Contribution to the Problems of Rock Bursts in Coal Mines

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Abstract:
With the progress of mining into higher depths we are more often dealing with the danger of appearance of anomal geomechanical events. In Czech Republic it is mainly rock bursts. The energy accumulated in rocks cause the origin of rock bursts. In this paper it will be dealing with distribution of accumulated energy in coal rock mass and with possibility of unlocking of these energy during the rock bursts. Accumulated energy depends on stress value. Therefore the stress distribution in exploited rock mass is very important. Different influencing factors of stress distribution will be discussed. Accumulated energy depends also on elastic modulus of the rocks. Due to much smaller elastic modulus of coal seam, the specific accumulated energy is highest in the seam. So to this energy we have pay the maximal attention. For assessment of the danger of rock burst origin is proposed the value of accumulated energy in seam on unit of seam area.

1. Introduction

A rock burst is a very dangerous phenomenon, known to world mining for more than 100 years. The risk and intensity of rock bursts increase as mining advances into deeper layers. The first rock bursts documented on the territory of the Czech Republic go as far ago as 1870s. The biggest rock bursts occurred in the Ostrava-Karviná mining district after 1970. Therefore, a geomechanical service was established in 1975, dealing mainly with the problems connected with rock bursts. Much has been done since to reduce the occurrence of rock bursts. The seams are exploited under very complicated mining-geological conditions of multiseam deposit, and rock bursts occur from time to time in spite of the application of anti-burst measures. There is a number of factors influencing rock burst occurrence. It is necessary to define the influence of those factors further and more precisely, so that anti-burst measures can be applied more effectively. The principle of rock bursts is the transformation of energy accumulated in rock mass into kinetic energy. Therefore, it is necessary to examine the level of accumulated energy, conditions under which this energy is released, and circumstances preventing it from releasing into mine workings.

2. Energetic characteristic of rock mass

Zero deformation of rock can be assumed in a certain distance from a mine working. In this case, specific elastic energy \( \varepsilon \) can be determined from the equation:
\[ w_e = \frac{\sigma^2}{2E} \] (1)

where \( \sigma \) - maximum normal stress,
\( E \) - real elasticity modulus of rock mass, defined as
\[ E = \frac{E_a}{\beta} \] (2)

where \( E_a \) - elasticity modulus of rock, determined by the uniaxial loading test,
\( \beta \) - coefficient, defined as
\[ \beta = 1 - \frac{2\mu^2}{1 - \mu} \] (3)

where \( \mu \) - Poisson's ratio.

It can be seen from (1) that accumulated energy is influenced mainly by the height of acting stress, because energy hinges on stress in the square. Vertical geostatic stress can be determined from deposition depth. In the course of longwalling, stress acting around the longwall is increased two to three times, exclusively owing to the strength of overburden. Since vertical stress in the seam is equal to that in the direct overburden or footwall, the distribution of accumulated energy depends on elasticity modulus of rocks. The elasticity modulus of the surrounding rocks in the Carboniferous coal deposit is by about one order higher than that in the coal seam itself. This means that specific accumulated energy in the seam is by about one order higher than that in the surrounding rocks. The characteristic of specific accumulated energy in relation to depth is schematically shown in Fig. 1.
Distribution of accumulated energy according to Fig. 1 applies to geostatic stress state, but a similar distribution of accumulated energy can be found in mining-influenced rock mass. In more-or-less isotropic rock mass, the energy accumulated in the course of exploitation will correspond to the situation shown in Fig. 1. In the case of rock mass with higher differences of strength and thickness of layers, both acting stress and accumulated energy are different.

In addition to elastic energy, changes of potential energy also play role in exploited rock mass. Potential energy released in the course of exploitation can be determined from the subsidence of overlayers. Specific released potential energy can be expressed from energy released from volume unit of undermined overlayers. Specific potential energy of an element of the overburden of an exploited seam is as follows:

\[ w_{ov} = \rho_{ov} \cdot g \cdot m \cdot a \]  

(4)

where \( w_{ov} \) - specific potential energy of undermined overburden (MJ m\(^{-3}\)), 
\( \rho_{ov} \) - real volumetric density of overburden rock (10\(^6\) kg m\(^{-3}\))
\( g \) - acceleration of gravity (m s\(^{-2}\))
\( m \) - exploited seam thickness (m)
\( a \) - exploitation coefficient

The exploitation coefficient characterizes the ratio between the magnitude of surface subsidence and exploited seam thickness (providing that mined-out area is sufficiently large). The exploitation coefficient hinges on the liquidation method of mined-out area (caving versus backfilling), exploitation depth and character of overburden. Under the conditions of the Ostrava-Karviná mining district and in the case of mining with caving, the coefficient ranges between 0.7 and 0.8.

