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DETERMINATION AND ASSESSMENT OF THE LOADINGS ON RIGID GUIDE SYSTEMS DUE TO HORIZONATAL BUMPS AT THE INTERACTION WITH THE CONVEYANCES DURING THE HOISTING

Summary. Results obtained from investigations of the dynamic loadings on rigid guide systems for conveyances in vertical mine shafts are presented. The investigations served for laying down the universal compulsory principles for the assessment of the loading on these guide systems and for the specification of the priorities to be followed in the implementation of systematic measures for the preventive maintenance in shaft tubes. The determination and the assessment of the loadings on rigid guide systems considered the system properties both of the conveyances (as far as their effect on the horizontal forces is concerned) and also of the guide systems themselves (as far as the absorption of the horizontal forces is concerned). The most important system properties were found to be the mass distribution and the elasticity in the case of the conveyances and the spring constant of the supporting frame in the case of the rigid guide system. The influence of real system properties on the horizontal forces and the loadings is determined quantitatively and qualitatively. The calculation results were confirmed by measurements in shaft tubes.

1. PRELIMINARY REMARKS

At the Institute for Safety in Mines Leipzig (Institut fur Bergbausicherheit), investigations were carried out on the dynamic loading on rigid guide systems for conveyances in vertical mine shafts. Their aim was to lay down fundamentals for the assessment of the loadings on rigid guide systems and for the specification of the priority to be observed in the implementation of systematic methods for the preventive maintenance in the shaft tubes.

As a result of these investigations, a measuring procedure rotinaly applied for the logging of the operational state, assessment criteria of the dynamic loadings and of the operational safety and the procedure for the specification of the priority to be observed in the implementation of the measures for preventive maintanance of the guide systems were elaborated. The total complex of these results is regularly applied in mining practice

Although number of detailed investigation results on loadings are already available, only the concept of the taken method will be explained in the present contribution for lack of time. Results related to the loadings are only represented to the extent required for the proof of the relationships.

2. THE CONCEPT FOR THE DETERMINATION AND THE ASSESSMENT OF THE LOADINGS ON THE RIGID GUIDE SYSTEMS

2.1. General remarks

In the GDR, the same concept was followed as by GÖTZMANN [1] and by SLONINA and HUPFER [2] in the German Federal Republic, and by KAWULOK [3] in the Peoples Republic of Poland. The principal of this concept is to determine the horizontal bumping forces on the rigid conveyance guide indirectly by measuring the accelerations on the force transmitting points of the conveyance.

Despite the problems often raised with respect to this approach in the scientific special literature, this concept was carried on more consequently than in the cited countries. This consequence is caracterized by detailed investigations of the influences upon the system properties both of the guide systems and also of the conveyances' will the aim of preparing this knowledge for practical use.

The bumping parts are the conveyance on one hand, and the guide rod-bunton-systems on the other hand. As assessment parameters, the maximum loadings of the elements of this guide system are used. This means that not only the amount of the bumping forces must be known, but also the locations of their occurence in the guide system and, consequently, the elements of the guide systems subiected to the highest loadings, taking into account the support conditions in the shaft lining and their coupling in the guide system.

The measuring device routinely used was already reported about in detail [4], while on the further investigations related to the qualification of the assesment cirtieria, only a short report was given during the 21. International Conference of Safety in Mines Research Institutes in Sydney [5].

The influence of the system properties of both bumping parts, that is the say conveyance and guide system, were theoretically studied and got confirmed or precised by measurements on real hoisting plants.

2.2. Consideration of the system properties of the conveyances with respect to their influence on the horizontal forces

An essential influence on the amount of the horizontal bumping forces is exercised by the mass distribution of the conveyance over the volume, its elasticity and the position of the force transmitting points (guide shoes or roller guidances)referred to its mass center point. These parameters, on their turn, depend on the kind of the conveyance (skip or cage) and on its loading state. For the determination of the bumping forces from the measured accelerations, we will consider the bumping mass of the conveyance mavable at three degrees of freedom (figure 1).

