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ROZKŁAD TEMPERATURY POWIERZCHNI ZEWNĘTRZNEJ ELEMENTU ELASTYCZNEGO PRZY RÓŻNYCH REŻIMACH EKSPLOATACJI

Streszczenie: W artykule zbadano, jak zmienia się temperatura zewnętrznej powierzchni elementu sprężystego w różnych trybach pracy sprzęgła. W tym celu zaprojektowano obiekt badań, który zostanie szczegółowo opisany w niniejszym artykule. Ciśnienie w elemencie sprężystym dla porównania było nadal stałe. Na podstawie zmierzonych wartości przedstawiono, jak znacząco wzrosła temperatura na powierzchni elementu sprężystego.

Słowa kluczowe: procesy termodynamiczne, temperatura otoczenia, element pneumatyczny, ciśnienie, sprzęgło.

INFLUENCE OF EXTERNAL SURFACE TEMPERATURE IN FLEXIBLE ELEMENT DURING VARIOUS OPERATIONAL REGIMES

Summary: The paper examines how the temperature of the outer surface of the resilient element changes in different operating modes. For this purpose, we have designed a test facility that will be described in detail in this article. On this instrument, we can vary the amplitude of the oscillation and also make measurements at different speeds. The pressure in the elastic member for comparison was still constant. From the measured values we show how significantly the temperature on the surface of the elastic element increased. We find out if this temperature is more influenced by the amplitude or the rate at which this amplitude arises.

Keywords: thermodynamic processes, couplings, measurements, flexible elements, pressure.

1. Introduction

Our scientific works have been dedicated to the transmission of torque for a long time. Vibration, torsional vibration and noise are generated when transmitting torque. Therefore, it is important to prevent such mechanisms in some way so as not to

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damage some members or eventually break down the whole device. When designing torsionally oscillating mechanical systems, it is necessary to proceed in such a way that the adverse effects of torsional oscillations are eliminated as much as possible.
To reduce the adverse effects of torsional vibration, it is advantageous to use flexible shaft couplings. These make it possible to tune the torsionally oscillating system, i. e. adapt its stiffness, damping or mass parameters so that it does not cause a dangerous resonant state during the operating mode of the system [1], [2], [3], [5]. In the field of tuning of torsionally oscillating mechanical systems, our workplace currently uses high-elastic shaft couplings.
It is important to note that these resilient pneumatic couplings use resilient elements. These resilient elements are subjected to dynamic stress and heat is also produced as a result of this stress. Since these elements are made of rubber materials, and rubber as a material, it is quite important to determine what temperatures occur 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, ageing and fatigue of the rubber.
The aim of the paper is to find out how the temperature of the elastic element changes at different speeds and amplitudes under dynamic stress. For each research we have a device that we describe in the article.

2. Influence of temperature on basic rubber properties

Rubber as a technical material is very often used for its specific properties. Rubber isolator is widely used in the field of vibration and noise reduction of piston pump due to its simple structure, high bearing capacity and good damping effect [9]. However, the rubber isolator has stiffness nonlinearity and damping nonlinearity, and its dynamic characteristics are not only influenced by static preload, but also influenced by excitation amplitude and excitation frequency [10], [11]. If we load the rubber part in any way, 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 [4], [6]. 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 [12].
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.

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 [7, 8].

3. Description of the test equipment and definition of basic movements

To investigate the properties of elastic elements, we designed and constructed a test device. All measurements were carried out on a test facility located in the laboratory of our department.

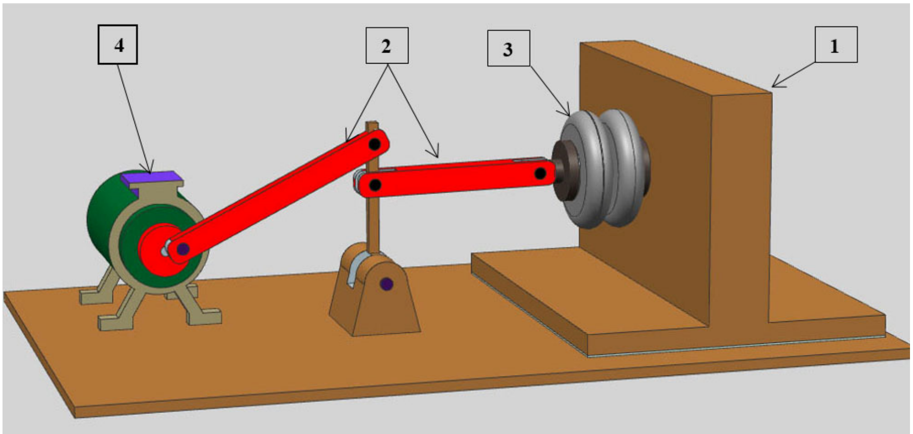

Figure 1. The scheme of the test apparatus for measuring the temperature

The diagram of the test device for measuring the temperature of the separate pneumatic-elastic element PE-130/2 is shown in Fig. 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. 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}.

