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CONCEPTUAL PRINCIPLES OF DESIGN PROCEDURE LONGITUDINAL – COMPRESSION ROD ELASTIC ELEMENTS OF THE TRANSMISSION MECHANISM STOP VALVES DEVICES

Conceptual principles of design procedure longitudinally compression rod elastic elements of the transmission mechanism stop valves devices. Showing its application for design longitudinally compressed elastic rod elements stop valves devices.

Keywords: rod, longitudinally-compressed rod, elastic element, stop valves devices.

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КОНЦЕПТУАЛЬНІ ЗАСАДИ МЕТОДИКИ РОЗРАХУНКУ ПОЗДОВЖНЬО СТИСНУТИХ СТРИЖНЕВИХ ПРУЖНИХ ЕЛЕМЕНТІВ КЛАПАННИХ ЗАПІРНИХ ПРИСТРОЇВ

Розглянуто концептуальні засади методики розрахунку поздовжньо-стиснутих стрижневих пружних елементів запірних пристроїв. Показано застосування методики для розрахунку поздовжньо-стиснутих стрижневих пружних елементів запірних пристроїв.

Ключові слова: стрижень, поздовжньо-стиснутий стрижень, пружний елемент, запірний пристрій.

Formulation of the problem. The functioning of technological processes production and operation of machinery with the required quality at a given intensity imposes high conditions to the capacity for work and durability to stop valves devices hydraulic and pneumatic control systems during established period accident-free operation. Traditionally, these devices include: the basic node of saddle – valve, the working chamber of the injection, deferent and drainage pipelines, engine, transmission element – rod and guides. Rod and guides form the pair friction with a guaranteed working gap. At flow control with low and ultra low temperatures stop valves devices with the pair friction characterized by unstable functioning. Reason behind this is freezing rod in guides. Improving the reliability of the stop valves devices in this case, achieved by eliminating pair friction – rod and guides, and placement engine in a warm zone with significantly higher temperatures. For this in stop valves devices is proposed to use transmission mechanism consisting of elastic, long rods with sliding hinge supports. Force of engine moves sliding hinge supports along the axis of rods. Rods become deformed in the direction of perpendicularly to the axis. Valve moves to the saddle and stoping the flow of working environment and provides hermetic sealing of joint saddle and valve. Formation conceptual principles of design procedure longitudinal compression rod elastic elements of the transmission mechanism stop valves devices is a prerequisite for calculation and design this devices.

Analysis of previous studies. With sufficient completeness conceptual principles and nonlinear statics of the thin elastic rod is represented in a monograph [1]. The design scheme and the method of calculating engine stop valves devices for cryogenic temperatures are presented in the article [2]. In the article [3] are presented the method of calculating the thin elastic rod vibration engine. Studies in these monograph and articles is a necessary base of studies presented in this article.

The purpose of the work. The purpose of this work is rectification conceptual principles of design procedure longitudinal-compression rod elastic elements stop valves devices is a prerequisite for calculation and design this devices.

Main studies. Calculation of longitudinal-compression rod elastic elements of the transmission mechanism stop valves devices is the appointment of geometric dimensions of the rod out the conditions necessary to ensure progress and efforts sealing valve while ensuring terms of strength. Design schem of the transmission mechanism performed on the basis of longitudinal-compression elastic rods is presented at Fig. 1. The valve is installed in the middle section of the rod through the constraint type spherical hinge (at fig.1 is not shown). The most complete requirements to ensure the necessary effort in tandem sealing valve-seat performance meets this constraint with "hard" elastomers. Calculation of the geometric dimensions of the rod to provide the necessary progress valve drive without the efforts of the valve assuming that: – in each time the rod is in static equilibrium; – mass of rod is ignored; – rod material is in the range of elasticity; – flexural stiffness of the rod began in length; – action line drive force remains constant during the deformation of the rod and passes through the centers of end sections of the rod; – deformation curvature center line of the rod of one order of its length; – rod symmetric.

