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DIRECTIONS OF DEVELOPING DESIGN SCHEMES AND CALCULATIONS OF ELASTIC COUPLINGS

Petro KORUNIAK, Candidate of Technical Sciences, Associate Professor
Stepan Gzhytskyi National University of Veterinary Medicine and Biotechnologies of Lviv
Iryna NISHCHENKO, Candidate of Physics and Mathematics Sciences, Associate Professor
National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”
Oleksii SHVETS, Candidate of Technical Sciences, Associate Professor
Serhiy BEREZOVETSKYI, Candidate of Technical Sciences, Associate Professor
Stepan Gzhytskyi National University of Veterinary Medicine and Biotechnologies of Lviv

КОРУНЯК Петро Степанович, к.т.н., доцент
Львівський національний університет ветеринарної медицини та біотехнологій ім. С.З. Гжицького
НІЩЕНКО Ірина Іванівна, к.ф-м.н., доцент
Національний технічний університет України "Київський політехнічний інститут імені Ігоря Сікорського"
ШВЕЦЬ Олексій Петрович, к.т.н., доцент
БЕРЕЗОВЕЦЬКИЙ Сергій Андрійович, к.т.н., доцент
Львівський національний університет ветеринарної медицини та біотехнологій ім. С.З. Гжицького

A large number of elastic couplings are used in mechanical engineering. Couplings with metal elastic elements come with constant and variable stiffness. As part of drives, they can play the role of safety devices in which the elastic element, which is designed to transmit a certain torque, is destroyed during overloads. The development of the design of a safety-compensating coupling and the method for calculating its parameters will make it possible to determine permissible dynamic loads at the design stage.

Purpose is to develop a design scheme of a coupling with an elastic metal element with compensation and safety functions and a method for calculating its parameters, which ensures reliable operation without destruction of the elastic element during overload.

Using well-known analytical methods for solving statically indeterminate equations, for given structural parameters of the elastic element, dependencies are proposed for determining dynamic loads in straight sections of the spring and possible displacement of the support element. Based on the analysis of literary sources and patent search, variants of design solutions for elastic couplings are proposed. The elastic element of the device is proposed in the form of a closed star-shaped flat spring tangent to the half couplings with its protrusions. New mathematical dependences are obtained for determining dynamic loads in elastic metal elements of safety-compensating couplings. For the adopted coupling sizes, graphical dependences of dynamic loads on the design parameters of the elastic element of the coupling are determined and constructed.

The design of the proposed elastic coupling is simple, technologically feasible, and reliable in operation; it can be effectively used in the design of low- and medium-power drives for various mechanisms and machines, ensuring compensation of misalignments, reduction of dynamic loads, and protection of drive components from overload-induced damage while maintaining stable torque transmission.

Key words: *design, coupling, spring element, torque, stress, diagram, deformation, reaction, dynamic loads.*
Eq. 12. Fig. 12. Table. 1. Ref. 16.

1. Problem formulation

The main purpose of couplings is to transfer rotational motion and torque from one shaft of the mechanism to another. However, along with the kinematic and power connection of individual parts of the machine, couplings also perform such functions as compensation for shaft misalignment, damping during operation of vibrations, shocks and impacts, preventing overloads and quick disconnection of machine elements, etc.

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The variety of engineering and technical problems that have to be solved in mechanical engineering and other industries requires the use of not only standard couplings, but also the development of new multifunctional devices.

2. Analysis of recent research and publications

Elastic couplings have become widespread in engineering. As the name suggests, a characteristic element of these couplings is a link, the feature of which is deformation. Due to this, they soften (dampen) shocks, shocks and vibrations, allow angular relative rotation, which contributes to the smooth operation of the machine and prevents the appearance of resonant torsional vibrations. In addition, this type of coupling does not require precise alignment of the connected shafts [2].

A large number of elastic couplings of various designs are used in mechanical engineering. According to the material of the elastic elements, these couplings are divided into two groups: couplings with metal and non-metallic elastic elements. In turn, the former, depending on their characteristics, come with constant and variable stiffness [1, 4, 5, 6, 9, 11, 14, 16].

