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Effect of Uncertainty in Basing Hydraulic Prop Rod on Dimensional Wear of its Basic Surfaces

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Abstract: Hydraulic power cylinders are the main bearing elements of powered supports at mining enterprises, ensuring reliable fixation of the roof in the required working position, as well as providing advancement of the support in the face. Thus, hydraulic power cylinders ensure stoping safety, so strict requirements are im-posed on them both in terms of workmanship and operational reliability. To ensure reliability and efficiency of powered support operation in faces, it is necessary to ensure stable service life of their hydraulic props, which mainly depends on the quality of manufacturing of mating surfaces and the accuracy of assembling functional joints. The required accuracy of hydraulic prop joints is achieved by selective assembly, which allows ensuring the specified technical requirements and service life of the joints. At the same time, along with the issues of ensuring the accuracy of assembling the props to provide proper safety of the face operation, it is extremely important to identify and analyze the causes of dimensional wear of critical parts of the joints, leading to decreasing service life of the hydraulic props in the course of exploitation. In the paper, using the methods of the analytical theory of bases, the reasons for formation of positional variations of the parts of the powered support hydraulic prop joints in the course of assembling and operation of the unit are identified and described. It was found that arising mismatches and formation of local stress zones on the cylinders, pistons and rods, characterized by intense wear, occurs due to the uncertainty of basing (positioning) of rod and piston in hydraulic cylinder. The dependencies allowing calculating deviation of the rod axis from the required position, taking into account the initial clearance gap in the joints and the adopted design parameters of the hydraulic cylinder, have been obtained.

Keywords: powered support, hydraulic prop, assembling accuracy, wear, location uncertainty, base change, positional variations.

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Влияние неопределенности базирования штока гидростойки на размерный износ его базовых поверхностей

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Аннотация: Для обеспечения надежности и эффективности эксплуатации в забоях механизированных крепей необходимо обеспечить стабильный ресурс работы входящих в их состав гидростоек, который главным образом зависит от качества изготовления сопряженных поверхностей и точности сборки функциональных соединений. Требуемая точность соединений гидростоек достигается селективной сборкой, что позволяет обеспечить заданные технические требования и ресурс соединений. Вместе с тем наряду с вопросами обеспечения точности сборки данных узлов для гарантии должной безопасности работы в забоях чрезвычайно важными являются выявление и анализ причин размерного износа ответственных деталей соединений, приводящих к уменьшению ресурса гидростоек в процессе эксплуатации. В статье при помощи методов аналитической теории баз выявлены и описаны причины формирования позиционных отклонений деталей соединений гидростойки механизированной крепи в процессе сборки и эксплуатации узла. Установлено, что возникновение перекосов и образование на цилиндрах, поршнях и штоках локальных напряженных зон, характеризующихся интенсивным износом, происходит вследствие неопределенности базирования штока и поршня в гидроцилиндре. Получены зависимости, позволяющие рассчитать отклонение оси штока от требуемого положения с учетом исходного зазора в соединениях и принятых конструктивных параметров гидроцилиндра.

Ключевые слова: механизированная крепь, гидростойка, точность сборки, износ, неопределенность базирования, смена баз, позиционные отклонения

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Hydraulic power cylinders are the main bearing elements of powered supports at mining enterprises, ensuring reliable fixation of the roof in the required working position, as well as providing advancement of the support in the face. Thus, hydraulic power cylinders ensure stoping safety, so strict requirements are imposed on them both in terms of workmanship and operational reliability. At the same time, the condition of working surfaces of the hydraulic cylinder elements plays decisive role in ensuring proper service life of the critical joints. General technical requirements for manufacture of hydraulic props of powered supports and the main parameters are regulated by the standards [1-3].

As production statistics show, the main failures of mine supports in most cases are caused by seal failure of the hydraulic cylinder joints due to wear of the mating surfaces, which causes leakage of the hydraulic fluid and, correspondingly, the loss of the support bearing unit working ability. The latter can cause the roof collapse, emergency situation, and even lead to casualties. All this requires systematic monitoring of the condition of sealing elements, timely replacement of failed hydraulic cylinders with new or repaired ones [4–6].