The released potential energy corresponding to a unit rock column of the height of the distance between the exploited seam and the surface is acting on the unit mined-out area. This unit energy can be determined as:

\[ w_{un} = \rho_{ov} \cdot g \cdot H \cdot m \cdot a \]  

(5)

where \( w_{un} \) - potential energy per unit of mined out area (MJ m\(^{-2}\))

This potential energy per unit of mined out area is high, but its releasing takes a long time. We can assume that, under the conditions of relatively hard Carboniferous massif, the releasing of a substantial portion of potential energy takes about 10 years. Unlike this kind of energy, elastically accumulated energy of rock mass can, under certain conditions, release very quickly. Therefore, it is necessary to examine conditions of sudden releases of elastically accumulated energy of rock mass in order to evaluate the mechanism of rock bursts.

3. Conditions of releasing of elastic energy

It has been stated in the last chapter that the highest value of specific elastic energy is found in the seam. At the same time, we can see that, in the course of rock bursts, rock extrudes into mine working in the direction of the seam plane. This, along with other
knowledge, indicates that, under the conditions of coal Carboniferous deposits, a substantial amount of energy is released from the seam in the course of a rock burst. Static evaluation of such situations shows that the maximum stress acting on the seam is the vertical stress. At the same time, this stress causes friction on the boundaries between the seam and adjacent rocks. Therefore, increased stress acting on the seam cannot induce a sudden release of energy accumulated in the seam. How can sudden releases of energy accumulated in the seam be explained, then?

The explanation lies in the analysis of rock mass behavior in relation to the propagation of elastic waves. It is generally known that the velocity of elastic waves depends on the character of environment, in which the waves propagate. Velocities of elastic waves in adjacent rocks and in the seam are especially different. Elastic waves propagate much more quickly in adjacent rocks than in coal. It means that it can happen on the boundary between coal and adjacent rock that the elastic wave, propagating from adjacent rock, extrudes the roof (base) of the coal seam into the seam center, after which the opposite reaction follows. This oscillation of adjacent rock is much faster than the corresponding motion of the seam on the abovementioned boundary. If the intensity of propagation of elastic waves is sufficient, the seam can even be ripped off the adjacent rock. The physical effect of this is, essentially, as if we eliminated friction on contact planes of the seam and adjacent rock. This enables the transformation of accumulated energy into kinetic energy. The seam always tends to extrude from areas with higher stress into areas with lower stress - i.e. into mine workings. Under normal conditions, this extrusion is prevented by the friction. Accumulated energy can be released from the seam only by means of the propagation of elastic waves of sufficient intensity. The propagation of elastic waves itself can cause a certain destruction of mine workings. However, the character of deformation of mine workings caused by the propagation of elastic waves is different from the destruction of mine workings caused by energy release from the seam. Rock bursts induced exclusively by elastic waves are known e.g. from a number of ore mines. Since we, under the conditions of Czech coal mines, can monitor rock-burst deformations caused by the movement in the direction of the seam plane, great attention must be paid to the energy accumulated in the seam.

In the course of exploitation, energy accumulated in the seam is not distributed uniformly in the seam area. As already mentioned, this energy hinges on acting stress in the square. This acting stress is characteristic for every mine working. Minimum stress acts on the sides of the mine working, then it increases with the distance from the mine working up to a certain maximum, after which it starts to decrease down to a certain value of initial acting stress. An area with substantially reduced stress thus exists around every mine working. This area has no redundant energy that could contribute to destructive energy of rock bursts. On the contrary, this area impedes rock bursts.