In general, the stiffness of the springs C is defined as:

$$C = \frac{dM}{d\varphi}, \tag{1}$$

where M – torque; φ – relative angle of rotation of the coupling halves.

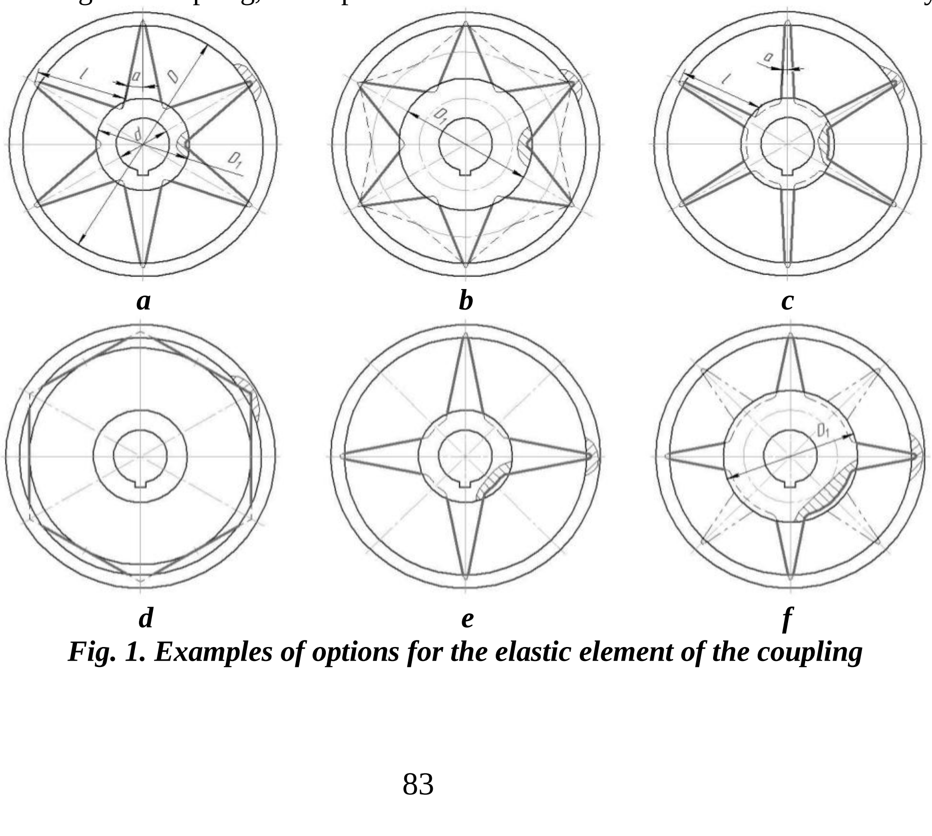
Along with the listed features, these couplings can play the role of safety devices, in which the elastic element, which is designed to transmit a certain torque, collapses during overloads in most designs.

3. The purpose of the article

The purpose of these studies is to develop a design scheme and study a coupling with an elastic metal element with compensation and safety functions without destroying the latter during overload.

4. Results and discussion

Analyzing the known designs and operation of elastic couplings with metal elements, it was found that it can be located on the cylindrical surface of the device or in a plane perpendicular to the axis of rotation. In the development of the latest design schemes of couplings, several variants of their execution have been developed [8]. The closed-type elastic element is made star-shaped from an elastic metal strip of a certain width and thickness. Its design parameters will be determined by the dimensions of the half-couplings (D, D_1), number of vertices (n) this star and material. Such couplings are designed to transmit small torques and depending on the fastening of this spring, it can perform the functions of an elastic or elastic-safety coupling



