses due to the change from a rotational movement to a rectilinear reciprocating motion. For this purpose, we have designed a test device that can change different speeds to this movement. Due to the stress of the elastic elements by the rectilinear reciprocating movement, a heat is formed inside the elastic element. The aim of the article is to determine the course of the temperature inside the elastic element from the measured values.
Keywords: pressure, temperature, flexible element, measurements, rectilinear reciprocating motion, speed

1. INTRODUCTION

One of the most widely used shaft couplings is flexible couplings, in which the torque is transmitted from the drive to the driven part of the coupling by a flexible member. Flexible shaft couplings balance the axial, radial and angular misalignments of the connected shafts, are able to accumulate the kinetic energy of the system and dampen torsional vibrations. The most commonly used non–metallic resilient members include resilient members made of rubber–cord material. At present, attention is being paid to the development and research of pneumatic flexible members, which are formed from a rubber–cord casing filled with a gaseous medium. When performing the above–mentioned basic functions of flexible shaft couplings, mechanical energy is converted into thermal energy, which can lead to physico–chemical changes in the flexible member [1,3,5,6].
At our workplace, we have been dealing with the issue of flexible shaft couplings and torque transmission for a long time. We have also developed a test device for testing flexible couplings and flexible elements used in these couplings. Vibration, torsional vibration and noise are generated during torque transmission. Therefore, it is important to prevent such mechanisms in some way so as not to damage some members or possibly damage the entire device. When designing torsionally oscillating mechanical systems, it is necessary to proceed in such a way that the adverse effects of torsional vibrations are eliminated as much as possible. To reduce the adverse effects of torsional vibrations, it is advantageous to use flexible shaft couplings.
These make it possible to tune the torsionally oscillating system and adjust its stiffness, damping or mass parameters so that during the operating mode of the system there is no dangerous resonant state and this would cause the failure of the equipment in which they are used. In the field of tuning torsionally oscillating mechanical systems, high–elastic shaft couplings are currently used at our workplace.
It is important to note that these flexible pneumatic couplings use flexible elements. These resilient elements are dynamically stressed and heat is also generated as a result of this stress. Since these elements are made of rubber materials and rubber as a material is quite sensitive to heat, it is important to determine what temperatures arise during operation in these elements.
In order to ensure the long–term service life of flexible shaft couplings, the maximum permissible temperature for flexible couplings with rubber members should not exceed 70 °C. The temperature of the elastic members affects the elastic modulus of the rubber in compression, damping, relaxation, aging and fatigue of the rubber [2]. At the department of design and transport engineer SJF TU in Košice, attention has been paid to the development and research of pneumatic flexible shaft couplings for a long time.
The aim of the article is to find out how the temperature inside the elastic element changes at different speeds and constant pressures under dynamic stress [7, 8, 9, 12].

2. INFLUENCE OF TEMPERATURE DYNAMIC STRESS ON RUBBER PROPERTIES

If we load the rubber part in any way (pressure, pull, shear, torsion or combined), we supply it with energy. After the end of the load, we do not get this energy all the way back – some of it is converted into heat. Under dynamic stress, part of the energy supplied is converted to heat for each cycle. This means that the temperature of the rubber part rises until a thermal equilibrium occurs. The amount of heat supplied from the internal energy losses equals the amount of heat dissipated by conduction or radiation from the surface of the rubber element. Due to the low thermal conductivity of the rubber, there is a large temperature gradient in the rubber part [10, 11, 13].

Temperature rise at high alternating stress amplitudes in conjunction with high frequencies leads very rapidly to thermal cracks inside the rubber which can result in various breakdowns or damage to different devices.

The temperature has a significant effect on relaxation. In a broader sense, relaxation is considered to be processes related to the transition from an unbalanced state to an equilibrium state. If an external force field is applied to the system at equilibrium from a certain point in time, the system assumes a new equilibrium state which is different from the original one and is dependent on the intensity and nature of the force field. If the transition from the initial to the final state were immediate, the system would always be in balance. In practice, the system under consideration passes from a baseline to a series of transient non–equilibrium states. There is a time effect, system reactions are delayed, hysteresis occurs.

