TRANSPORT PROBLEMS 2022 Volume 17 Issue 4
PROBLEMY TRANSPORTU DOI: 10.20858/tp.2022.17.4.15

Keywords: flexible coupling; dynamic characteristic

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INFLUENCE OF CHANGES IN THE WORKING TEMPERATURE OF FLEXIBLE COUPLINGS ON THEIR STIFFNESS CHARACTERISTICS

Summary. This article compares flexible couplings of the spider-type insert, and the tire-type insert. The influences of the volume and hardness of the elastomeric connector on the characteristics of this type of coupling, as well as the course of the change of the stiffness coefficient as a result of changes in the operating temperature, are presented. In drive systems, flexible couplings undergo very frequent changes within a wide range of operating temperatures, which causes a change in the dynamic parameters of the flexible couplings during operation.

1. INTRODUCTION

Rising temperature of elastic elements is often the cause of flexible coupling failure. The focus of our research are the influence of the operating temperature of flexible couplings, which is not normally carried out in this type of research with an elastomeric coupling. There is a lack of research on the influence of ambient temperature on the behavior of the connector at higher temperatures. If the operational parameters of the flexible couplings are given, the temperature at which these tests were carried out is not available. On the other hand, ambient temperature and heat generation because of the deformation of the elastomeric element can have a significant impact on its dynamic properties [2, 8, 30]. The tests conducted in this study were carried out experimentally on a test stand designed and manufactured to test elastomeric couplings [21, 31].

Heating elastomeric elements change the dynamic properties of flexible couplings [20, 26] and sometimes damage the drive system [6, 11]. Therefore, it is important to test influence of the temperature on the properties of elastomeric materials used in flexible couplings at increased operating temperatures. Flexible coupling failures cause serious damage even to hole machine. The heating of elastomer components is a severe cause of failure. The maximum operating temperature is limited to 70–110 °C, depending on the elastomeric material [1, 13]. Therefore, it is important to study various elastomeric materials used in flexible couplings. The influence of temperature on the change of dynamic parameters, such as stiffness and damping, is crucial in this type of coupling [3, 4]. Often, torsional vibrations that occur in the drive system cause self-heating of the elastomer joint, and the associated temperature increase leads to accelerated damage of the flexible coupling. A loss of the function parameters has been determined at an unknown temperature [5, 9]. Various types of flexible couplings are used in the drive systems of handling machines. The variety of constructions is dictated in practice by the applicability of

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a given coupling, mainly based on the transmitted torque and, to a lesser extent, based on the viscoelastic properties of the elastomeric connector used in each type of flexible coupling [12, 15].

In the drive system of transport machines, the flexible coupling is its smallest element used, but it can influence the operation of a drive system. Therefore, research related to the behavior of this type of flexible coupling in a drive system is important [17, 20]. This is not significant only in terms of the transmitted torque but also in terms of the elastic-damping parameters of the small flexible elements at increased temperatures inside the drive system (Fig. 1).

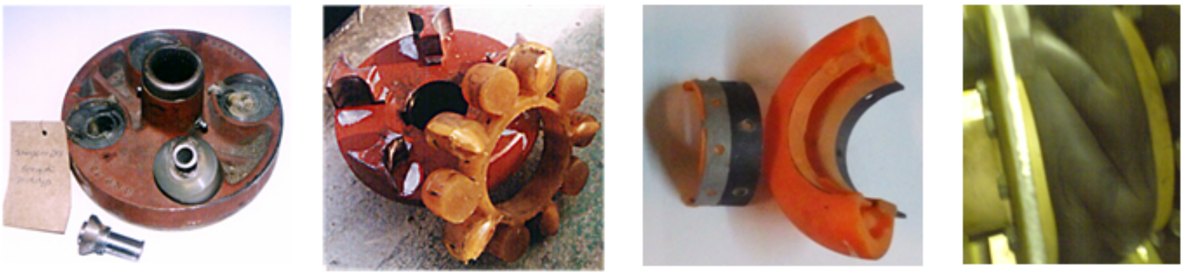

Fig. 1. An example of damage to an elastomeric element of flexible coupling as a result of a maladjusted operating temperature in the drive system