a ***b*** ***c***

d ***e*** ***f***

Fig. 1. Examples of options for the elastic element of the coupling

Fig. 2 shows the structural diagram of such a coupling. Let us consider the operation of one of the teeth (arches) of the elastic n – star coupling [7, 12]. It consists of two symmetrically arranged rectilinear elements with a length of L, which form angles α with the axis of symmetry (Fig. 3). The lower ends of these elements are rigidly clamped, and the upper ones are connected by an arc of a circle of radius r. A force acts on the upper supporting end of one of the rectilinear elements F perpendicular to this element, which can be determined by the formula:

$$F = \frac{2M}{dn}, \tag{2}$$

where M – the torque transmitted by the clutch; d – coupling diameter; n – the number of teeth (protrusions) of the elastic element.

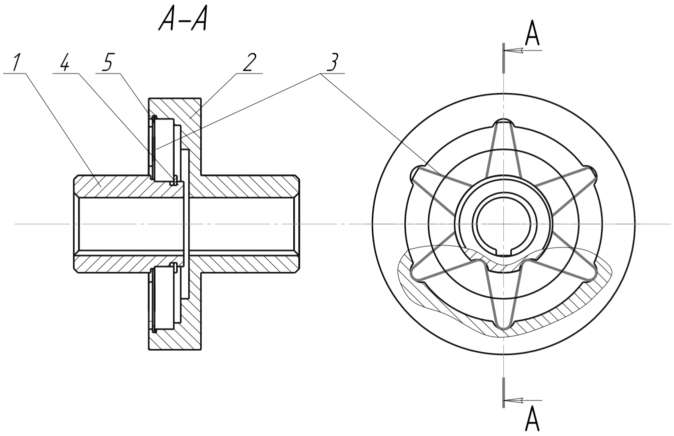


Fig. 2. Structural diagram of a coupling with a star-shaped flat spring: 1, 2 – coupling halves; 3 – elastic element; 4, 5 – retaining rings

For the geometrically correct shape of the elastic element of the proposed coupling design, the following equalities can be written:

$$\frac{D_1}{2}\sin\left(\frac{\pi}{n}\right) = L\sin(\alpha) + r\cos(\alpha);$$
$$\frac{D}{2} = \frac{D_1}{2}\cos\left(\frac{\pi}{n}\right) + L\cos(\alpha) + r - r\sin(\alpha), \tag{3}$$

where D, D_1 – outer and inner diameters of the coupling.

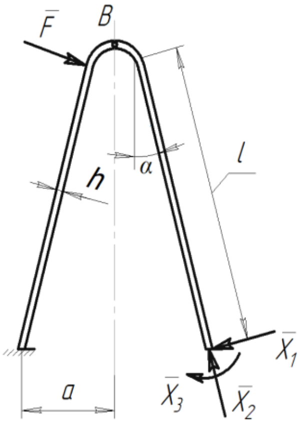


Fig. 3. Calculation diagram of an elastic element

From these relations (3) we find the angle of inclination α and the length L of the straight section of the elastic element:

$$\alpha = \arcsin\left(\frac{D_1}{2k}\sin\left(\frac{\pi}{n}\right)\right) - \arcsin\left(\frac{r}{k}\right);$$
$$L = \left(\frac{D_1}{2}\sin\left(\frac{\pi}{n}\right) - r\cos(\alpha)\right) / \sin(\alpha), \tag{4}$$

where $k = \sqrt{\left(\frac{D_1}{2}\sin\left(\frac{\pi}{n}\right)\right)^2 + \left(\frac{D}{2} - \frac{D_1}{2}\cos\left(\frac{\pi}{n}\right) - r\right)^2}$

The system of equations is three times statically indeterminate [10, 13, 16]. We choose the main system by discarding one of the supports of this straight section of the spring, and replacing its action by two mutually perpendicular forces X_1, X_2 directed along it and the reference moment X_3.

According to the method of forces, unknown forces are determined from a system of linear algebraic equations:

$$\sum_{j=1}^{3} \delta_{ij} X_j + \Delta_{iF} = 0, \quad . \tag{5}$$

We assign a single value to each unknown in turn and construct bending moment diagrams. M_1, M_2, M_3 from these efforts, as well as a diagram of bending moments from a given load (force F).