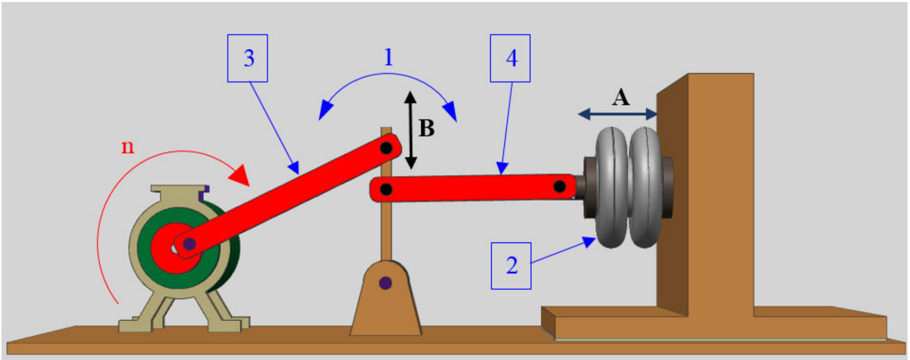

Figure 2. Description of the basic movements of the test equipment

The basic movements of the whole test device and the principle of the whole mechanism are described in Fig. 2. 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}.

The test rig consists of several basic parts of the frame assembly. 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 Fig. 2. 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, the proposed mechanism consisting of the arm (3) and the arm (4) performs a rocking motion 1. The speed of this oscillating motion depends on the speed and the amplitude of the oscillation depends on the arm mounting (3). For this measurement, we used 2 arm mounts (3) to change dimension B. At the first mount, we performed measurements at amplitude A = 4mm. Changing the arm attachment (3) 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 Tair, the temperature of its inner surface Tin and the temperature of its outer surface Tout. In these measurements, only the outer surface temperature was examined. The temperature monitoring point is shown in Fig. 2 indicated by position 2. The ambient temperature at the beginning of the measurement was T_0 = 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 Fig.1 and Fig 2. The course of measured values can be seen in Fig. 3.

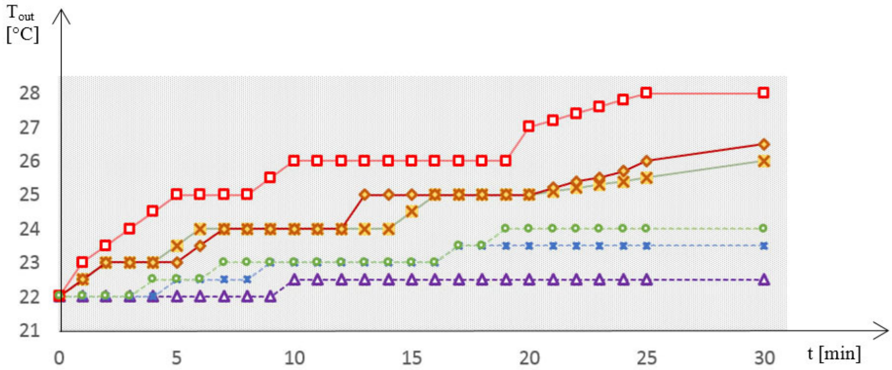

Figure 3. Comparison of measured external temperature values T_{out} at pressure p = 300kPa amplitude A = 4mm and A = 5,6mm at three different revolutions $n=400min^{-1}$, $n=600min^{-1}$ and $n=800min^{-1}$

The 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 tempe-rature mostly stabilized. After 30 minutes the temperature did not change anymore and the courses were constant.

The temperature of the outer surface of 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 22.5 °C. At 10 minutes, the value rose to 22.5 °C and remained constant. The temperature of the outer surface of the elastic element at a set amplitude of A = 4mm and a speed of n = $600min^{-1}$ varied in the range of 22 °C to 23.5 °C. The value at this amplitude increased gradually until it reached a final value of 23.5 °C within 17 minutes. The temperature of the outer surface of 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 24 °C. The value at this amplitude was gradually increased, similarly to the speed n = $600min^{-1}$, until it reached a final value of 24 °C at 19 minutes. The temperature of the outer surface of the elastic element at a set amplitude of A = 5.6mm and a speed of n = $400min^{-1}$ varied in the range of 22 °C to 25.5 °C. The temperature rose linearly for 30 minutes and remained constant. The temperature of the outer surface of 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 26 °C. The value at this amplitude was gradually increased until it reached a final value of 26 °C. At maximum speed, the temperature of the outer surface of the resilient 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 = 25 minutes it reached a final value of 28 °C. This temperature has not changed with time.