Flexible couplings, in addition to the basic tasks that must be fulfilled in the drive system (ie, transmitting the torque M_o [Nm], transmit the rotational speed n [rpm]), compensate for inaccuracies in the positioning of the journals of the mating shafts [23, 24]. ~~It~~ Flexible couplings should have a specific ability to damp torsional vibrations resulting from dynamic surpluses that accumulate on the elastomeric element (especially in the range of resonance velocity of the drive system) [27, 29]. These parameters are determined by the elastomer material from which the flexible element of the coupling is made [32]. It is worth noting that the designs of the flexible couplings are very different. The difference between flexible couplings lies in the fact that an elastomeric element is placed between the members, which can be screwed on by preload [35, 37, 38].

In industrial practice, an increased flexible coupling for a given drive system of a transport machine should not be selected solely based on the amount of torque transmitted, as is traditionally done based on the catalog data of a given manufacturer of flexible couplings [16]. In addition, the selection of the size and type of flexible coupling should take into account the dynamic parameters of this type of coupling. Many authors have researched flexible couplings in drive systems in various situations. The conducted tests do not consider all cases and do not show the drive system or how it would behave when using a flexible coupling with a different temperature work of flexible element design in a drive system. There are no tests to compare the behavior and influence of the temperature data of the elastomeric element used in the flexible coupling. In particular, the effect of linkage with a different temperature structure of the elastomeric element on the dynamic properties of such a drive system is unknown. A comparison of the couplings for a given drive system of a transport machine at different temperatures of work requires the quantification of the dynamic parameters of the flexible couplings, the main parameters (which include the damping and stiffness coefficient), and the temperature range in which the elastomeric element of the coupling will operate. Very little information in the literature on the operation of flexible couplings at raised operating temperatures. Only in a few works [9, 18, 19] have the authors discussed this topic related to the research of flexible couplings considering these types of temperature parameters. When these factors are given, they are generally determined under load conditions at ambient temperature. The second aspect of the problem of selecting flexible couplings for drive systems is that these couplings operate under various environmental conditions in which varying values of ambient temperature may prevail. To fill this research gap, the authors conducted a series of laboratory tests on various types of flexible couplings while changing the operating temperature of a given coupling to see how it affects the main characteristics of flexible couplings [22].

The amount of energy dissipated in a flexible coupling was then determined as an internal friction work of the flexible connector. Various types of elastomers (rubber, polyurethane, and polypropylene) used in this type of flexible coupling show particularly high internal friction [28, 34].

Each flexible coupling is characterized by different features and operational capabilities (Fig. 2). Therefore, the manufacturer catalog information is mainly related to the nominal torque transmitted by the drive system increased by safety factors [21].

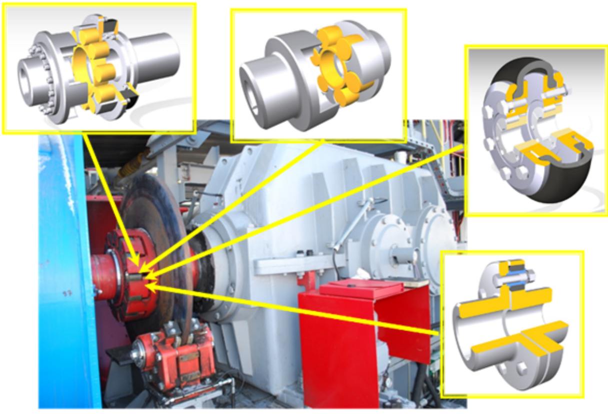

Fig. 2. Possible torsionally flexible mechanical couplings that can be chosen for use in the drive system of a belt conveyor

Due to the damping ability (and thus mechanical conversion) of flexible couplings, the dynamic stresses of these couplings convert the damping energy into heat. At high frequencies or high amplitudes, flexible couplings may cause the element to overheat beyond the permissible value specified by the manufacturer. Changing the operating temperature often changes the characteristics of the flexible coupling, altering the behavior of the drive system as a result of dynamic excitations. Therefore, we decided to investigate the extent to which the temperature of the flexible element influences the characteristics of flexible couplings [14, 32].