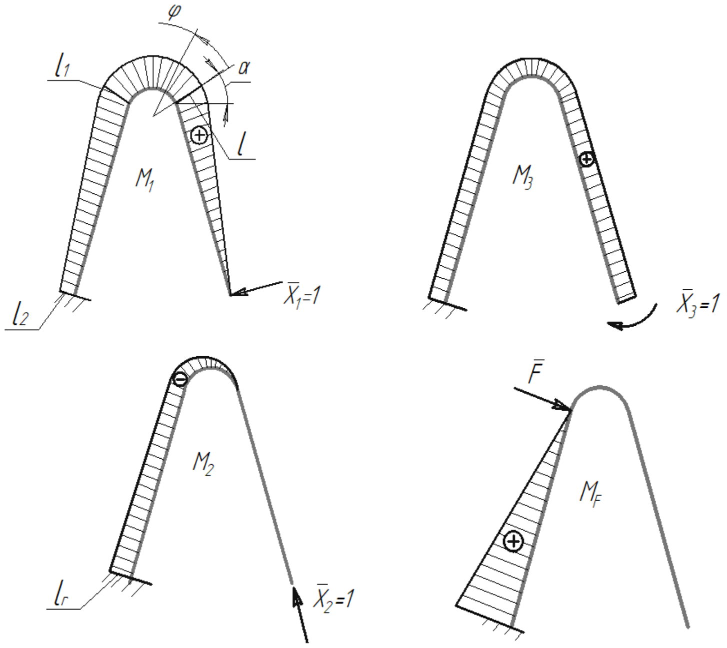


Fig. 4. Bending moment diagrams from unit forces X_1 =1; X_2 =1; X_3 =1 and F from a given external load

Using Mohr's integral and Vereshchagin's method [3, 7] of multiplying graphs, we obtain analytical expressions by which we can calculate the values of the coefficients δ_{ij} and free members Δ_{iF} :

$$\delta_{11} = \frac{1}{EI}\left(\frac{L}{3}(L^2 + a_1^2 + a_2^2 + a_1 a_2) + L^2 r_1 + 2Lrr_2 + \frac{r^2 r_1}{2} + \frac{r^3 \sin(4\alpha)}{4}\right);$$

$$\delta_{22} = \frac{1}{EI}\left(\frac{L}{3}(b_1^2 + b_2^2 + b_1 b_2) + r^2(r_1 - 2r_3 + \frac{r_1}{2} - \frac{r\sin(4\alpha)}{4})\right); \quad \delta_{33} = \frac{1}{EI}\left(2L + r_1\right);$$

$$\delta_{12} = \delta_{21} = \frac{1}{EI}\left(\frac{L}{6}(a_1 b_1 + a_2 b_2 + (a_1 + a_2)(b_1 + b_2)) - (Lrr_1 + r^2 r_2 - \frac{rr_3^2}{2} - Lrr_3\right);$$

$$\delta_{13} = \delta_{31} = \frac{1}{EI}\left(\frac{L}{2}(L + a_1 + a_2) + Lr_1 + rr_2\right);$$

$$\delta_{23} = \delta_{32} = \frac{1}{EI}\left(\frac{L}{2}(b_1 + b_2) - rr_1 + rr_3\right);$$

$$\Delta_{1F} = \frac{FL^2}{6EI}(a_1 + 2a_2); \quad \Delta_{2F} = \frac{FL^2}{6EI}(b_1 + 2b_2); \quad \Delta_{3F} = \frac{FL^2}{2EI}, \tag{6}$$

where E – Young's modulus; $I = \frac{bh^3}{12}$ – moment of inertia of the cross section.

$$r_1 = r(\pi - 2\alpha); \quad r_2 = r(1 + cos(2\alpha)); \quad r_3 = r\sin(2\alpha);$$

$$a_1 = L + r_3; \quad a_2 = a_1 - L\cos(2\alpha); \quad b_1 = -r_2;$$

Substituting into the system of equations (5) the obtained values δ_{ij}, Δ_{iF}, we find reactions X_1, X_2, X_3, which, as a multiplier, includes the force F.