Relaxation is more pronounced at a lower temperature at which all relaxation periods are prolonged. Some relaxation periods, previously short and negligible, will now become comparable to the duration of the force field. If the temperature decreases further, the relaxation times can be so prolonged that on the contrary the field exposure time appears short. Relaxation gradually slows down so that its impact is practically negligible. At high temperatures, relaxation usually takes place so fast that the deformation development reaches the limit values practically immediately, with negative effects. On the contrary, at low temperatures the relaxation is so slow that it is not necessary to consider the elastic deformation.

In practice, rubber parts are most often stressed by varying stress, usually periodic. Each periodic event can be considered as the sum of sinusoids of different amplitudes and frequencies [7, 9, 12].

As the temperature rises, the rate of chemical reactions increases and this also causes faster aging of the rubber. Adverse changes prevail, which may result in partial or complete destruction of the product. Due to the aging of the rubber, the rubber irreversibly changes due to chemical reactions. These reactions take place inside the mass or on the surface.

Thus, we can state that the temperature of the rubber elements is very important. It is important to monitor this temperature and ensure that it does not exceed the critical values that may adversely affect the properties of the rubber in operation and, in the worst case, also damage these rubber elements and thereby damage the device in which they are used.

3. DESCRIPTION OF THE TEST EQUIPMENT

All measurements were carried out on a test facility located in the laboratory of our department. The diagram of the test device for measuring the temperature of the separate pneumatic–elastic element PE–130/2 is shown in Figure 1. This device allows us to stress the elastic elements by dynamic stress at different speeds, and we can also vary the stress amplitude to a certain extent.

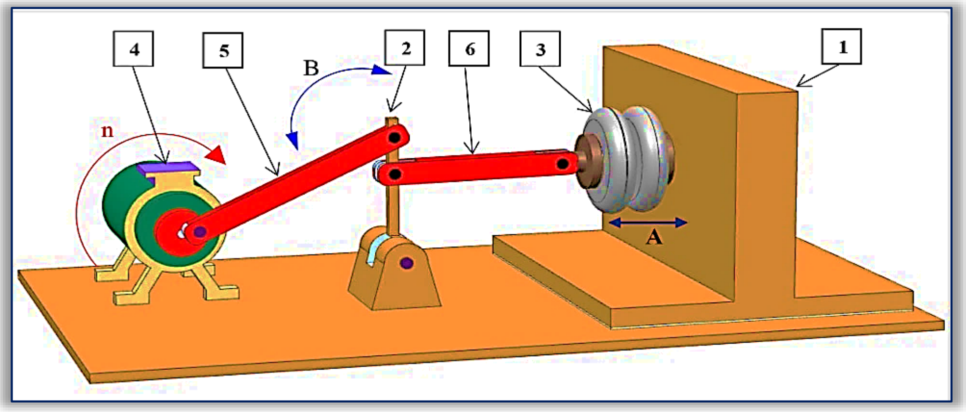

Figure 1. Scheme of test mechanism and description of basic movements

The test device consists of dismantling the frame (1) in which the pneumatic–elastic element PE–130/2 (3) is mounted. This element is double–corrugated and we use it in flexible pneumatic shaft couplings developed at our department. These elements are made of rubber–cord material and can operate at a working pressure of 100–700kPa. The rotary to linear reciprocating transducer (2) has also been developed at our department and we can change the amplitude of dynamic stress by simply changing the arm attachment. We use the SM 160L DC motor (4) with an output of 16 kW with an additional thyristor speed controller of the IRO type with the possibility of a continuous speed change from 0 – 2000 min^{-1}.

The basic movements of the whole test device and the principle of the whole mechanism are described in Figure 1. The electric motor can be rotated in the range of 0 – 2000 min^{-1}. We are taking our measurements at three different speeds of n=400min^{-1}, n=600min^{-1} and n=800min^{-1}.