One of the basic disadvantages of rubber is the high sensitivity of its mechanical properties to temperature changes. Changes in the physical and mechanical properties of rubber result in torsional vibrations, not only with changing ambient temperature but also with heat release because of periodically changing dynamic excitation forces. Depending on the damping, the amplitude, and the frequency of the vibration, some energy is converted into heat, thus increasing the temperature of the rubber damping element [6].

2. TESTING THE ELASTOMERIC ELEMENTS OF FLEXIBLE COUPLINGS

In industrial practice, the selection of a flexible coupling for a given drive system is mainly determined by the amount of nominal torque M_o [Nm] transmitted by the drive system. The amount of torque is adapted to the existing power of the drive unit. The amount of torque transferred in the case of elastomeric couplings in the manufacturer's catalog series of types is dictated by the appropriate increase in the volume of the elastomer used and its hardness. First, before starting this research, the authors took a measurement for the purpose of volumetric analysis of the elastomeric element used in flexible tire-type couplings. The measurement consisted of determining the volume of the elastomeric material Q [cm^3] and the hardness of this material that influences the amount of torque transmitted by a given flexible coupling [25]. The analysis of the size of the elastomeric material used was presented as a function of the transmitted maximum torque M_o (Fig. 3).

The presented table shows a linear dependence of the increase in volume of the elastomeric connector *Q [cm3]* as a function of the transmitted torque M_o *[Nm]*. An analysis of the obtained diagram indicates that the amount of torque obtained, apart from the elastomer volume, is also influenced by the hardness of this material. Elastomers with a low hardness of about 35–64 ShoreA do not cause a significant increase in transmitted torque despite the double volume, and the characteristics are mild. However, with higher hardness (that is, above 70 ShoreA), the characteristic is steeper, meaning that the influence of hardness results in much greater possibilities of torque transmission for the same elastomer volume. The value of the transmitted torque depends not only the volume but also the hardness of the elastomer itself, from which a given flexible connector is made (Fig. 3).

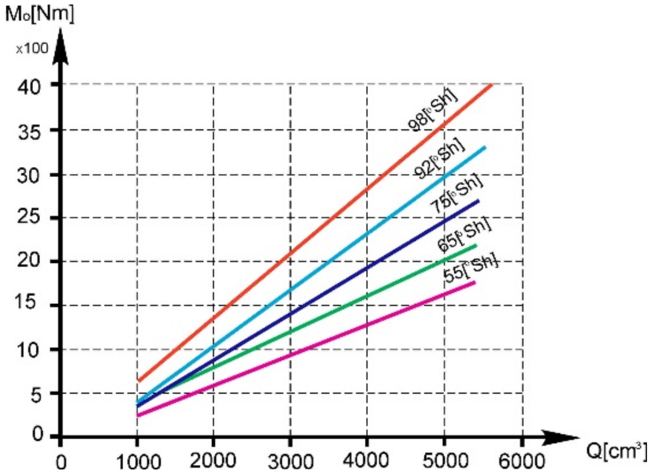

Fig. 3. Influence of the volume Q [cm^3] of the flexible connector on the amount of nominal torque M_o [Nm] transmitted for torsionally flexible couplings

2.1. Laboratory stand for testing flexible couplings

To investigate the operational parameters of flexible couplings, such as stiffness and damping, the authors built an innovative laboratory stand based on two cooperating induction motors with a chamber isolating the flexible coupling from the environment to simulate the variable operating temperature of a flexible coupling. The stand enabled setting a variable torque and changing the operating temperature of the coupling. This allowed the authors to determine the stiffness and damping characteristics of the tested flexible couplings under the influence of temperature changes in the working environment. The variable temperature setting system enabled the temperature to be changed from -10 °C to 60 °C. Fig. 4 shows a general view of the laboratory stand for determining the operational characteristics of flexible couplings under the influence of temperature changes.