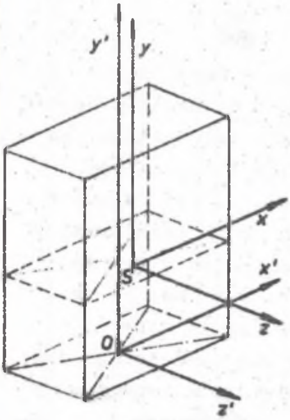

Fig. 1. Scheme of the free oscillating conveyance

According to BERG [6], the bumping mass direction, on the inertial caracteristica and on the special position of the bumping points referred to the mass center point. This results in the indication of the equations determining the mass coefficient and strictly applying to the non-elastic (rigid) conveyance. In the general rule, the mass coefficient q is defined to the ratio of the bumping mass m^x to the total mass m of the conveyance.

The equations determining the mass coefficient are

- for bumps in the direction on the front end:

$$q_{st} = \left[1 + \frac{p_y^2}{r_z^2} + \frac{p_z^2}{r_y^2} \right]^{-1} \tag{1}$$

- for bumps in the direction on the sidewalls:

$$q_{f1} = \left[1 + \frac{p_x^2}{r_y^2} + \frac{p_y^2}{r_x^2} \right]^{-1} \tag{2}$$

In these formula, p_x, p_y, p_z are the coordinates of the force-transmitting points on the conveyance (guide shoes) with reference to the mass center point, and r_x, r_y, r_z are the inertial radii around the main axis x, y, z passing through the mass center point of the conveyance (see figure 1).

More you will succeed in considering the mass distribution of real conveyances in these calculations (figure 2), more the mass coefficient determined in this way will be precise.

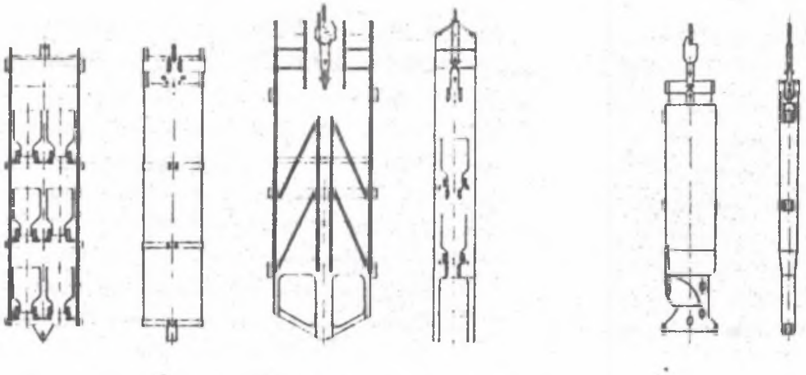

Fig. 2. Real conveances

For several real conveyances, we calculated the mass coefficient in this way, although we were well aware of the fact that no considereation was given to the elasticity of the conveyances in this calculation. As this influence is only very difficult to assess and as the real conditions can hardly be reproduced in detail in a theoretical way, simultaneous measurements of the bumping forces and of the bump accelerations were carried out on real conveyances during the hoisting in order to clear up the relationships. For the measurements, use was made of the force measuring shoe represented in figure 3. According to the 2. Newton axiom, the bumping masses were determined by the division of the simultaneously measured bumping forces and the accelerations and were indicated as normalized mass coefficients. Figure 4 representes the cumulated frequencies of the mass coefficients on the front in determined from several measuring trips for a definite conveyance. Consequently, the coefficient is independent on the conveyance speed, circumstance considerably simplifying the further application of the results. In this figure, the strong scattering of the obtained values becomes already evident. This is also confirmed by figure 5 showing that this phenomenon results from the scattering of the measured accelerations and forces.

In figure 6, comparisons are finally established between the mass coefficients obtained experimantally and theoretically. On the top, the theoretically obtained values are compared with the mean values determined experimentally. On the bottom, consideration is given to the strong scattering by establishing a comparison with the values obtained experimentally for the cumulated frequencies of 90%.

Also in the last case, the actual mass coefficients are always inferior to the calculated ones what is attributed to the influence of the elasticity of the conveyance. When we use the theoretical values for the further considerations, then we dispose of safety reserves.