Due to the rotation of the electric motor (n), the proposed mechanism consisting of the arm (5) and the arm (6) performs a rocking motion B. The speed of this oscillating motion depends on the speed and the amplitude of the oscillation depends on the arm mounting (2). At the first mount, we performed measurements at amplitude A = 4mm. Changing the arm attachment (5) to the second position changed the amplitude A = 5.6mm. Touch digital multimeters were used to investigate the temperature M–3870D METEX with heat probe ETP–003: −50 – +250 °C. Monitor 3 different temperatures on the device. The temperature of the air inside the flexible element T_{in}, in these measurements, only the temperature inside the elastic element was examined. We sense the temperature in the internal flexible element of the sensor.

The ambient temperature at the beginning of the measurement was T0 = 22 °C. Said temperatures were recorded at t = 1, 2, 3, … 30 min at set speeds, air pressure and strain amplitude.

4. RESULTS OF EXPERIMENTAL MEASUREMENTS

All measurements were carried out on a testing device Figure1. The course of measured values can be seen in Figure 2. The measurements were performed at a constant pressure of p = 300 kPa over a period of 0 to 30 minutes. The values were recorded every minute. After several measurements, we found that after 25 minutes the temperature mostly stabilized. After 30 minutes the temperature did not change anymore and the courses were constant.

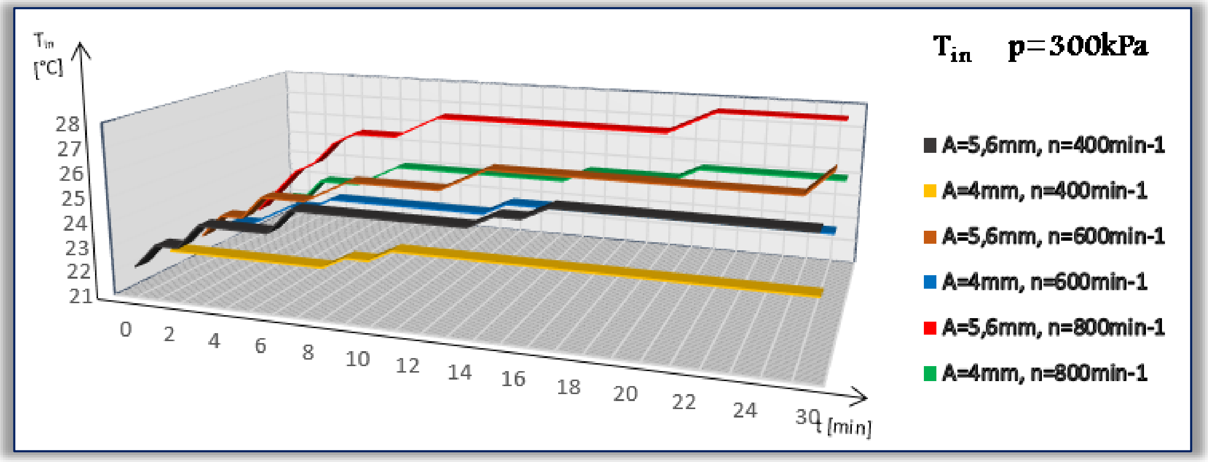

Figure 2. Comparison of measured the temperature inside the elastic element T_{in} at constant pressure p = 300kPa amplitude A = 4mm and A = 5,6mm at three different revolutions n=400min^{-1}, n=600min^{-1} and n=800min^{-1}.

The temperature inside the elastic element at a set amplitude of A = 4mm and a speed of n = 400min^{-1} varied in the range of 22 °C to 23 °C. At 11 minutes, the value rose to 23 °C and remained constant. The Temperature inside the elastic element at a set amplitude of A = 4 mm and a speed of n = 600min^{-1} varied in the range of 22 ° C to 24 ° C. The value at this amplitude increased gradually until it reached a final value of 24 ° C within 13 minutes.

The temperature inside the elastic element at a set amplitude of A = 4mm and a speed of n = 800min^{-1} varied in the range of 22 °C to 25 °C. The value at this amplitude was gradually increased, similarly to the speed n = 600min^{-1}, until it reached a final value of 25 °C at 20 minutes.