It is known that the remanufacturing of hydraulic power cylinders in the conditions of specialized repair shops is rather laborious and costly process. At the same time, the quality of the restored surfaces, for example, the cylinder bearing surface, the rod working surfaces, should not be inferior to the corresponding indicators of new parts, since these surfaces determine the proper service life and bearing capacity of the joints. The required accuracy of the hydraulic props joints is achieved by selective assembly using the methods of group and inter-group interchangeability. This assembly technique ensures compliance with the specified technical requirements and the availability of the required joint service life [7–12]. At the same time, along with the issues of ensuring the assembly accuracy provide proper safety of work in the faces, it is extremely important to analyze the reasons for the change in the relative position of a hydraulic prop joint parts in the course of operation, their positional variations from the required position, arising mismatches under load, which produce significant effect on the stress state, the process of part wear, and the joint service life [13, 14].

Due to the presence of a gap in the sliding joints of hydraulic cylinder, the deviations of the position of the hydraulic prop rod are manifested as an uncertainty of its basing, which occurs due to unorganized change of bases resulting from elastic movements and deformations in the hydraulic prop under the load on its working surfaces.

To identify and unambiguously mathematically describe the basing schematics for parts and units, we use the method of identification and modeling of bases [11, 12, 15, 16].

The coordinates of the position of a part or unit supporting points can be divided into two groups: plane coordinates (X_i, Y_i, Z_i), which determine the supporting points location on three

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base surfaces (plan view of the base surface), and normal coordinates (Δx_i, Δy_i, Δz_i), defining the deviations of the supporting points in the direction perpendicular to the basing surfaces.

If the normal coordinates of the supporting points are grouped by base and written in the sequence of decreasing points on the bases, then we get a column matrix *T* of normal coordinates, which uniquely determines the basing schematic and the location of points on the coordinate planes.

The main bases of a hydraulic prop, which determine its position in the powered support, are two hemispheres (Fig. 1), which allows the prop to self-align under the external load, thus providing the required kinematic flexibility.

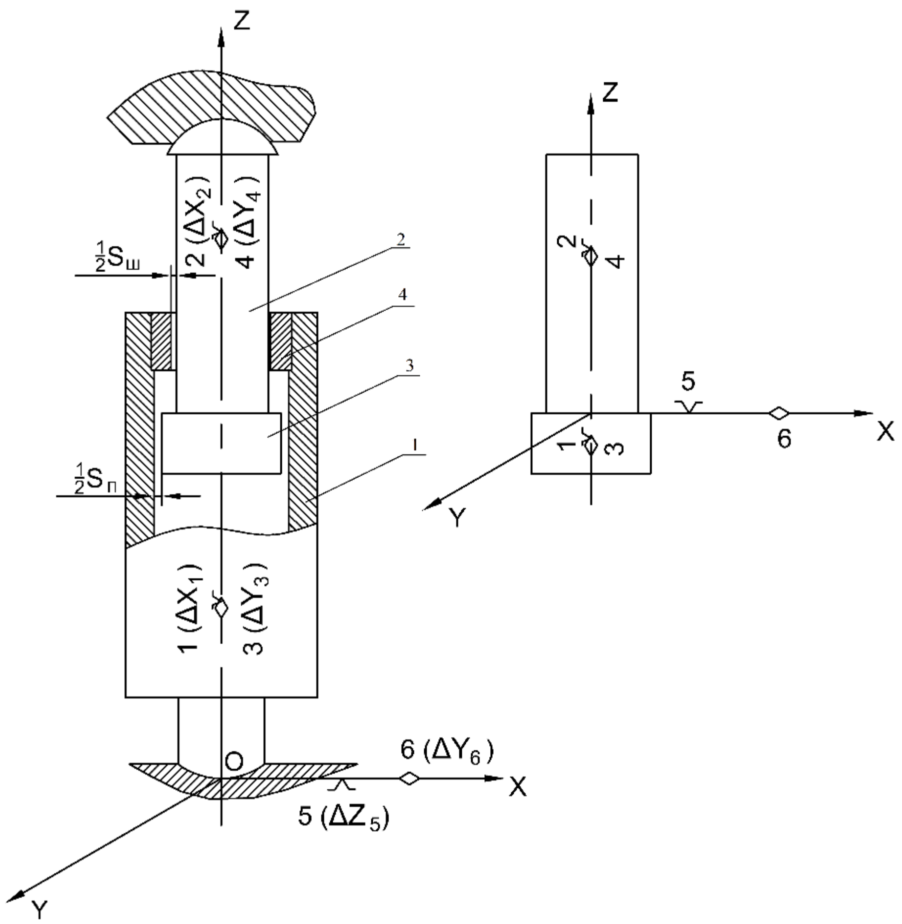

Fig. 1. Hydraulic prop elements basing schematics:
1 – cylinder; *2* – rod; *3* – piston; *4* – neck bush