The basic units included in the laboratory stand for testing the characteristics of elastomeric couplings (Fig. 6) are two induction motors (1 and 2), the torque meter (5), a frequency converter (10), a microprocessor controller (11), and a system measuring the relative torsion angle of the flexible coupling elastomer element (7, 8, 9). The stand was mounted on a rigid frame (6). The flexible coupling with an elastomeric connector (3) was mounted between the motors (1) (2) on the common shaft (4), together with the torque meter (5) and the discs (8) measuring the twist angle of the coupling.

The methodology of this investigation of mechanical characteristics was reduced to the forced shear of the flexible coupling between two induction motors (1) and (2) (Fig. 4) with changes of torque in time. The variable torque caused deformation of the elastomeric connector (3) mounted between the measuring discs (8) [20]. The principle of operation of the laboratory stand to test the elastomeric element of flexible couplings is to change the mechanical load between two motors (1) and (2) connected by the measuring shaft (4) with a flexible coupling. Motor (1) is connected directly to the power supply network (rated voltage Uz=400 [V], frequency f=50 [Hz]). The angular velocity of the engine (2) is controlled by a frequency converter (10). This connection makes it possible to change the angular velocity of the motor (2) due to the possibility of changing the frequency of its supply, which is realized by the frequency converter (10) [21].

The casing is made of sheet metal (1) with internal insulation in the form of polyurethane foam (2) (Fig. 5) to ensure a constant temperature in the range of -10 to 60 ° C. The interior of the housing is filled with polyurethane foam. The chamber has two holes for rotating shafts and an opening for supplying hot air from the heater to a working flexible coupling. Paraffin bags were used to obtain the negative temperature; After being removed from the freezer, they were covered with the coupling elastomeric element, which made it possible to obtain the flexible coupling lowest temperature of the elastomeric element (i.e., -10 °C).

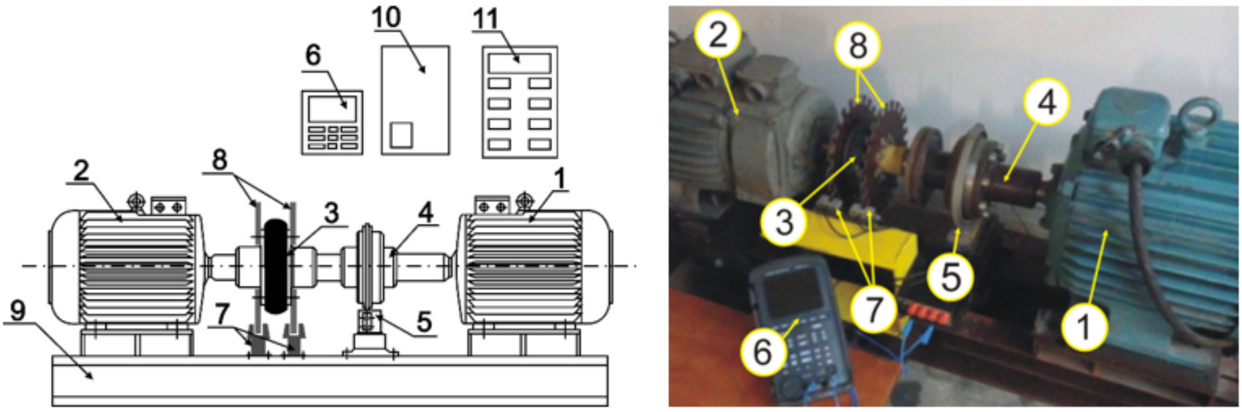

Fig. 4. Laboratory stand used to determine the mechanical characteristics of flexible couplings: 1 - induction motor operating at a constant angular velocity, 2 - induction motor operating at a variable speed, 3 - flexible coupling with an elastomeric connector, 4 - measuring shaft of torque, 5 - torque meter, 6 - oscilloscope, 7 - sensor of the relative twist angle, 8 - measuring discs, 9 - frame, 10 - frequency converter, 11 - microprocessor used to control the variable dynamic torque

For changing temperatures, a thermal chamber was also constructed (Fig. 5).