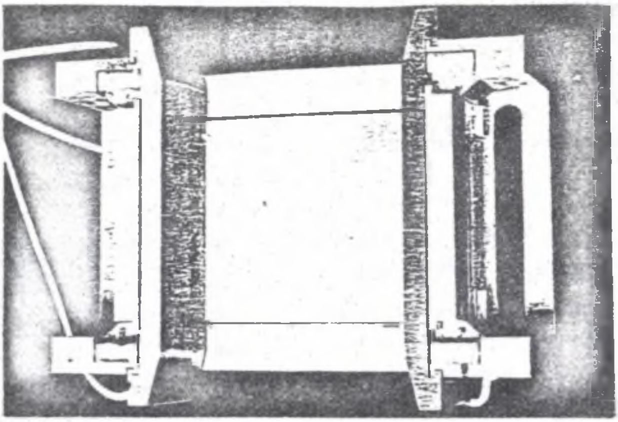

Fig. 3. Force measuring shoe

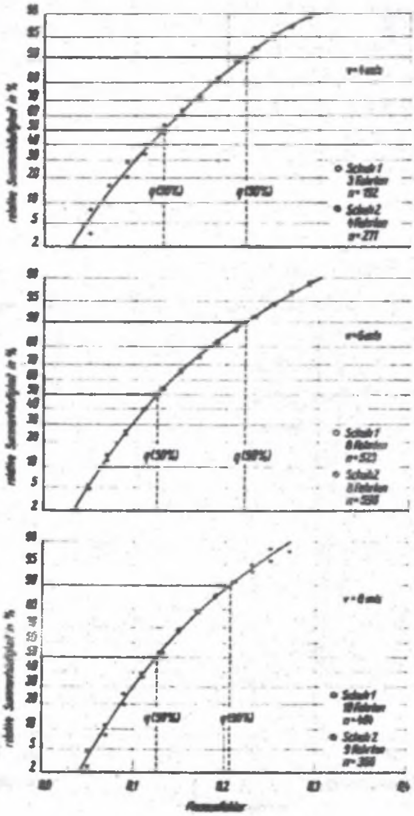

Fig. 4. Cumulated frequencies of the mass coefficient on the front end

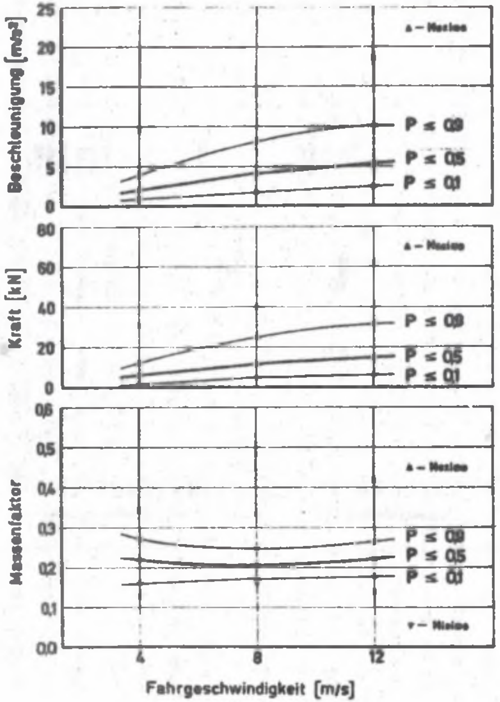

Fig. 5. Accelerations, forces and mass coefficient determined by the measurements and calculations

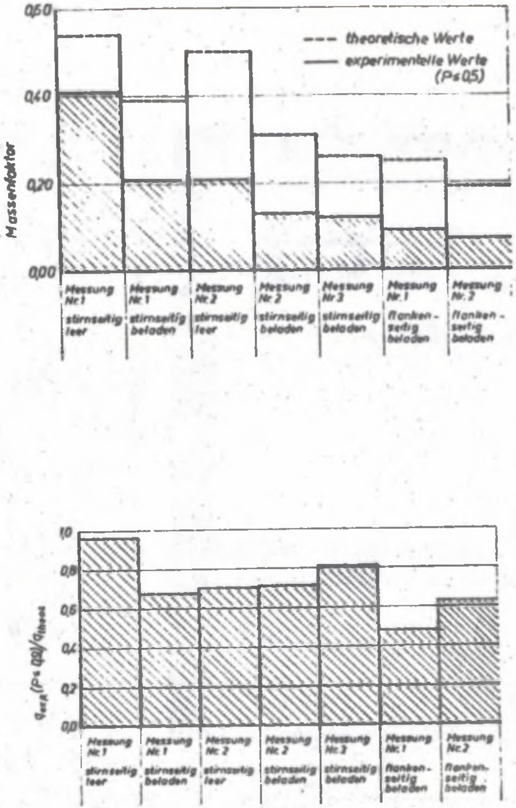

Fig. 6. Comparison between the mass coefficients obtained theoretically and experimentally