4. Circumstances impeding rock bursts

The evaluation of forces impeding rock bursts follows from the situation shown in Fig. 2.
In this figure, $\sigma_p$ represents initial acting stress, $\sigma_b$ represents stress circumscribing the area with redundant energy that exerts in the course of rock burst. Redundant energy is located in the area c. The width of the area that impedes the rock burst is b.

The area b must be extruded as energy is being released from the area c. To do this, two types of forces must be overcome. It is the force needed to change the momentum (i.e. invoke motion), and the force needed to overcome friction between the seam and adjacent rock in the area b. On the assumption of constant seam thickness, forces impeding the rock burst can be calculated from the relationship:

$$F_b = I_b \cdot b \cdot m \cdot \rho_v \cdot a + I_b \cdot b \cdot \sigma_b \cdot f$$

where $F_b$ - force impeding rock bursts,
$I_b$ - length of the area b along mine workings ($I_b = l + 2c$),
$b$ - width of the area impeding rock bursts,
$m$ - seam thickness,
$\rho_v$ - volumetric density of the seam,
$a$ - acceleration of the area b during the rock burst,
$f$ - coefficient of friction between the seam and adjacent rock.

If we evaluate possible magnitudes of both kinds of forces impeding rock bursts, we will find out that the force needed to change the momentum is by an order lower than the force needed to overcome friction. Since the latter does not depend on the seam thickness, and the energy from the area c, which plays role during the rock burst, is
directly proportional to the seam thickness, we come to the explanation of the fact that the risk of rock bursts increases with the seam thickness

- If the seam thickness is unstable, the risk of rock bursts can increase or decrease according to the direction of the thickness change. If the seam thickness grows with its distance from the mine working, the risk of rock bursts decreases - see Fig. 3.

![Fig. 3](image)

In this case, the area impeding rock bursts offers much bigger resistance against extrusion into the mine working.

In the opposite case - Fig. 4 - the seam thickness decreases with its distance from the mine working - there is a considerable reduction of forces impeding rock bursts.

![Fig. 4](image)

In the Czech Republic, the width of the zone necessary to impede rock bursts has so far been determined from the depth of the seam deposition and the exploited seam thickness, also taking into account the method of liquidation of mined-out area. In fact, the width of the zone necessary to impede rock bursts should be determined according to the level of elastic energy accumulated in the seam, also taking into account changes of the seam thickness. To determine the accumulated energy, acting stress must be known. However, the determination of absolute values of acting stress is a big problem. Further research is necessary in order to be able to determine acting stress at least for operational purposes.

The extension of the zone impeding rock bursts is mainly realized by the drilling of relief holes (of the diameter of 100 to 200 mm) and relief blasting. However, these preventive measures can, in case of variable thickness, influence the risk of rock bursts in a different way. This is only a part of the problem that awaits its research solution.

5. Conclusion

Both prognosis of rock bursts and preventive measures must be improved to improve the anti-burst prevention.
In the area of rock burst prognoses it would be very advisable to assess the risk according to potential energy per unit of mined out area \( w_{\text{m}} \) in the equation (5). To do this, acting stress must be known, however. In order to determine acting stress, it is necessary to improve various methods of mathematical modelling and use suitable methods of geomechanical monitoring [2].

The value of potential energy per unit of mined out area \( w_{\text{m}} \) should also serve as a basis for the determination of the width of the area impeding rock bursts.

A lot of attention should also be paid to the monitoring of changes of seam thickness around mine workings. An operationally utilizable method must still be developed to do this, however.

Also, the standard methods of preventive measures should correspond with the character of the development of the seam thickness. It is clear from the analysis of cases, in which the seam thickness decreases with its distance from mine working, that the use of relief drilling is not able to induce needful influence. In some cases the influence can even be opposite. It seems that the use of relief blasting is more suitable in such cases. However, the changes of the seam caused by relief blasting must be examined more detailedy.

Some aspects of rock burst occurrence have been discussed in this paper and certain conclusions and recommendations for further research have been formulated on the basis of their analysis. The complex of problems that should be solved in connection with rock bursts is much wider, however. Persistent occurrence of rock bursts requires that even greater attention is paid to this danger, aiming to improve both prognostic and preventive methods.

References