Large elastic bending of rod is the cause of its calculation through accurate solution of equilibrium equation of elastic rod line [1]:

$$k - k_0 = \frac{M}{H}, \tag{1}$$

where M – bending moment in the cross section of the rod; κ and κ_0 – curvature elastic-curved longitudinal axis of the rod and its original outline; $H = E \cdot J$ – bending stiffness of the rod; E – Young's modulus; J – axial moment of inertia of the cross-sectional area. Conceptually study the elastic bending rod for large movements related to the main class of problems of nonlinear statics of thin rods [1]. Schemes deformation of the rod (Fig. 1) differ only in terms of securing the ends of the rod. For the same coordinate system scheme (a, b) and (c, d) are calculated similarly. For fixing the hinge rod end (schem a, b at Fig. 1) boundary conditions: $M_{0'} = 0$, $k_0 = -{}^1\!/_{R_0}$. To fixing console (schem c, d at Fig.1): $x_{0'} = {}^p\!/_2$, where $x_{0'}$ - the angle of the tangent at O to the axis x¢; R_0 – initial curvature radius rod. Studies carried out in all cases for half a rod. Addresses three forms of balance rod: without inflection (characterized by lack of inflection point on an elastic line), the first two forms of an inflection (one point of inflection in the conditional extension of the elastic line or the last), because the other forms of balance no practical value for the transmission mechanisms.

For the circuit in Fig. 1 (a), (b) because the solution of equations of type (1) analytical dependence for the form axis, coordinate its middle and stresses in the rod sections. For without inflection form:

$$\begin{cases} x_1' = \dfrac{l}{k \cdot b} \cdot E\left(\arcsin\sqrt{\dfrac{1}{k^2} - \dfrac{H}{4 \cdot R_0^{\,2} \cdot P_{np}}},\ k\right) - \left(\dfrac{2}{k^2} - 1\right) \cdot \dfrac{l}{2}; \\ y_1' = \dfrac{l}{k \cdot b}\left(1 - \sqrt{\dfrac{H \cdot k^2}{2 \cdot R_0 \cdot P_{np}}}\right); \\ s_{\max} = \left|\dfrac{p}{2} - \dfrac{2 \cdot b}{k}\right| \cdot \dfrac{E \cdot h}{p \cdot R_0}, \end{cases} \tag{2}$$

where $l = p \cdot R_0$ - length of the rod, $b = \frac{l}{2} \cdot \sqrt{\frac{P_{np}}{H}}$ – force scaling factor, k — elastic line parameter, $b = k \cdot F\left(\arcsin\sqrt{\frac{1}{k^2} - \frac{H}{4 \cdot R_0^{\,2} \cdot P_{np}}}\right)$, *E(y,k), F(y,k)* — elliptic integrals of Legendre second and of the first kind respectively.