The temperature inside the elastic element at a set amplitude of A = 5.6 mm and a speed of n = 400min^{-1} varied in the range of 22 °C to 26 °C. The temperature rose linearly for 30 minutes and remained constant.

The temperature inside the elastic element at a set amplitude of A = 5.6 mm and a speed of n = 600 min^{-1} varied in the range of 22 °C to 27 °C. The value at this amplitude was gradually increased until it reached a final value of 27 °C.

At maximum speed, the temperature inside the elastic element at the set amplitude A = 5.6mm and speed n = 800min^{-1} varied in the range of 22 °C to 28 °C. The value at this amplitude gradually increased similarly to the speed n = 600min^{-1}. At t = 19 minutes it reached a final value of 28 °C. This temperature has not changed with time.

As can be seen from Figure 2, that with increasing time, the temperature of the elastic element increases, while at 30 minutes all values stabilize to a constant value which then does not change. Measurements at amplitude A = 4mm were lower than those at higher amplitude A = 5.6mm. For both amplitudes, the temperature of the outer surface varied in the range of 22°C, which was ambient temperature up to a maximum value of 28 °C. We reached this value at a maximum speed of 800 min^{-1}. The comparison of the rising temperature versus speed is described in Figure 3 and Figure 4.

The effect of amplitude on the temperature of temperature inside the elastic element at 400 min^{-1}, 600 min^{-1} and 800 min^{-1} can be compared in the following Figure 5, Figure 6 and Figure 7.

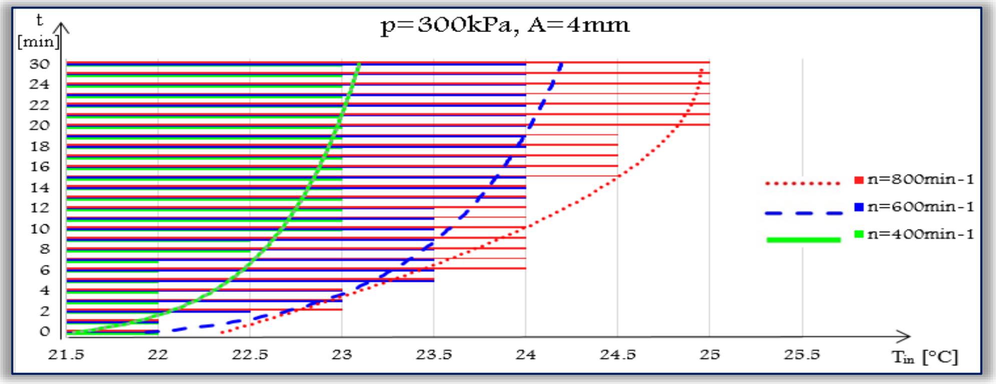

Figure 3. Comparison of measured development values temperature inside the elastic element T_{in} for speed n = 400, 600 and 800 min^{-1} constant pressure p = 300kPa amplitude A = 4mm.

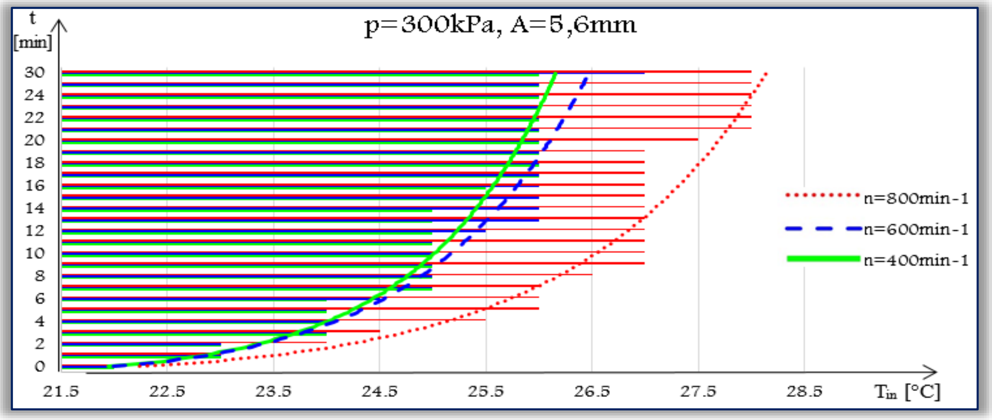

Figure 4 Comparison of measured development values the temperature inside the elastic element T_{in} for speed n = 400, 600, 800 min^{-1} constant pressure p = 300kPa amplitude A = 5,6 mm.