Fig. 5. Thermal chamber for a torsionally flexible coupling: 1 - sheet metal, 2 - polyurethane foam

2.2. The influence of the operating temperature of the flexible coupling susceptible to the stiffness characteristics

Three flexible couplings were tested on the test stand: two with a spider-type insert and one with a tire-type insert (Tab. 1). The methodology carried out for testing the flexible couplings was reduced to the forced relative twisting of the elastomeric element used in the coupling between two cooperating induction motors with variable torque. These quantities are necessary to build the appropriate dynamic characteristics for the tested couplings.

The characteristics of the flexible couplings were based on the torque value M_o as a function relative twist angle φ of the elastomeric element by function (1).

$$M_o=f(\varphi) \quad . \tag{1}$$

The characteristics created on this basis were used to determine parameters such as the damping coefficient ψ and the stiffness coefficient c. The numerical values of these coefficients are of particular importance during the dynamic analysis of the model that cooperates with a flexible coupling according to Equation (2). In the case of flexible couplings, the value of the dynamic stiffness coefficient c_d is influenced by the variable components of the dynamic torque, such as the dynamic torque amplitude M_A

and the frequency of dynamic torque ω_s. For the characteristics of the flexible coupling slightly deviating from the linear characteristics, a linear stiffness coefficient c was determined. However, for couplings with characteristics that deviate from the linear ones, the stiffness coefficients α_o and β_o were approximated according to the third degree polynomial according to Equation (2) (Fig. 7).

a) b)

Fig. 6. Flexible couplings tested a) the spider-type insert, b) tire-type insert

$$M_o(\varphi) = \alpha_o\, \varphi + \beta_o\, \varphi^3 \quad (2)$$

Table 1 shows examples of the values of these coefficients for the researched flexible couplings with different levels of hardness.

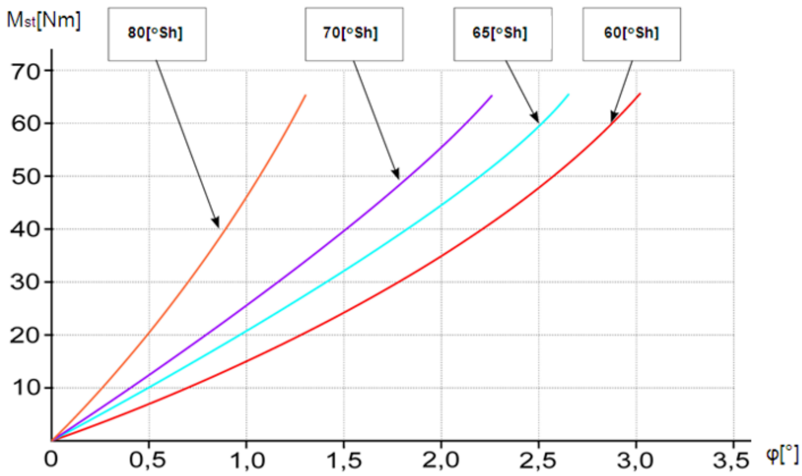

Fig. 7. Static characteristics of tire-type and spider-type flexible couplings

Table 1

Parameters of the characteristics of the tested flexible couplings

Type of flexible coupling	Hardness of the elastomer element [ShoreA]	Volume of the elastomer element Q[cm^3]	Stiffness coefficients of the flexible coupling		
			c_{st}[Nm/°]	α_{st}[Nm/°]	β_{st}[Nm/(°)^3]
Spider flexible coupling	80	178 10^3	53.1	50.2	0.57
	70	100 10^3	17.5	10.5	1.33
Tire flexible coupling	65	112 10^3	17.7	10.3	1.52
	60	106 10^3	22.0	15.5	1.24