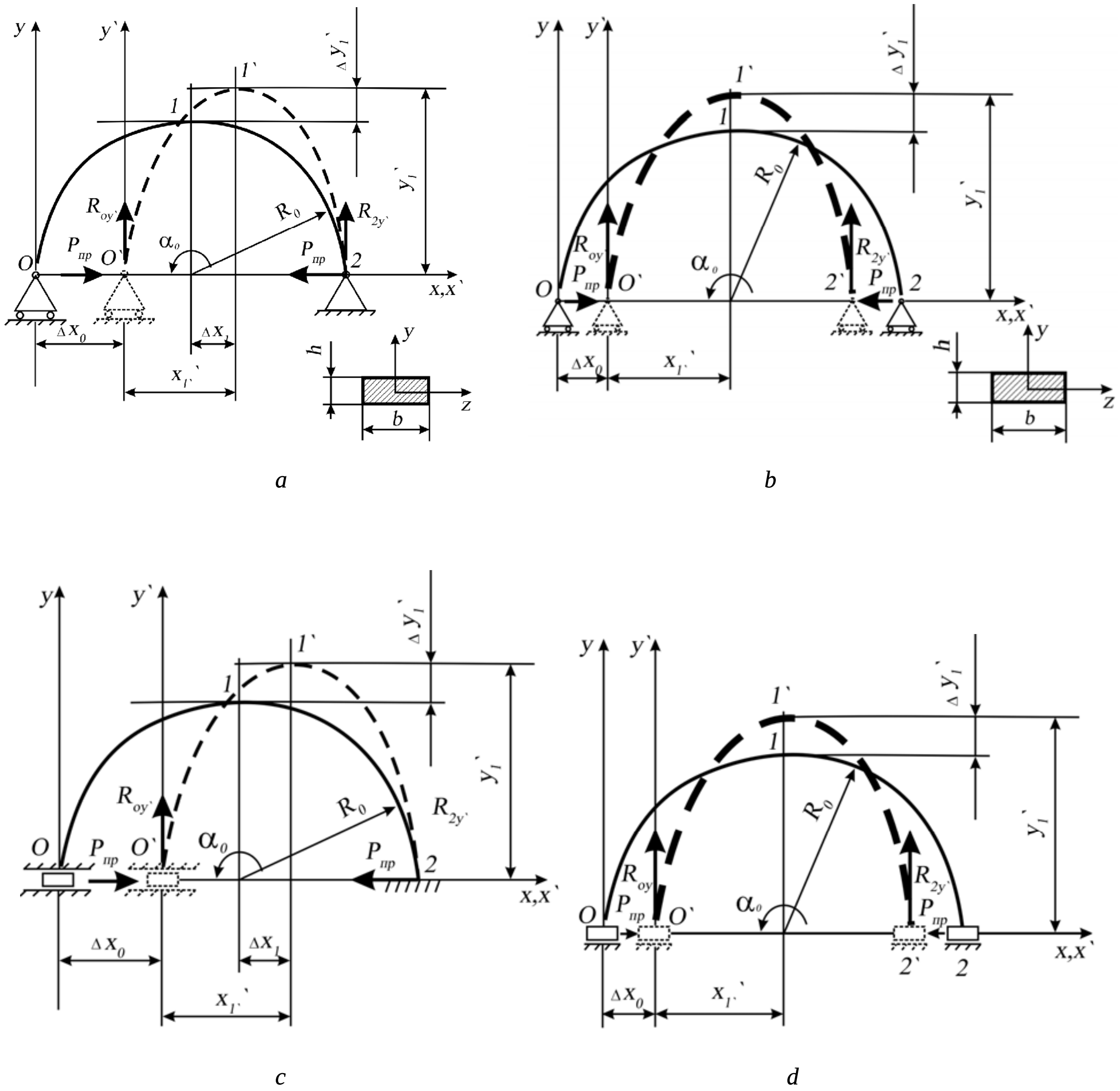

Fig. 1. Design schems of the transmission mechanism

For first inflection form

$$\begin{cases} x_1' = \dfrac{p \cdot R_0}{b} \cdot E\left(\arccos\left(\dfrac{p}{4 \cdot b \cdot k}\right), k\right) - \dfrac{p \cdot R_0}{2}; \\ y_1' = \dfrac{p \cdot R_0}{b}\left(k - \dfrac{p}{4 \cdot b}\right); \\ b = F\left(\arccos\left(\dfrac{p}{4 \cdot b \cdot k}\right), k\right); \\ s_{\max} = \left|\dfrac{p}{2} - 2 \cdot k \cdot b\right| \cdot \dfrac{E \cdot h}{p \cdot R_0}; \end{cases} \qquad (3)$$

For second inflection form

$$\begin{cases} x_1' = \dfrac{p \cdot R_0}{b} \cdot \left(2 \cdot E \cdot \left(\dfrac{p}{2}, k \right) + E\left(\arccos\left(\dfrac{p}{4 \cdot k \cdot b} \right), k \right) \right) - \dfrac{p \cdot R_0}{2}; \\ y_1' = \dfrac{p \cdot R_0 \cdot k}{b} \left(-\dfrac{p}{4 \cdot k \cdot b} - 1 \right); \\ b = 2 \cdot F\left(\dfrac{p}{2}, k \right) + F\left(\arccos\left(\dfrac{\sqrt{H}}{2 \cdot R_0 \cdot k \cdot \sqrt{P}} \right), k \right); \\ s_{\max} = \left| \dfrac{p}{2} + 2 \cdot k \cdot b \right| \cdot \dfrac{E \cdot h}{p \cdot R_0}; \end{cases} \quad (4)$$

In the case of fixing the ends rod Fig. 1 (c), (d) to coordinates and stresses in the cross sections of rod are determined by the formulas:

for without inflection form

$$\begin{cases} x_1' = \dfrac{p \cdot R_0}{2} \cdot \left(\dfrac{2}{k \cdot b} \cdot E\left(\dfrac{p}{4}, k \right) - \dfrac{2}{k^2} + 1 \right); \\ y_1' = \dfrac{p \cdot R_0}{k \cdot b} \left(1 - \sqrt{1 - \dfrac{k^2}{2}} \right); \\ b = k \cdot F\left(\dfrac{p}{4}, k \right); \\ s_{\max} = \left| \dfrac{p}{2} - \sqrt{2} \cdot k \cdot b \right| \cdot \dfrac{E \cdot h}{p \cdot R_0}; \end{cases} \quad (5)$$

