17th International Mining Congress and Exhibition of Turkey- IMCET2001, ©2001, ISBN 975-395-417-4

Mathematical Modelling of the Roadheader's Cutting Process

M.Dolipski, MJaszczuk, P.Cheluszka & P.Sobota
Institute of Mining Machinery, Faculty of Mining and Geology, Silesian University of Technology, Gliwice, Poland

ABSTRACT: The roadheader's cutting system is a complex process characterized by continuous distribution of the mass, with its concentration being visible in such elements as; die rotor of the driving motor, the disks of the flexible coupling, the gear wheels and the cutter heads. The moment of load forces on the shaft of the cutter head is the effect of the action of the roadheader on the rock mass when cutting the room being driven. The forced excitation of vibrations in the cutting system results from resistances to cutting of the rock. Recognition of the physical essence of the process of mining the rock in the course of particular movements of the boom and the modelling of cuts taken by conical cutting tools of the cutter head are starting points for determining the run of such forces.

1 DYNAMIC MODEL

The roadheader's cutting system consists of an asynchronous motor, a flexible coupling, reduction gear and cutter heads. The system can incorporate two transverse cutter heads or a longitudinal one. This complex system is characterized by a continuous distribution of the mass with its concentration being visible in such elements as: the rotor of the driving motor, the disks of the flexible coupling, the gear wheels and the cutter heads. The design of the roadheader's cutting system is conducive to the construction of a physical model featuring a discrete structure (Fig. 1). Thus, it is composed of rotating concentrated masses with moments of inertia / that are connected to each other by means of weightless viscoelastic elements, the specific torsional rigidity of which is *k* and the damping coefficient is *c.* In Figure I, the following items have been marked: rotor of the asynchronous motor (index *W),* disks of the flexible coupling (index *K), n* - stage reduction gear and cutter heads (index G). The physical model

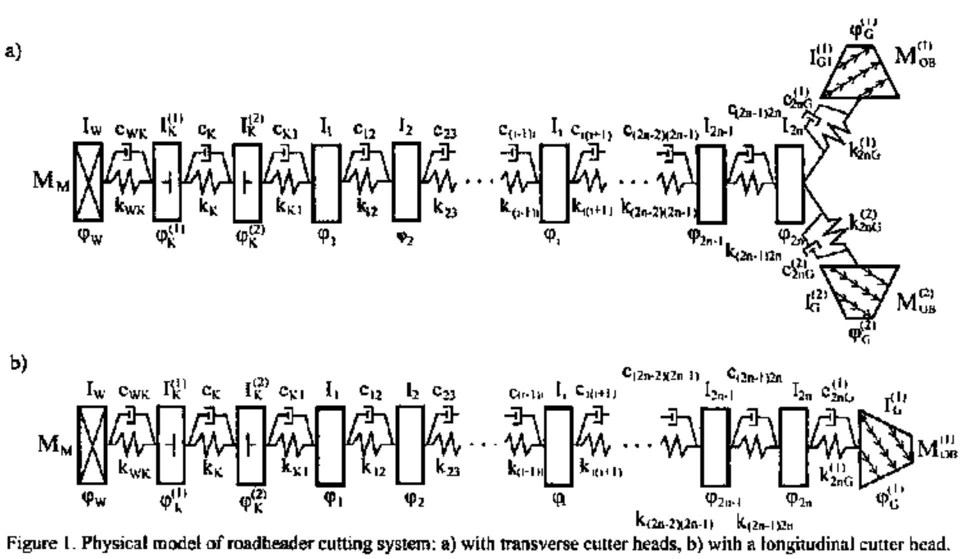

Figure I. Physical model of roadheader cutting system: a) with transverse cutter heads, b) with a longitudinal cutter head.

of the roadheader's cutting system is subjected to the action of external loads in the form of a driving torque M_M and a moment of load forces of the cutter head *MOB* (Dolipski & Cheluszka, 1999).

Motion in the physical model of the roadheader's cutting system is described by a system of ordinary differential equations of the second order (Table 1). The quantity *WG* stands for a number of cutter heads {*WG = 1* corresponds, in this case, to a roadheader equipped with a longitudinal cutter head, *WG = 2* signifies a roadheader with transverse cutter heads). A reduced driving torque applied to a shaft of the cutter head *MM* is determined by means of the relationship given in a previous paper (Dolipski, 1993). The moment of load forces acting on a shaft of a cutter head *MOB* is an effect of the action of cutting tools on the rock mass when mining the road head being driven. It is necessary to model the process of mining the rock mass with cutter heads so that a run of such loading can be determined.