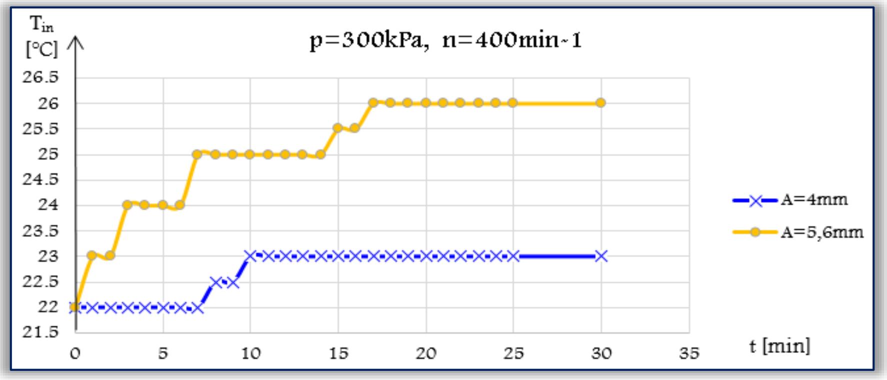

Figure 5. Comparison of measured values temperature inside the elastic element T_{in} for amplitudes A = 4 and 5,6mm at speed n = 400 min^{-1} and constant pressure p = 300kPa.

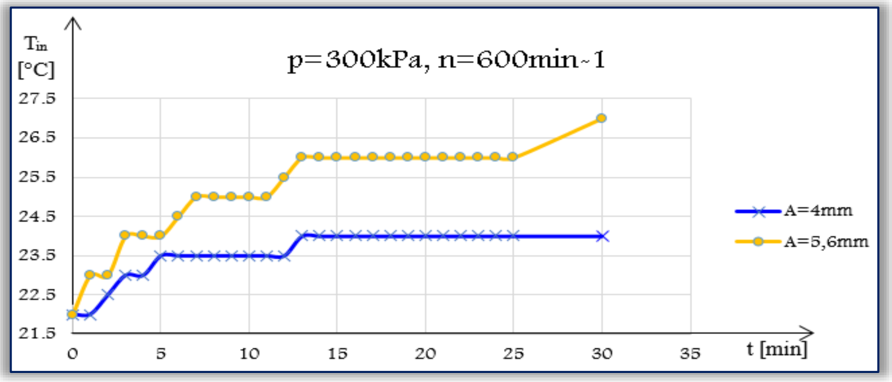

Figure 6. Comparison of measured values temperature inside the elastic element T_{in} for amplitudes A =4 and 5.6mm at speed n = 600 min^{-1} and constant pressure p = 300kPa.

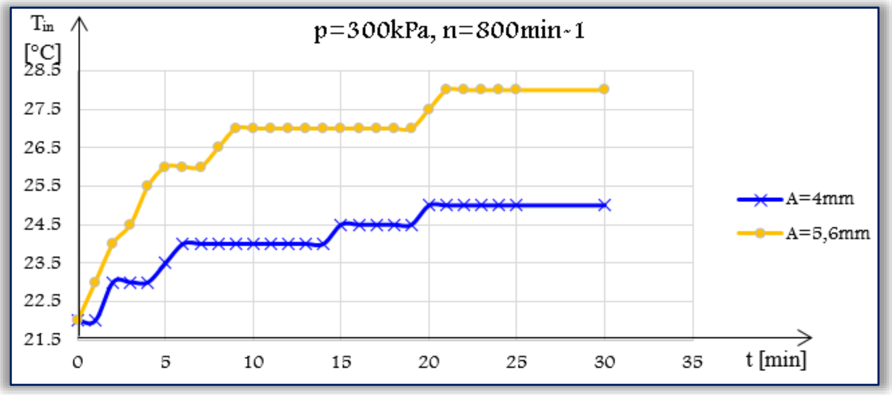

Figure 7. Comparison of measured values temperature inside the elastic element T_{in} for amplitudes A = 4 and 5,6mm at speed n = 400 min^{-1} and constant pressure p = 300kPa.