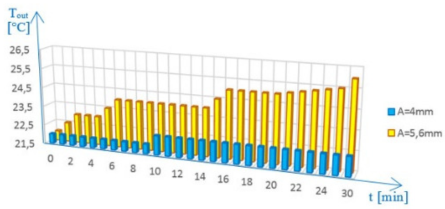

Figure 4. Comparison of measured external temperature temperature values T_{out} for amplitudes A = 4mm and A = 5.6mm at speed n = 400 min^{-1}

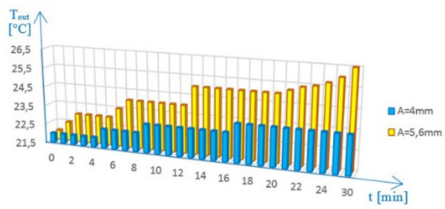

Figure 5. Comparison of measured external temperature temperature values T_{out} for amplitudes A = 4mm and A = 5.6mm at speed n = 600 min^{-1}

As can be seen from Fig. 3, 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}.

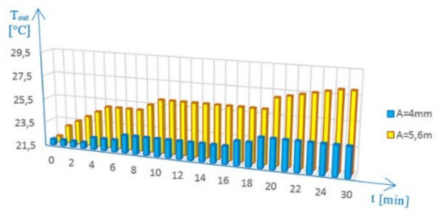

Figure 6. Comparison of measured external temperature temperature values T_{out} for amplitudes A = 4mm and A = 5.6mm at speed n = 800 min^{-1}

The effect of amplitude on the temperature of the outer surface of the elastic element at 400 min^{-1}, 600 min^{-1} and 800 min^{-1} can be compared in the following Fig. 4, Fig. 5 and Fig. 6.

In Fig. 4, we can compare the temperature change of the outer surface of 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 0.5 °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 30 minutes at 26°C.

At higher speeds of n = 600min-^{1}, the temperature of the outer surface of the resilient element increased very much as at speeds of n = 400min^{-1} (Fig. 5). At an amplitude of A = 4mm, the temperature rose by up to 1.5 ° C and stabilized at 23.5 °C after 19 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 4 °C and reached a final value of 26 °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 outer surface of the elastic element in Fig. 6. At an amplitude of A = 4mm, the temperature was increased by 2.5 °C, reaching a final value in 19 minutes and its value was 24.5 °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 25 minutes.

4. Conclusion

Throughout the research, we can say that we found interesting temperature changes in the outer surface of the elastic element. The paper examines how the temperature of the outer surface of the resilient element varies under different operating modes. These flexible elements are used in flexible pneumatic couplings developed in our workplace. Flexible pneumatic shaft couplings transmit torque and therefore the elastic elements used therein are dynamically stressed. Because, due to this dynamic stress, the elastic elements heat up, and since they are made of rubber, it is very important to find out what temperatures we are in and whether this temperature will have a negative effect on the properties of the elastic elements. A change in the properties of the elastic element, or possibly damage due to heat, may have a negative effect on the elastic shaft coupling and this may cause damage to the device in which the coupling is located.

Therefore, we designed and constructed a test device, which we described in detail in this article. We have described the basic movements that the test equipment can perform. In this device we can change the amplitude of the oscillation and we can also make measurements at different speeds and different pressures in the elastic element. We measured at different amplitudes. The pressure in the spring element was still constant for comparison. The measurements were performed at three different speeds. The main goal was to find out what has a greater effect on the change in temperature of the outer surface of the elastic element. It was important to find out what temperature values were reached and whether these values could cause a change or damage to the elastic element. From the measured values it can be stated that the temperature rose very similarly. At the lowest speeds n = 400 min^{-1} and 600 min^{-1}. At higher speeds of 800 min^{-1}, the values were higher by 2 °C for amplitude A = 4 mm and 6 °C for amplitude A = 5.6 mm. In all measurements, the temperature stabilized after 30 minutes. The temperature stabilized after 9 minutes. In any case, the temperatures did not exceed 28 °C, so it can be stated that the elastic elements can operate under such conditions without any change in performance and trouble-free operation. The change in amplitude had a greater effect on the change in outer surface temperature than the change in speed. In conclusion, I can say that the elastic elements can work without problems under the given conditions, because the influence of temperature does not significantly affect their properties.

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