2 MODELLING OF THE CUTTING PROCESS EFFECTED BY MEANS OF CUTTER HEADS

Modelling of the rock-cutting process with cutter heads covers the following phases:

I. finding out the cutting tools arranged on a cutter head which take part in the process of mining the road head of the roadway being driven;
II. establishing cutting zones for tools engaged in the cutting process determined by: the value of the angle at which the tip of a cutting tool enters a cutting zone ôc and of the angle at which the tip of the cutting tool leaves the cutting zone da;
III. the projection of cuts taken by cutting tools for preset parameters: the mechanical properties of the rock being cut, the stereometric features of the cutter head, cutting tools and boom as well as the operational parameters of the roadheader,
IV. defining the kinds of particular cuts and determining the function runs relating to the depth of cuts taken during the revolution of a cutter head ***g =f(VG>>***
V. determining a run of components of the load of the cutting tools: cutting forces P_s *=f((pG),* pressing down forces *Pi - f(($cj* and side force ***Pb =/(<?c),***
VI determining a run of the moment of load forces of the cutter head M_{OB} *=f(<pG)* which is the fi'ieed excitation of torsional vibrations in the roadheader's cutting system.

As die basic technique used for driving the roadway consists of the mining of a road head by extracting the layers parallel to the floor, there are three movements of the boom involved in the process of rock mining which must be taken into consideration:

- displacement of the boom in a direction parallel to the longitudinal axis of the roadway,
- swinging of the boom in a plane parallel to the floor,
- swinging of the boom in a plane perpendicular to the floor in the vicinity of one or the other sidewall of the roadway.

The displacement of the roadheader's boom in the direction parallel to the longitudinal axis of the roadway is connected with the sumping of tiie cutter heads in the rock. With a roadheader which incorporates transverse cutter heads, there are three technological variants to be distinguished (Dolipski & Cheluszka 2000):

I. sumping İn when the boom İs being displaced in a direction parallel to the longitudinal axis of the roadway at a speed v_p (Fig. 2a),
II. sumping in when the boom is being displaced in a direction parallel to the longitudinal axis of the roadway at a speed v_p along with one-side swinging of the boom in a plane parallel to the floor effected at the same time at a speed $v_{,m}$ (Fig. 2b),
III. sumping m when the boom İs being displaced m a direction parallel to the longitudinal axis of the roadway and swung in a plane parallel to the floor at the same time (Fig. 2c).

When transverse cutter heads are advanced towards a road head, the cutting tools move along plane curves having die form of cycloids. This results from the composition of vectors of two speeds, i.e., of a speed of the displacement of cutter heads in a direction parallel to the longitudinal axis of the roadway, and of a tangential velocity of cutting tools rotating around the axis of rotation of the cutter heads. The vectors of these speeds lie in the same plane. During the displacement of transverse cutter heads İn a plane parallel to the floor towards a sidewall of the roadway, cutting tools move along screw lines circumscribed on a side surface of the torus. In this case, the speed vectors in question are perpendicular to each other.

The sumping in of a longitudinal cutter head is of a typical boring character (Fig. 3). A hole made by the tips of the cutting tools arranged over the smallest radii is gradually extended by means of the tips of successive cutting tools, while the tips are describing circles with greater and greater diameters. The cutting tools move in this time along screw lines described on a side surface of the cylinder.

The basic working movement accompanied by the process of the mining of a roadheader covers swinging of a boom m a plane parallel to the floor at

Table 1. Equations of motion in a physical model of the roadheader's cutting system