In Figure 5, we can compare the temperature change of the inside the elastic element at two different amplitudes A = 4mm and A = 5.6mm for a pressure of 300kPa and a speed of 400 min^{-1}. We can see that at a smaller amplitude A = 4mm the temperatures are significantly lower than at a higher amplitude. At an amplitude of A = 4mm, the temperature rose only by 1°C and settled to constant value immediately after 10 minutes. At a higher amplitude, the temperature increased linearly and was higher by 4°C. It stabilized only after 17 minutes at 26°C.

At higher speeds of n = 600min–1, the temperature of the outer inside of the resilient element increased very much as at speeds of n = 400min^{-1} (Figure 6). At an amplitude of A = 4mm, the temperature rose by up to 2°C and stabilized at 24°C after 11 minutes. At an amplitude of A = 5.6 mm, the values increased in the same way as at the speed of n = 400 min^{-1}. It increased by 5°C and reached a final value of 27°C in 30 minutes. Waveforms at 400 min^{-1} and 600 min^{-1} are very similar and do not record any significant temperature increase.

At the speed n = 800min^{-1} we can observe the temperature increase of the inside the elastic element in Figure 7. At an amplitude of A = 4mm, the temperature was increased by 3°C, reaching a final value in 20 minutes and its value was 25°C. At a higher amplitude A = 5.6mm the temperature increase is more pronounced. The temperature was increased from 6°C to 28°C from an initial ambient temperature of 22 °C. The temperature increase is faster and the temperature has stabilized to the final temperature in 21 minutes

5. CONCLUSIONS

The effect of temperature on flexible elements made of rubber but also on all other elements is important. The cell examines how the temperature inside the elastic element changes at three different speeds and constant pressure in the elastic element. Flexible elements are used in flexible pneumatic couplings developed at our workplace. Flexible pneumatic shaft couplings transmit torque and therefore the flexible elements used in them are dynamically stressed. Different speeds provide different operating modes. As a result of these speeds, the elastic elements are dynamically stressed and heated. The elastic elements are made of rubber, it is very important to find out what temperatures we are moving in and whether this temperature inside the elastic element will not have a negative effect on the properties of the rubber. A change in the properties of the flexible element or possible damage due to heat can have a negative effect on the flexible shaft coupling and this can cause damage to the device in which this coupling is located.

For this purpose, we designed a test device, which we described in detail in this article. In this device we can change the amplitude of the oscillation and we can also perform measurements at different speeds and different pressures in the elastic element. We investigate properties at constant pressure p = 300kPa.

We performed measurements at amplitude A = 4mm and amplitude A = 5.6mm. We set the test equipment to three speeds 400min^{-1}, 600 min^{-1} and 800min^{-1}. The main goal was to determine the temperature inside the flexible element. We determined whether this temperature would not rise to critical values that would cause damage to the flexible element and equipment failure.

From the measured values we can state that the temperature rose very similarly at speed n = 400min^{-1} and speed 600 min^{-1}. At the speed 800min^{-1} and amplitude A = 5.6 mm, the values of only about 3 °C higher than in the case of the amplitude A = 4 mm. In all measurements, the temperature stabilized and after 30 minutes or sometimes earlier and did not change. With increasing amplitude and increasing speed, the temperature stabilization time increased. In none of the measurements did the temperature change after 30 minutes.

Temperatures did not exceed 28°C in any of the test measurements. We can state that elastic elements can work in such conditions without changing the properties and without failure. The influence of temperature at constant pressure and speed up to 800min^{-1} does not have a significant effect on the properties of elastic elements.

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