Bending moments in an arbitrary cross-section are determined by the formula:

$$M = M_F + M_1 X_1 + M_2 X_2 + M_3 X_3, \tag{7}$$

and longitudinal forces

$$N_1 = -X_2; \quad N_2 = X_2\cos(2\alpha) - X_1\sin(2\alpha). \tag{8}$$

The permissible value of the force F is found from the condition of strength of straight sections:

$$\frac{|N|}{bh}+\frac{6|M|}{bh^2}\le[\sigma]. \tag{9}$$

and for a curved section according to the formula:

$$\sigma_{\max}=\frac{\mathrm{N}}{A}+\frac{M}{A(r-r_0)}\cdot\frac{r-r_0-\frac{h}{2}}{r-\frac{h}{2}}, \tag{10}$$

where $A=bh-$ cross-sectional area of the arch; $W=\dfrac{bh^2}{6}$ – axial moment of inertia; $r_0=\dfrac{h}{\ln\left[\left(r+h/2\right)/\left(r-h/2\right)\right]}$ radius of curvature of the neutral layer during pure bending of the curved beam.

The maximum moment that the coupling can transmit is calculated by the formula:

$$M_{\max}=n(F\cos\alpha(D/2-r+r\sin\alpha)-Fr\sin\alpha\cos\alpha). \tag{11}$$

Let's find the displacement Δ the point of application of force F in the direction perpendicular to the axis of symmetry. To do this, you need to apply a unit force in this direction, construct a bending moment diagram from its action, which is then multiplied by the total bending moment diagram of the arch, i.e.

$$\Delta=\frac{L^2 cos\alpha}{6EI}(2(LF+a_2X_1+b_2X_2)+X_3+a_1X_1+b_1X_2). \tag{12}$$

The calculations were performed with the following geometric and physical parameter values: D = 0,12 m, D_1 = 0,06 m, r = 0,05D_1, b = 0,012 m, h = 0,0025 m, [σ] = 160 MPa; E = 2 10^5 MPa.

For example, consider a coupling consisting of three elastic elements (n = 3). First, using formulas (4), we determine the angle of inclination of the straight sections of the elastic element to its axis of symmetry α = 28,2579°,and then the length of these sections L = 49,3 mm. Further, after calculating the coefficients δ_{ij} and free members Δ_{iF} according to formulas (6), we solve the system of linear algebraic equations and find (in fractions of the force F) the values of the reaction components in rigid clamping X_1 = -0,6186F; X_2 = 1,2788F and the value of the reference moment X_3 = 0,0239F. Longitudinal forces and bending moments are calculated using formulas (7). Then, the maximum absolute values of these internal force factors are substituted into the strength condition (8) and the permissible value of the force is found F = 285,7689 H. The maximum torque that this elastic coupling can transmit is calculated by the formula (11) $M_{\max}$ = 43,0428 Nm.

A similar calculation is performed if the coupling contains a different number of elastic elements (n = *4, 5, 6, 8*). The results of these calculations are given in Table 1.

Table. 1

Results of calculation of coupling parameters

N	α^o	*L(мм)*	X_1	X_2	X_3	*F(H)*	M_{max}*(Нм)*
4	26,523	41,5	-0,559F	1,2773F	0,0185F	312,34	63,718
5	23,686	37,1	-0,467F	1,3033F	0,0141F	372,41	97,20
6	20,812	34,3	-0,375F	1,3410F	0,0108F	457,36	146,21
8	15,934	31,3	-0,230F	1,4341F	0,0067F	528,40	231,69

Next, we present the results of the research for the adopted coupling dimensions presented in the form of graphical dependences of dynamic loads on the design parameters of the elastic element.