However, if the further investigation of the definite shaft hoisting plant should reveal that this statement of the mass coefficients results in loading reaching or exceeding the admissible values, then the actual mass coefficients have to be used in order to take full advantage of the reserves still available. The latter ones, can however only be determined by measurements occasioning great efforts.

2.3. Consideration of the system properties of the guide system with respect to the absorption of the horizontal forces

As a criterion for the quality of the safety state of the rigid shaft furniture, use in made of the maximum stress occurring in the elements of these construction parts as a result of the horizontal force actions. By means of figure 7 representing a very simplified guide rod-bunton-system, two potential points of application of the horizontal bumping force are shown. The problem is to determine the maximum stresses brought about by a clearly defined bumping force both in the guide rod and also in the buntons, taking into consideration the clamping conditions of the buntons in the shaft lining and the guide rod-bunton-links as well as the elasticity of the supporting frame on the concerned point of force application.

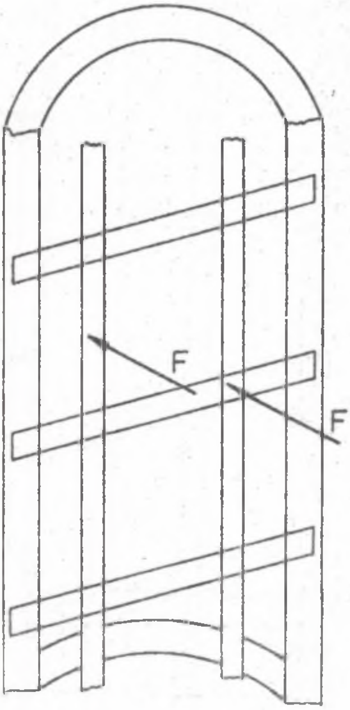

Fig. 7. Scheme of a guide rod-bunton-system with horizontal acting forces

The guide rod lines carried upon numerous buntons and equipped with joints of high bending strength is approached to by a simplified model of the guide rods carried by four buntons which is represented in figure 8. For the force application point X, we will consider the value range $1 \leqslant X \leqslant 2$ in the normalized representation. In the numerical calculation it is possible to narrow this range to $1 \leqslant X \leqslant 1{,}5$ because of the symmetry of the problem.

The differential equation of the bending line which is equal to the 4th derivation of the deflection from the longitudinal coordinate x, is separately solved for the sections i = I, II, III, IV. Hence, it follows for the bending lines of the guide rod lines carried by four yielding buntons that the relation is

$$w_i = C_{i0} + C_{i1}X + C_{i2}X^2 + C_{i3}X^3 \qquad (3)$$

The meaning of the used symbols is a follows:

w_i - deflection in the sections $i = I, II, III, IV$
x - longitudinal coordinate of the guide rod lines
C_i - constants of the bending line in the sections $i = I, II, III, IV$.

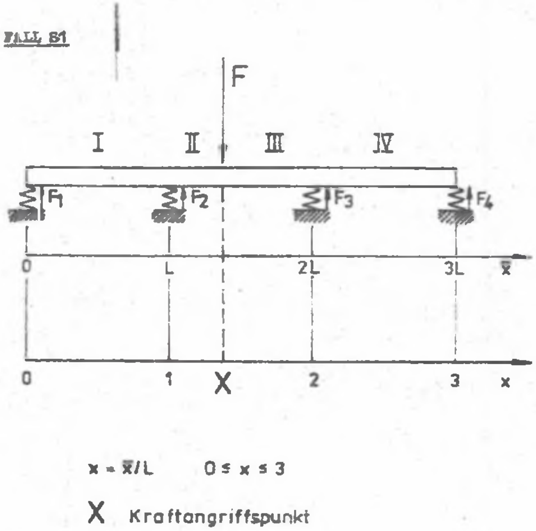

Fig. 8. Model of the guide rod carried by four yielding buntons

It is possible to determine the constants C_i of the equation systems (3), taking into account the conditions of boundary, of transition and of step. For this purpose, use is made of the expression c which is meant to be the normalized spring constant of the bunton during its interaction with the guide rod lines and, consequently, takes into account the clamping condition of this linkage:

$$c = \frac{CL^3}{6EI} \tag{4}$$

The meaning of the used symbols is a follows:
C - spring constant of the bunton
L - bunton spacing
E - elasticity of the guide rod material
I - areal moment of inertia of the guide rod.

For the supporting forces F_i acting on the individual buntons, the calculation yields expressions which are indicated as normalized forces $F_{ni} = F_i/F$:

$$F_{ni} = A_i/B \tag{5}$$

Therewith, A_i and B are constants. The constants A_i are quite definite functions of X and c, whereas the constant B is only a function of c:

$$A_1 = 14 - 6X + c(60 - 73X + 24X^2 - 2X^3) + \\ + c^2(24 - 46X + 27X^2 - 5X^3) \tag{6}$$

$$A_2 = B - 2X + c(-5 + 73X - 42X^2 + 6X^3) + \\ - 3c^2(8 - 32X + 24X^2 - 5X^3) \tag{7}$$

$$A_3 = 2 + 2X + c(-2 - 17X + 12X^2 - 6X^3) + \\ + 3c^2(7 - 23X + 21X^2 - 5X^3) \tag{8}$$

$$A_4 = -4 + 6X + c(3 - 17X + 6X^2 + 2X^3) + \\ + c^2(-6 + 19X - 18X^2 + 5X^3) \tag{9}$$

$$B = (2 + 5c)(10 + 3c) \tag{10}$$

Using the support forces F_{ni} in combination with c and the force application point X, it is possible to determine the constants C_i for the sections i = I, II, III, IV for the following normalized values:

$$(3C/F)C_{I0} = 3F_{n1} \tag{11}$$

$$(3C/F)C_{I1} = F_{n4} - F_{n1} + c(18X - 9X^2 + X^3 - 10F_{n2} - 8F_{n3}) \tag{12}$$

$$(3C/F)C_{I2} = 0 \tag{13}$$

$$(3C/F)C_{I3} = c(X - 3 + 2F_{n2} + F_{n3}) \tag{14}$$

$$(3C/F)C_{II0} = 3F_{n1} + 3cF_{n2} \tag{15}$$

$$(3C/F)C_{II1} = F_{n4} - F_{n1} + c(18X - 9X^2 - 19F_{n2} - 8F_{n3}) \tag{16}$$

$$(3C/F)C_{II2} = 9cF_{n2} \tag{17}$$

$$(3C/F)C_{II3} = c(X - 3 - F_{n2} + F_{n3}) \tag{18}$$

$$(3C/F)C_{III0} = 3F_{n1} + 3c(-X^3 + F_{n2}) \tag{19}$$

$$(3C/F)C_{III1} = F_{n4} - F_{n1} + c(18X + X^3 - 19F_{n2} - 8F_{n3}) \quad (20)$$

$$(3C/F)C_{III2} = 9c(-X + F_{n2}) \quad (21)$$

$$(3C/F)C_{III3} = c(X - F_{n2} + F_{n3}) \quad (22)$$

$$(3C/F)C_{IV0} = 3F_{n1} + 3c(-X^3 + F_{n2} + 8F_{n3}) \quad (23)$$

$$(3C/F)C_{IV1} = F_{n4} - F_{n1} + c(18X + X^3 - 19F_{n2} - 44F_{n3}) \quad (24)$$

$$(3C/F)C_{IV2} = 9c(-X + F_{n2} + 2F_{n3}) \quad (25)$$

$$(3C/F)C_{IV3} = c(X - F_{n2} - 2F_{n3}) \quad (26)$$

When these constants are used in the equations (3) by way of substitution, they yield the deflection as a function of x in the normalized dimensionless representation:

$$(3C/F)\, w_i\, (x) \quad (27)$$

The maximum bending stress of the guide rod is obtained by the second derivation of the bending line for the relation:

$$s(x) = w''(x) = 2C_{i2} + 6C_{i3}x \quad (28)$$

When the calculated respective constants are used in this equation by way of substitution, then the bending stresses of the guide will be immediately obtained.