The static characteristics changed as a result of the change in the volume and hardness of the elastomer used to construct the elastomeric element of a flexible coupling. For example, the coefficient for the spider-type coupling with a hardness of 80 ShoreA and a volume $Q = 178\ 10^3\ cm^3$ of the spider connector was $c_{st} = 53.1$ Nm/°. Meanwhile, the tire type coupling with a hardness 65 ShoreA and a volume of the tested tire connector of $Q = 112\ 10^3\ cm^3$ had a coefficient of $c_{st} = 17.7$ Nm/° (which is three times lower than that of the spider type coupling). The analysis of these characteristics also shows that the hardest characteristics are couplings with the largest volume of the flexible element, while the characteristics of high compliance have tire-type couplings made of an elastomer with a hardness of 60 ShoreA and 65 ShoreA (Tab. 1).

These coefficients value increase more quickly when the volume of the tire connector used is raised, than its hardness increases (Fig. 7) [25]. Fig. 8 compares all the obtained mechanical load characteristics of the tested spider-type coupling in the temperature range of -10 to 60 ºC. Specifically, this figure shows the influence of temperature on these characteristics.

Changes in characteristics depending on temperature variation (in the flexible coupling type in the range of -10 to 60 °C are shown in Fig. 8b. The presentation of all the load characteristics of a given coupling in one diagram revealed that in all the tested couplings, the torsional angle of increasing coupling increased with the temperature for the same loading moment. In turn, the stiffness coefficient decreased. Fig. 8a shows the change in the stiffness coefficient for the flexible spider-type couplings as the working torque increased from 20 Nm to 200 Nm. Based on the characteristics presented, the coefficient of change in the stiffness coefficient is based on these characteristics (Fig. 9). It can be seen that changes in the operating temperature of the flexible couplings changes during the operation of the drive system were accompanied by a visible change in its operating parameters, which very often leads to changes in the dynamic properties of the entire drive system.

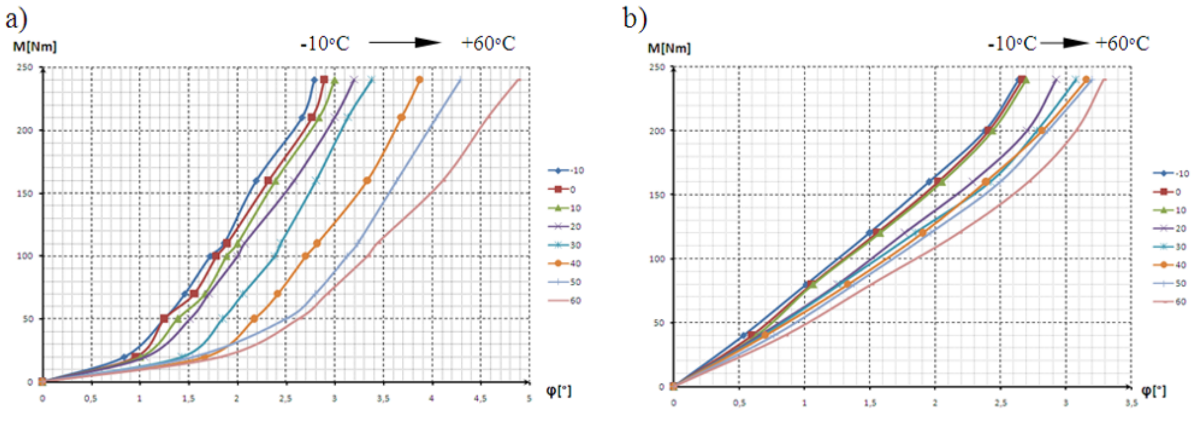

Fig. 8. Changes in the characteristics of the a) spider-type and b) tire-type couplings