This means that the prop is based according to the schematic with the use of double guiding base (see Fig. 1), which is described by the rowed matrix:

$$T = (\Delta x_1, \Delta x_2, \Delta y_3, \Delta y_4, \Delta z_5, \Delta y_6). \qquad (1)$$

According to (1), the components (Δx_1, Δx_2, Δy_3, Δy_4) are the normal coordinates of the supporting points of the double guiding base, the role of which is played by the *0Z* axis, and the components Δz_5, Δy_6 are the normal coordinates of the supporting points of the supporting bases, which are *X0Y* (Δz_5) and *X0Z* (Δy_6) planes.

Self-alignment of the prop along the base is ensured by the support points (Δx_1, Δy_3), and self-alignment along the roof, by the support points (Δx_2, Δy_4).

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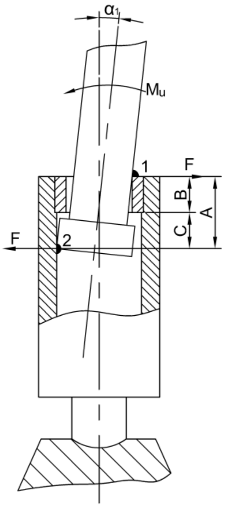
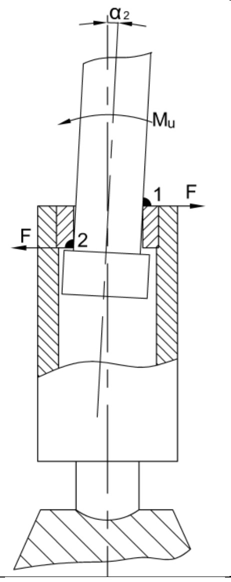
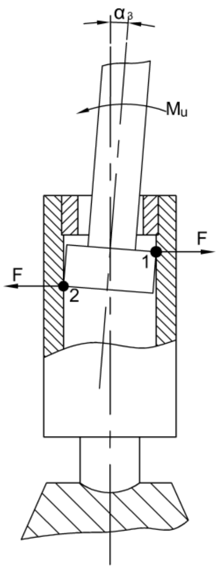
Table 1

Position schematics and calculation formulas to determine the deviations of the rod and piston in the hydraulic prop

Schematic No.	Schematic of the piston and rod position in the cylinder when changing bases	Description of unorganized change of bases by matrices of normal coordinates
1		Basing schematic: $T = (\Delta x_1, \Delta x_2, \Delta y_3, \Delta y_4, \Delta z_5, \Delta y_6)$; values of normal coordinates: $\Delta x_1 = 0{,}5S_{\text{p}}$; $\Delta y_3 = 0{,}5S_{\text{p}}$; $\Delta x_2 = 0{,}5S_{\text{r}}$; $\Delta y_4 = 0{,}5S_{\text{r}}$; angle of the rod axis vertical deviation: $\alpha_{1} = \frac{1}{2A}\cdot\left(S_{\text{вт}} + S + S\right)$
2		Basing schematic: $T = (\Delta x_1^*, \Delta x_2^*, \Delta y_3^*, \Delta y_4^*, \Delta z_5, \Delta y_6)$; values of normal coordinates: $\Delta x_1^* = S_{\text{r}}$; $\Delta y_3^* = S_{\text{r}}$; $\Delta x_2^* = S_{\text{r}}$; $\Delta y_4^* = S_{\text{r}}$; angle of the rod axis vertical deviation: $\alpha_2 = \frac{S_{\text{ш}}}{B}$
3		Basing schematic: $T' = (\Delta x_1', \Delta x_2', \Delta y_3', \Delta y_4', \Delta z_5, \Delta y_6)$; values of normal coordinates: $\Delta x_1' = S_{\text{вт}}$; $\Delta y_3' = S_{\text{вт}}$; $\Delta x_2' = S_{\text{вт}}$; $\Delta y_4' = S_{\text{вт}}$; angle of the rod axis vertical deviation: $\alpha_3 = \frac{S_{\text{п}}}{C}$

Note. M_u - bending momentum acting on the rod; *F* is the normal load on the joints parts, which increases as a result of the rod mismatch; 1, 2 - supporting points – zones of critical loading on the joints parts.