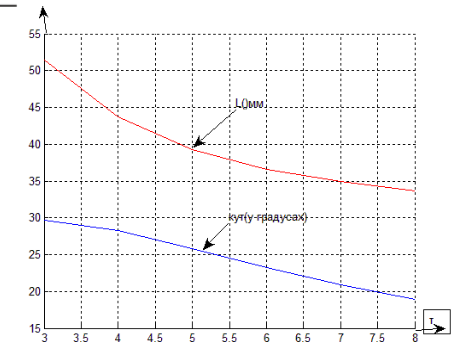


Fig. 5. Change in the length L and the angle of inclination α of the wall of the elastic element of the coupling depending on the number of elastic elements (n = 3, 4…8)

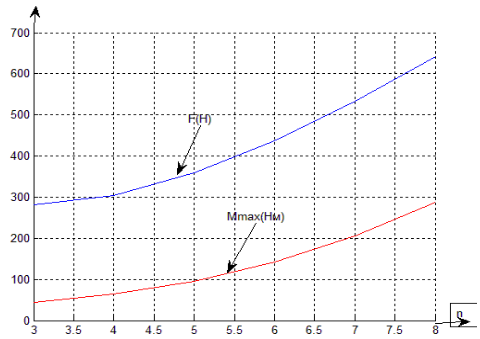


Fig. 6. Maximum value of force F and moment M_{max} with different numbers of elastic elements

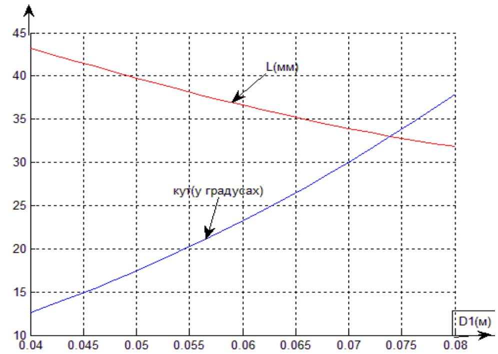


Fig. 7. Change in the length L and the angle of inclination α of the wall of the elastic element of the coupling depending on the diameter D_1 (n = 6)

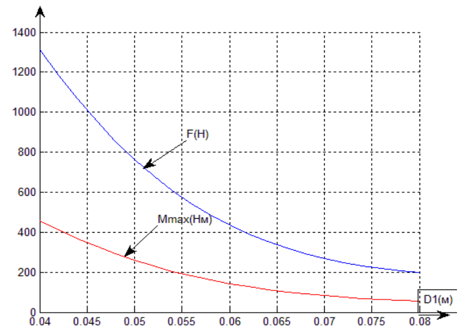


Fig. 8. Maximum value of force F and moment M_{max} depending on the diameter D_1 (n = 6)

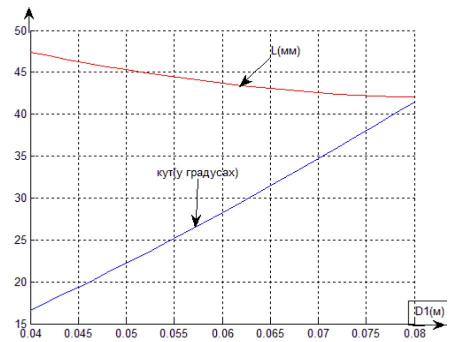


Fig. 9. Change in the length L and the angle of inclination α of the wall of the elastic element of the coupling depending on the diameter D_1 (n = 4)

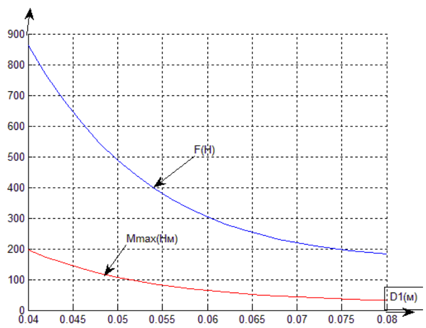


Fig. 10. Maximum value of force F and moment M_{max} depending on the diameter D_1 (n = 4)