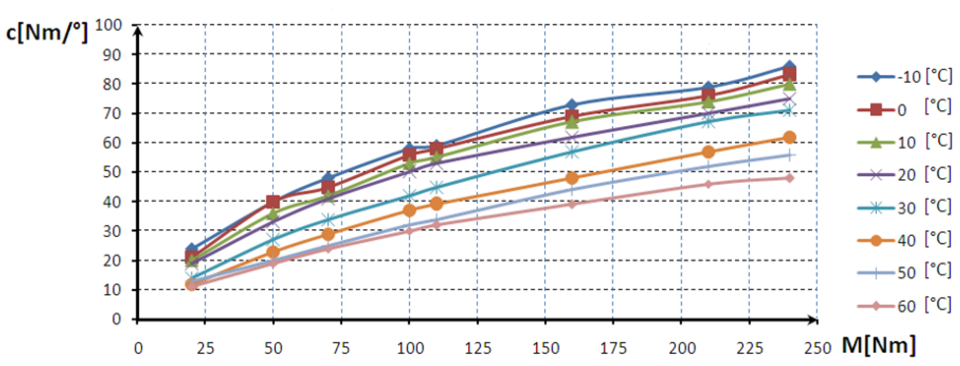

Fig. 9. Graphs showing the course of the stiffness coefficients in the spider-type coupling in the temperature range of -10 to 60 °C

Fig. 10 presents the change in the stiffness coefficient for the flexible tire-type coupling. An analysis of this diagram indicated that the temperature change also clearly influences the change in this coefficient. As a result, changes in temperature lead to significant changes in this coefficient (though to a lesser extent than in the case of spider-type couplings with a spider connector).

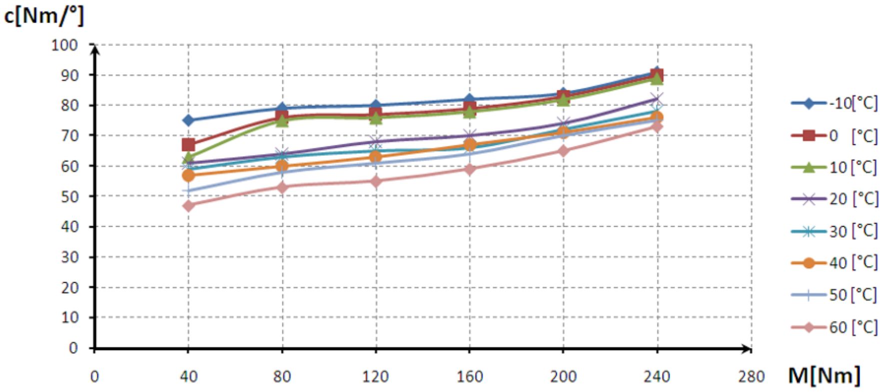

Fig. 10. The course of changes in the stiffness coefficients *c* for the tire type coupling in the temperature range of -10 to 60 °C

3. CONCLUSIONS

In the case of the tested flexible couplings, the stiffness and damping coefficients play an important role, and their values change. In the tests of flexible tire- and spider-type couplings, the external temperature played a role in the stiffness characteristics, thus influencing the increased heating of the flexible element. Analysis showed that in the case of the flexible spider-type coupling, the elastomer stiffness decreased by 35% at the operating temperature of 60 °C compared to the elastomer stiffness at 20 °C. For flexible coupling, the stiffness at -10 °C increased by 10% in relation to stiffness at 20 °C. Meanwhile, at a temperature of 60 °C, its stiffness decreased by 10% compared to its stiffness at 20 °C. The stiffness characteristics of tire-type flexible elastomeric couplings were less sensitive to temperature changes than those of flexible spider-type elastomeric couplings.

The volume of the elastomer used to build the joint clearly influenced the value of the stiffness coefficients. It is possible to adjust the stiffness coefficients for flexible couplings. The volume of the elastomer used is adjusted in relation to the hardness of the elastomer used, but tests should be performed in the selected operating temperature ranges. This is a significant problem for the flexible couplings selected on strength calculations. Further research in this direction is required.

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Received 24.06.2021; accepted in revised form 02.12.2022