for first inflection form

$$\begin{cases} x_1' = \dfrac{p \cdot R_0}{b} \cdot E\left(\arcsin\left(\dfrac{\sin(p/4)}{k} \right), k \right) - \dfrac{p \cdot R_0}{2}; \\ y_1' = \dfrac{p \cdot k \cdot R_0}{b} \left(1 - \cos\left(\arcsin\left(\dfrac{\sin(p/4)}{k} \right) \right) \right); \\ b = F\left(\arcsin\left(\dfrac{\sin(p/4)}{k} \right), k \right); \\ s_{\max} = \left| \dfrac{p}{2} - \dfrac{\sqrt{2} \cdot b}{k} \right| \cdot \dfrac{E \cdot h}{p \cdot R_0}; \end{cases} \quad (6)$$

for second inflection form

$$\begin{cases} x_1' = \dfrac{p \cdot R_0}{b} \cdot \left(2 \cdot E\left(\dfrac{p}{2}, k \right) - E\left(\arcsin\left(\dfrac{\sin(p/4)}{k} \right), k \right) \right) - \dfrac{p \cdot R_0}{2}; \\ y_1' = \dfrac{p \cdot R_0 \cdot k}{b} \left(\cos\left(\arcsin\left(\dfrac{\sin(p/4)}{k} \right) \right) + 1 \right); \\ b = 2 \cdot F\left(\dfrac{p}{2}, k \right) - F\left(\arcsin\left(\dfrac{\sin(p/4)}{k} \right), k \right); \\ s_{\max} = \left| b \cdot \cos\left(\dfrac{p}{4} \right) - \dfrac{p}{2} \right| \cdot \dfrac{E \cdot h}{p \cdot R_0}; \end{cases} \quad (7)$$

Forms of the rod defined by the minimum and maximum possible values force scaling factor b, specifying probable values k — elastic line parameter. Based on b determined form of the rod for a given load. Then to the equation between b and k (third order equation group equations (3)–(7)) iterative method is calculated parameter of elastic line, in which satisfied the equation for determining the coordinates of the middle of the rod and the maximum stresses in it.

Calculation of the geometric dimensions of the rod is carried out in two stages. The first stage – the preliminary calculation of the geometric dimensions of the rod. It consists in the selection of R_0, b and h, while ensuring the necessary moving of the middle part of the rod terms of strength. The second stage – final static calculation. On consideration of the force which is transmitted from the valve on the rod. Design schem shown in Fig. 2.

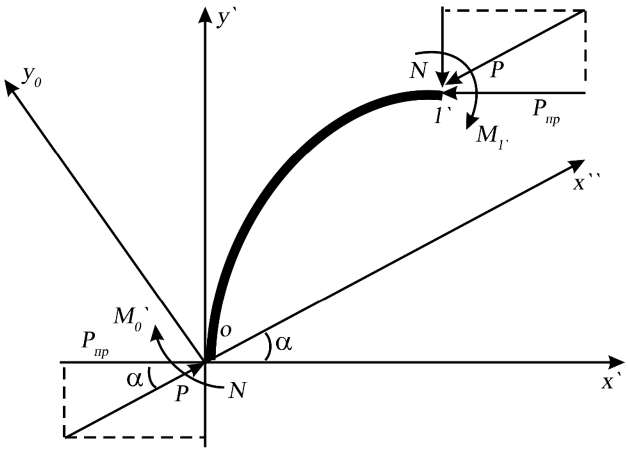

Fig. 2. Design schem deforming of the rod

Axis coordinates adopted as follows: top combined with extreme center-section rod; axis is directed along the line of action of the resultant force at the point of attachment of the rod, That is the addition of vectors efforts engine and reaction of constraint (in the support). The angle between the axes x' and x'' –

$a = arctg\left(\frac{N}{P_{ïð}}\right)$. Force 2N, which is passed from the valve to the rod has a constant direction and applied in the middle of the rod.