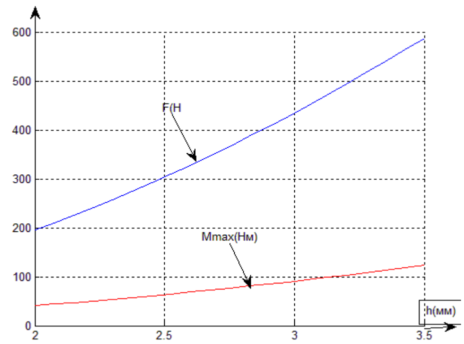


Fig. 11. Influence of the thickness h of the walls of elastic elements on the maximum values of force factors (n = 4)

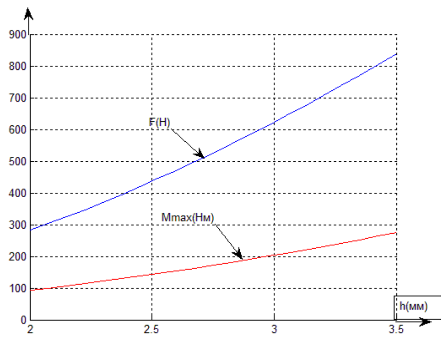


Fig. 12. Influence of the thickness h of the walls of elastic elements on the maximum values of force factors (n = 6)

From the obtained dependences it is clear that ensuring the maximum power parameters of the coupling operation requires an increase in the number of elastic elements or their sizes, in particular thickness.

5. Conclusion

The use of this calculation method makes it possible to determine the maximum stresses in the elements of a star-shaped spring and its design parameters. The developed design of an elastic coupling is distinguished by its simplicity, manufacturability, reliability of operation and can be used in the design of drives for mechanisms and machines of small power.

The first studies of the proposed design scheme of the coupling showed that the design parameters of the coupling halves, the shape and design parameters of the elastic element and their number significantly affect its technical characteristics. With an increase in the number of working areas (teeth) in the elastic element (star), as well as its dimensions (b, h), without changing the material, contribute to the growth of the transmission power factors.

During design, it should be remembered that with a decrease in the ratio of the diameters of the coupling halves, the maximum values of the force and torque that the coupling can transmit sharply decrease. The final design solution should be based on specific technical tasks.

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ШЛЯХИ РОЗВИТКУ КОНСТРУКТИВНИХ СХЕМ ТА РОЗРАХУНОК ПРУЖНИХ МУФТ

В машинобудуванні використовується велика кількість пружних муфт. Муфти з металевими пружними елементами бувають з постійною і змінною жорсткістю. У складі приводів вони можуть відігравати роль запобіжних пристроїв, у яких пружний елемент, який розрахований на передачу певного *крутного моменту, під час перевантажень руйнується. Розробка конструкції запобіжно-компенсуючої муфти та методики розрахунку її параметрів дасть можливість визначати допустимі динамічні навантаження на етапі проектування.*

Мета роботи полягає у розробці конструктивної схеми муфти з пружним металевим елементом з компенсаційними і запобіжними функціями та методики розрахунку її параметрів, за яких забезпечується надійна робота без руйнування пружного елемента під час перевантаження.

Використовуючи загальновідомі аналітичні методи розв'язку статично невизначених рівнянь, для заданих конструктивних параметрів пружного елементу запропоновані залежності для визначення динамічних навантажень у прямолінійних ділянках пружини та можливе переміщення опорної частини. На підставі проведеного аналізу літературних джерел та патентного пошуку запропоновані варіанти конструктивних рішень пружних муфт. Пружний елемент пристрою виконано у вигляді замкнутої зіркоподібної плоскої пружини дотичної до півмуфт своїми виступами. Отримані нові математичні залежності для визначення динамічних навантажень в пружних металевих елементах запобіжно-компенсаційних муфт. Для прийнятих розмірів муфти визначені та побудовані графічні залежності динамічних навантажень від конструктивних параметрів пружного елементу муфти.