A similar procedure is applied for the calculation of the buntons. For this purpose, the both models of figure 9 are considered (fixed clamping and free support). Furhter investigations revealed that the fixed clamping in the shaft lining reproduces quite well the real clamping conditions. We will do without the representation of the further relationships.
By means of computational steps comparatively less complicated, we finally succeed in indicating the maximum bending stress brought about just on the guide rod-bunton-fastening during the impact of the bumping force. Therewith, consideration is given to the partial reduction in load of the bunton, effect which is brought about by the adjacent joining in carrying the load.

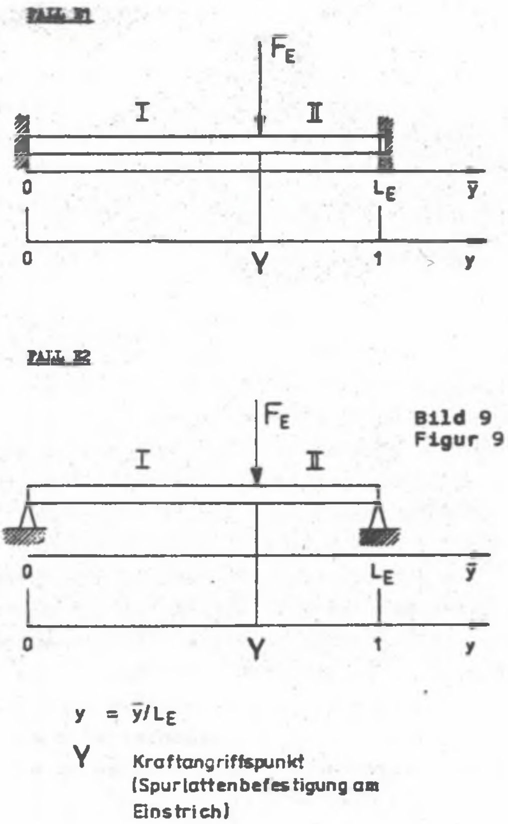

Fig. 9. Models for the bunton

2.4. The assessment of the loadings and oonclusions for the preventive maintenace

The maximum loadings (bending stresses) determined by measurement and calculation in the elements of the guide rod-bunton-system are used for the assessment of the safety engineering state of the shaft furniture and for the specification of the priority to be observed during the maintenance measures, especially with wooden guide systems. For this purpose, loading degrees of the rigid guide systems are specified as a function of the relation between the maximum and permissible bending stresses. By means of measurements and calculations and with consideration of the definite system properties, we determine the loading degree which, on itsturn, fixes the maximum intervall up to the next measurement, and on the other hand, the order and the speed of the maintenance measures to be taken.

A lower loading degree indicates the good state requiring only unsignificant expenditure for repair work and also allowing to carry out the next compulsory acceleration measurements only at the end of a longer period. A higher loading degree, however, requires to take immediate maintenance measures which must prove to be sucessful in a shorter period by the next measurement.

3. FINAL REMARKS

For some years past, the GDR has been applying assessment criteria which were derived in conformity with the deliberations exposed above. These criteria give large consideration to the system properties of the shaft hoisting plants and open up safety reserves still abailable what is quite legitim in connection with the strictly regimented supervision, including measuring engineering procedures. We are on the point to rationalize the expensive calculations by the use of the computer engineering. With the presented results, we answer to a basic concern of the research in the field of safety in mines which is to ensure the operational of safety and the permanent scheduled availability of our shaft hoisting plants with an expenditure as low as possible. The presented results have had their share in reaching this aim. The operators of the shaft hoisting plants are very thankful for the results because we were successful in avoiding breakdowns of service due to deficiencies of the wooden guide systems predominantly used which would have resulted in stops of the shaft hoisting plant.