First stage. From equation (1) are depending, determining the position of the ends of the rod and . stresses in the cross sections of rod. For the circuit in Fig. 1 (a), (b):

for without inflection form

$$\begin{cases} x_1'' = \frac{l}{k \cdot b} \cdot \left(E\left(\frac{a}{2}, k\right) + E\left(\arcsin\sqrt{\frac{1}{k^2} - \frac{H}{4 \cdot P \cdot R_0^{\,2}}}, k\right)\right) - \frac{l}{2}\left(\frac{2}{k^2} - 1\right); \\ y_1' = \frac{l}{k \cdot b} \cdot \left(\sqrt{1 - k^2 \cdot \sin^2\left(\frac{a}{2}\right)} - \sqrt{\frac{H \cdot k^2}{4 \cdot P \cdot R_0^{\,2}}} \right); \\ b = k \cdot \left(F\left(\frac{a}{2}, k\right) + F\left(\arcsin\sqrt{\frac{1}{k^2} - \frac{H}{4 \cdot P \cdot R_0^{\,2}}}, k\right)\right); \\ s_{\max} = \left| \frac{p}{2} - \frac{2 \cdot b}{k}\sqrt{1 - k^2 \cdot \sin\left(\frac{a}{2}\right)} \right| \cdot \frac{E \cdot h}{p \cdot R_0}; \end{cases}$$

$$b = \frac{l}{2} \cdot \sqrt{\frac{P}{H}}, \; P = \sqrt{P_{np}^{\,2} + N^2} \;;$$

for first inflection form

$$\begin{cases} x_1'' = \dfrac{p \cdot R_0}{b} \cdot \left(E\left(\arcsin\left(\dfrac{\sin(p/2)}{k} \right), k \right) + E\left(\arccos\left(\dfrac{p}{4 \cdot b \cdot k} \right), k \right) \right) - \dfrac{p \cdot R_0}{2}; \\ y_1' = \dfrac{p \cdot R_0}{b} \cdot \left(\sqrt{k^2 - \sin^2\left(\dfrac{a}{2}\right)} - \dfrac{p}{4 \cdot b} \right); \\ b = F\left(\arcsin\left(\dfrac{\sin(p/2)}{k} \right), k \right) + F\left(\arccos\left(\dfrac{\sqrt{H}}{2 \cdot R_0 \cdot k \cdot \sqrt{P}} \right), k \right); \\ s_{\max} = \left| \dfrac{p}{2} - 2 \cdot k \cdot b \cdot \cos\left(\arcsin\left(\dfrac{\sin(p/2)}{k} \right) \right) \right| \cdot \dfrac{E \cdot h}{p \cdot R_0}; \end{cases}$$

for second inflection form

$$\begin{cases} x_1'' = \dfrac{p \cdot R_0}{b} \cdot \left(2 \cdot E\left(\dfrac{p}{2}, k \right) - E\left(\arcsin\left(\dfrac{\sin(a/2)}{k} \right), k \right) + E\left(\arccos\left(\dfrac{\sqrt{H}}{2 \cdot R_0 \cdot k \cdot \sqrt{P}} \right), k \right) \right) - \dfrac{p \cdot R_0}{2}; \\ y_1'' = \dfrac{p \cdot k \cdot R_0}{b} \cdot \left(-\dfrac{\sqrt{H}}{2 \cdot R_0 \cdot k \cdot \sqrt{P}} - \cos\left(\arcsin\left(\dfrac{\sin(a/2)}{k} \right) \right) \right); \\ b = 2 \cdot F\left(\dfrac{p}{2}, k \right) - F\left(\arcsin\left(\dfrac{\sin(a/2)}{k} \right), k \right) + F\left(\arccos\left(\dfrac{\sqrt{H}}{2 \cdot R_0 \cdot k \cdot \sqrt{P}} \right), k \right); \\ s_{\max} = \left| \dfrac{p}{2} - 2 \cdot k \cdot b \cdot \cos\left(\arcsin\left(\dfrac{\sin(a/2)}{k} \right) \right) \right| \cdot \dfrac{E \cdot h}{p \cdot R_0}. \end{cases}$$

For the circuit in Fig. 1 (c):

for without inflection form

$$\begin{cases} x_1'' = \dfrac{p \cdot R_0}{2} \cdot \left(\dfrac{2}{k \cdot b} \cdot \left(E\left(\dfrac{a}{2}, k \right) + E\left(\dfrac{p}{4} - \dfrac{a}{2}, k \right) \right) - \dfrac{2}{k^2} + 1 \right); \\ y_1'' = \dfrac{p \cdot R_0}{k \cdot b} \cdot \left(\sqrt{1 - k^2 \cdot \sin^2\left(\dfrac{a}{2} \right)} - \sqrt{1 - k^2 \cdot \sin^2\left(\dfrac{p}{4} - \dfrac{a}{2} \right)} \right); \\ b = k \cdot \left(F\left(\dfrac{a}{2}, k \right) + F\left(\left(\dfrac{p}{4} - \dfrac{a}{2} \right), k \right) \right); \\ s_{\max} = \left| \dfrac{p}{2} - 2 \cdot k \cdot b \cdot \cos\left(\dfrac{p}{4} - \dfrac{a}{2} \right) \right| \cdot \dfrac{E \cdot h}{p \cdot R_0}; \end{cases}$$