Конструкція запропонованої пружної муфти є простою, технологічно доцільною та надійною в експлуатації; вона може бути ефективно використана при проектуванні приводів малої та середньої потужності для різних механізмів та машин, забезпечуючи компенсацію перекосів, зменшення динамічних навантажень та захист компонентів приводу від пошкоджень, спричинених перевантаженням, при цьому зберігаючи стабільну передачу крутного моменту.

***Ключові слова**: муфта, пружинний елемент, крутний момент, напруження, деформація, реакція, динамічні навантаження.*

Ф. 12. Рис. 12. Табл. 1. Літ. 16.

INFORMATION ABOUT THE AUTHORS

Petro KORUNIAK – Candidate of Technical Sciences, Associate Professor of the Department of Mechanical Engineering of the Stepan Gzhytskyi National University of Veterinary Medicine and Biotechnologies of Lviv (1 V. Velykoho Street, Dublyany, Lviv District, Lviv Region, Ukraine, 80381, e-mail: petrokoruniak@gmail.com, https://orcid.org/0000-0002-2370-6351).

Iryna NISHCHENKO – Candidate of Physics and Mathematics Sciences, Associate Professor of the Department of Mathematical Methods of Information Protection of the National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute" (37, Prospect Beresteiskyi, Solomyanskyi district, Kyiv, Ukraine, 03056, e-mail: nishchenkoii-ipt@lll.kpi.ua, https://orcid.org/0000-0001-7373-2286).

Oleksii SHVETS – Candidate of Technical Sciences, Associate Professor of the Department of Mechanical Engineering of the Stepan Gzhytskyi National University of Veterinary Medicine and Biotechnologies of Lviv (1 V. Velykoho Street, Dublyany, Lviv District, Lviv Region, Ukraine, 80381, e-mail: shvets2882@gmail.com., https://orcid.org/0000-0002-8988-9410).

Serhiy BEREZOVETSKYI – Candidate of Technical Sciences, Associate Professor of the Department of Mechanical Engineering of the Stepan Gzhytskyi National University of Veterinary Medicine and Biotechnologies of Lviv (1 V. Velykoho Street, Dublyany, Lviv District, Lviv Region, Ukraine, 80381, e-mail: siko@email.ua, https://orcid.org/0000-0001-6011-3726).

КОРУНЯК Петро Степанович – кандидат технічних наук, доцент кафедри машинобудування Львівський національний університет ветеринарної медицини та біотехнологій ім. С.З. Гжицького (вул. В. Великого 1, м. Дубляни, Львівський р-н, Львівська обл. Україна, 80381, e-mail: petrokoruniak@gmail.com, https://orcid.org/0000-0002-2370-6351).

НІЩЕНКО Ірина Іванівна – кандидат фізико-математичних наук, доцент кафедри математичних методів захисту інформації Національного технічного університету України "Київський політехнічний інститут імені Ігоря Сікорського", (Берестейський проспект 37, м. Київ, Солом'янський р-н, Україна, 03056, e-mail: nishchenkoii-ipt@lll.kpi.ua, https://orcid.org/0000-0001-7373-2286).

ШВЕЦЬ Олексій Петрович – кандидат технічних наук, доцент кафедри машинобудування Львівський національний університет ветеринарної медицини та біотехнологій ім. С.З. Гжицького (вул. В. Великого 1, м. Дубляни, Львівський р-н, Львівська обл. Україна, 80381, e-mail: shvets2882@gmail.com, https://orcid.org/0000-0002-8988-9410).

БЕРЕЗОВЕЦЬКИЙ Сергій Андрійович – кандидат технічних наук, доцент кафедри машинобудування Львівський національний університет ветеринарної медицини та біотехнологій ім. С.З. Гжицького (вул. В. Великого 1, м. Дубляни, Львівський р-н, Львівська обл. Україна, 80381, e-mail: siko@email.ua., https://orcid.org/0000-0001-6011-3726).