REFERENCES

1. Götzmann W.: Accelerometer for the testing of shaft guide. Glückauf 95 (1959), s.880-885.
2. Slonina W., Hupfer H.: Measuring device for the dynamic loading occurring on shaft hoisting plants. Glückauf-Forschungshefte 31 (1970), s. 246 - 256.
3. Kawulok S.: The influence of increase in the bunton spacing on the roading of the shaft furniture. Prace GIG, Katowice (1972) 550, s.1-26.
4. Wohlrab M , Hoffman P., Noack R.: Accelerameter 3-BME/1 for the supervision of conveying movement of guide-rodded conveyances of the vertical mine shaft hoistings. Neue Bergbautechnik 6 (1976) 8, s. 615-620.
5. Wohlrab M.: Horizontal dynamic loading of guides as a criterion for the assessment of the state of safety of shaft hoisting plants. Proceedings of the 21st International Conference of Safety in Mines Research Institutes. Sydney. 21-25.10.1985. Edited by A.R.Green. Rotterdam/Boston: A.A. Balkema. 1985, s.179-187.
6. Berg G.: Calculation of the mass participated in the bumps between the conveyances and the shaft furnitures. Bergakademie 19 (1967) 12, s.725--728

ZDEFINIOWANIE I OSZACOWANIE OBCIĄŻEŃ UKŁADÓW SZTYWNEGO PROWADNIKA WYWOŁANYCH POZIOMYMI UDERZENIAMI PODCZAS WZAJEMNEGO ODDZIAŁYWANIA NA ŚRODKI TRANSPORTU PRZY WYCIĄGANIU SZYBEM

Streszczenie

Przedstawiono wyniki badań obciążeń dynamicznych wywieranych na układy sztywnego prowadnika w odniesieniu do środków transportu w pionowych szybach kopalnianych. Badania te stanowiły podstawę dla ustalenia ogólnych obowiązujących zasad oceny obciążenia tych prowadnikowych układów i do wyszczególnienia pierwszeństwa podczas wdrażania systematycznych środków zaradczych celem profilaktycznej konserwacji rur szybowych. Określenie i szacowanie obciążeń układów sztywnego prowadnika obejmowało własności tego systemu odnośnie do zarówno środków transportu (jeśli idzie o ich wpływ na siły poziome), jak i samych układów prowadnika (w zakresie absorpcji sił poziomych). Stwierdzono, że najważniejszymi własnościami układu jest rozkład masy i sprężystość w przypadku środków transportu, natomiast stała sprężyny ramy nośnej w wypadku układu sztywnego prowadnika. Wpływ własności rzeczywistego układu na siły poziome i obciążenia definiowany jest jakościowo i ilościowo. Wyniki obliczeń zostały potwierdzone pomiarami w rurach szybowych.

ОПРЕДЕЛЕНИЕ И ОЦЕНКА НАГРУЗОК НА СИСТЕМЫ ЖЕСТКОГО НАПРАВЛЯЮЩЕГО ПРОВОДНИКА, ВЫЗВАННЫХ ГОРИЗОНТАЛЬНЫМИ УДАРАМИ ВО ВРЕМЯ ВЗАИМНОГО ВОЗДЕЙСТВИЯ НА ТРАНСПОРТНЫЕ СРЕДСТВА ПРИ ПОДЬЕМЕ ПО ШАХТНОМУ СТВОЛУ

Резюме

Рассматриваются результаты исследования динамических нагрузок, воздействующих на системы жесткого направляющего проводника, в отнесении к транспортным средствам в вертикальных шахтных стволах.

Исследования эти были приняты за основу при определении общих обязательных принципов оценки нагрузки на проводники этих систем, а также использовались для определения приоритетных заданий при внедрении систематических предупредительных мероприятий для профилактического обслуживания труб шахтных стволов.

Определение и оценка нагрузок на системы жесткого направляющего проводника охватывало особенности этой системы как по отношению к транспортным средствам /если идет речь о их влиянии на горизонтальные усилия/, так и распространялось на сами системы направляющего проводника /в пределах абсорбции горизонтальных сил/.
Установлено, что наиболее существенные особенности системы - это распределение массы и упругость если иметь в виду транспортные средства, и постоянная пружины несущей рамы - если иметь в виду систему жесткого направляющего проводника.
Влияние свойств действительной системы на горизонтальные силы и нагрузки определяется в качественном и количественном объеме.
Результаты полученных расчетов были подтверждены фактическими результатами измерений, полученными на трубах шахтных стволов.