for first inflection form

$$\begin{cases} x_1'' = \dfrac{p \cdot R_0}{b} \cdot \left(E\left(\arcsin\left(\dfrac{\sin(a/2)}{k} \right), k \right) + E\left(\arcsin\left(\dfrac{\sin(p/4 - a/2)}{k} \right), k \right) \right) - \dfrac{p \cdot R_0}{2}; \\ y_1'' = \dfrac{p \cdot R_0 \cdot k}{b} \cdot \left(\cos\left(\arcsin\left(\dfrac{\sin(a/2)}{k} \right) \right) - \cos\left(\arcsin\left(\dfrac{\sin(p/4 - a/2)}{k} \right) \right) \right); \\ b = F\left(\arcsin\left(\dfrac{\sin(a/2)}{k} \right), k \right) + F\left(\arcsin\left(\dfrac{\sin(p/4 - a/2)}{k} \right), k \right); \\ s_{\max} = \left| \dfrac{p}{2} - \dfrac{2 \cdot b}{k} \cdot \cos\left(\dfrac{p}{4} - \dfrac{a}{2} \right) \right| \cdot \dfrac{E \cdot h}{p \cdot R_0}; \end{cases}$$

for second inflection form

$$
\begin{cases}
x_1'' = \dfrac{p \cdot R_0}{b} \cdot \left(2 \cdot E\left(\dfrac{p}{2}, k \right) + E\left(\arcsin\left(\dfrac{\sin(a/2)}{k} \right), k \right) - E\left(\arcsin\left(\dfrac{\sin(p/4 - a/2)}{k} \right), k \right) \right) - \dfrac{p \cdot R_0}{2}; \\
y_1'' = \dfrac{p \cdot k \cdot R_0}{b} \cdot \left(\cos\left(\arcsin\left(\dfrac{\sin(p/4 - a/2)}{k} \right) \right) + \cos\left(\arcsin\left(\dfrac{\sin(a/2)}{k} \right) \right) \right); \\
b = 2 \cdot F\left(\dfrac{p}{2}, k \right) + F\left(\arcsin\left(\dfrac{\sin(a/2)}{k} \right), k \right) - F\left(\arcsin\left(\dfrac{\sin(p/4 - a/2)}{k} \right), k \right); \\
s_{\max} = \left| b \cdot \cos\left(\dfrac{p}{4} - \dfrac{a}{2} \right) - \dfrac{p}{2} \right| \cdot \dfrac{E \cdot h}{p \cdot R_0}.
\end{cases}
$$

The transition from the coordinate system $x^2\ 0\ y^2$ to the coordinate system $x¢\ 0\ y¢$ through known formula rotation axes.

Second stage. The initial data for calculation is the geometric dimensions of the rod. These data obtained in the first stage. For it calculation efforts engine in which formed reaction *2N* necessary efforts to seal the stopcock body (to valve) with the maximum permissible the stresses in the rod sections. Based on these results, are adjusted dimensions the rod and meet subject strength of rod and by the minimum size of the transmission mechanisms.

Conclusion. Specification conceptual principles of design procedure longitudinal – compression rod elastic elements of the transmission mechanism stop valves devices allows designers to obtain practical results with acceptable calculation error, which significantly reduces the probability of failure operation stop valves devices with the transmission mechanism as longitudinal – compression rod elastic elements.

1. Попов Е.П. Теория и расчет гибких упругих стержней. — М.: Наука, 1986. 2. Белоус Б. Д., Тыжай В. С. Конструкции и методика расчета приводов трубопроводной арматуры для криогенных температур. — Тезисы докладов научно-технического семинара “Совершенствование конструкции трубопроводной пневмогидроарматуры”. — К.: Центральный институт научно-технической информации и технико-экономических исследований по химическому и нефтяному машиностроении, 1987. 3. Білоус Б. Д., Білоус А. Б., Мандзюк М. Ф.Удосконалення методики статичного розрахунку вібраційного передавального механізму приводу запірного пристрою на основі поздовжньо-стиснутих пружних стрижнів // Вісн.Нац.ун-ту “Львівська політехніка” “Динаміка,міцність та проектування машин і приладів”. – Львів, 2008. – № 614. – С. 27–34.