In turn, basing of the piston and rod in the hydraulic cylinder is also carried out using a double guiding base (Table 1):

$$T = (\Delta x_1, \Delta x_2, \Delta y_3, \Delta y_4, \Delta z_5, \Delta y_6), \quad (2)$$

where $(\Delta x_1, \Delta y_3)$ are the normal coordinates of the supporting points, which determine the position (centering) of the piston in the cylinder; $(\Delta x_2, \Delta y_4)$ are the normal coordinates of the supporting points, which determine the position (centering) of the rod in the neck bush.

With correct basing (see Fig. 1), each element $(\Delta x_1, \Delta y_3)$ is equal to a half of the diametral clearance gap S_p between the piston and the cylinder:

$$\Delta x_1 = 0{,}5S_p; \ \Delta y_3 = 0{,}5S_p, \quad (3)$$

and the elements $(\Delta x_2, \Delta y_4)$ are equal to half of the diametric clearance S_r between the rod and the neck bush:

$$\Delta x_2 = 0{,}5S_r; \ \Delta y_4 = 0{,}5S_r. \quad (4)$$

However, under variable load, an unorganized change of the piston and rod bases takes place, which can be represented by three schematics presented in Table 1.

According to schematic No. 1, the unorganized change of bases leads to one-sided contact between the piston and the rod, when the clearance gap is filled on one side, and the equalities take place:

$$\Delta x_1 = S_p; \ \Delta y_3 = S_p; \quad (5)$$

$$\Delta x_2 = S_r; \ \Delta y_4 = S_r. \quad (6)$$

According to schematic No. 2, the unorganized change of bases leads to the fact that the basing of the rod and the piston takes place only along the neck bush (points 1 and 2):

$$T^* = (\Delta x_1^*, \Delta x_2^*, \Delta y_3^*, \Delta y_4, \Delta z_5, \Delta y_6), \quad (7)$$

with one-sided contact of the rod with the neck bush surface:

$$\Delta x_1^* = S_r; \ \Delta y_3^* = S_r; \quad (8)$$

$$\Delta x_2^* = S_r; \ \Delta y_4^* = S_r. \quad (9)$$

The upper symbol "*" means that the elements of the matrix (7) determine the basing along the neck bush (points 1 and 2).

According to schematic No. 3, the unorganized change of bases leads to the fact that the basing of the rod and the piston takes place only along the inner surface of the cylinder:

$$T' = (\Delta x_1', \Delta x_2', \Delta y_3', \Delta y_4, \Delta z_5, \Delta y_6), \quad (10)$$

with one-sided contact of the piston with the cylinder surface:

$$\Delta x_1' = S_{ВТ}; \ \Delta y_3' = S_{ВТ}; \quad (11)$$

$$\Delta x_2' = S_{ВТ}; \ \Delta y_4' = S_{ВТ}, \quad (12)$$

where $S_{ВТ}$ is the diametral clearance gap "cylinder pocket - outer surface of the neck bush" ("cylinder pocket - neck bush").

Taking into account the numerical values of the design parameters A, B, C, the vertical deviation of the rod axis α_1, α_2, α_3, due to the unorganized change of bases, can be calculated using the formulas given in Table 1.

Conclusions.

It has been established that the presence of gaps in the "cylinder - piston" and "neck bush - rod" joints leads to uncertainty in the piston and rod basing (positioning). Applying the analytical theory of bases enables determining numerical values of the angular and linear deviations of the joints parts arising in this case, depending on the adopted design parameters A, B, C.

With an unorganized change of bases, the load acting in the hydraulic prop is transmitted not along the working surfaces of the joint parts, but through small (in area) support points, causing increased stresses at the contact points and, as a result, local intensive wear, which leads to decreasing service life of the hydraulic prop.

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