$$
\begin{array}{llllll}
I_W \cdot \ddot{\varphi}_W & + k_{WK} \cdot \left(\varphi_W - \varphi_K^{(1)}\right) & + c_{WK} \cdot \left(\dot{\varphi}_W - \dot{\varphi}_K^{(1)}\right) & = M_M\left(\dot{\varphi}_W\right) & & \\
I_K^{(1)} \cdot \ddot{\varphi}_K^{(1)} & + k_{WK} \cdot \left(\varphi_K^{(1)} - \varphi_W\right) & + c_{WK} \cdot \left(\dot{\varphi}_K^{(1)} - \dot{\varphi}_W\right) & + k_K \left(\varphi_K^{(1)} - \varphi_K^{(2)}\right) & + c_K \cdot \left(\dot{\varphi}_K^{(1)} - \dot{\varphi}_K^{(2)}\right) & = 0 \\
I_K^{(2)} \cdot \ddot{\varphi}_K^{(2)} & + k_K \cdot \left(\varphi_K^{(2)} - \varphi_K^{(1)}\right) & + c_K \cdot \left(\dot{\varphi}_K^{(2)} - \dot{\varphi}_K^{(1)}\right) & + k_{K1}\left(\varphi_K^{(2)} - \varphi_1\right) & + c_{K1} \cdot \left(\dot{\varphi}_K^{(2)} - \varphi_1\right) & = 0 \\
I_1 \cdot \ddot{\varphi}_1 & + k_{K1}\left(\varphi_1 - \varphi_K^{(2)}\right) & + c_{K1} \cdot \left(\dot{\varphi}_1 - \dot{\varphi}_K^{(2)}\right) & + k_{12} \cdot \left(\varphi_1 - \varphi_2\right) & + c_{12} \cdot \left(\dot{\varphi}_1 - \dot{\varphi}_2\right) & = 0 \\
I_2 \cdot \ddot{\varphi}_2 & + k_{12} \cdot \left(\varphi_2 - \varphi_1\right) & + c_{12} \cdot \left(\dot{\varphi}_2 - \dot{\varphi}_1\right) & + k_{23} \cdot \left(\varphi_2 - \varphi_3\right) & + c_{23} \cdot \left(\dot{\varphi}_2 - \dot{\varphi}_3\right) & = 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \\
I_i \cdot \ddot{\varphi}_i & + k_{(i-1)i} \cdot \left(\varphi_i - \varphi_{i-1}\right) & + c_{(i-1)i} \cdot \left(\dot{\varphi}_i - \dot{\varphi}_{i-1}\right) & + k_{i(i+1)} \cdot \left(\varphi_i - \varphi_{i+1}\right) & + c_{i(i+1)} \cdot \left(\dot{\varphi}_i - \dot{\varphi}_{i+1}\right) & = 0 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \\
I_{2n-1} \cdot \ddot{\varphi}_{2n-1} & + k_{(2n-2)(2n-1)} \cdot \left(\varphi_{2n-1} - \varphi_{2n-2}\right) & + c_{(2n-2)(2n-1)} \cdot \left(\dot{\varphi}_{2n-1} - \dot{\varphi}_{2n-2}\right) & + k_{(2n-1)2n} \cdot \left(\varphi_{2n-1} - \varphi_{2n}\right) & + c_{(2n-1)2n} \cdot \left(\dot{\varphi}_{2n-1} - \dot{\varphi}_{2n}\right) & = 0 \\
I_{2n} \cdot \ddot{\varphi}_{2n} & + k_{(2n-1)2n} \cdot \left(\varphi_{2n} - \varphi_{2n-1}\right) & + c_{(2n-1)2n} \cdot \left(\dot{\varphi}_{2n} - \dot{\varphi}_{n2-1}\right) & + \sum_{j=1}^{WG} k_{2nG}^{(j)} \cdot \left(\varphi_{2n} - \varphi_G^{(j)}\right) & + \sum_{j=1}^{WG} c_{2nG}^{(j)} \cdot \left(\dot{\varphi}_{2n} - \dot{\varphi}_G^{(j)}\right) & = 0 \\
I_G^{(1)} \cdot \ddot{\varphi}_G^{(1)} & + k_{2nG}^{(1)} \cdot \left(\varphi_G^{(1)} - \varphi_{2n}\right) & + c_{2nG}^{(1)} \cdot \left(\dot{\varphi}_G^{(1)} - \varphi_{2n}\right) & = - M_{OB}^{(1)}\left(\varphi_G^{(1)}\right) & & \\
\vdots & \vdots & \vdots & & & \\
I_G^{(WG)} \cdot \ddot{\varphi}_G^{(WG)} & + k_{2nG}^{(WG)} \cdot \left(\varphi_G^{(WG)} - \varphi_{2n}\right) & + c_{2nG}^{(WG)} \cdot \left(\dot{\varphi}_G^{(WG)} - \dot{\varphi}_{2n}\right) & = - M_{OB}^{(WG)}\left(\varphi_G^{(WG)}\right) & &
\end{array}
$$

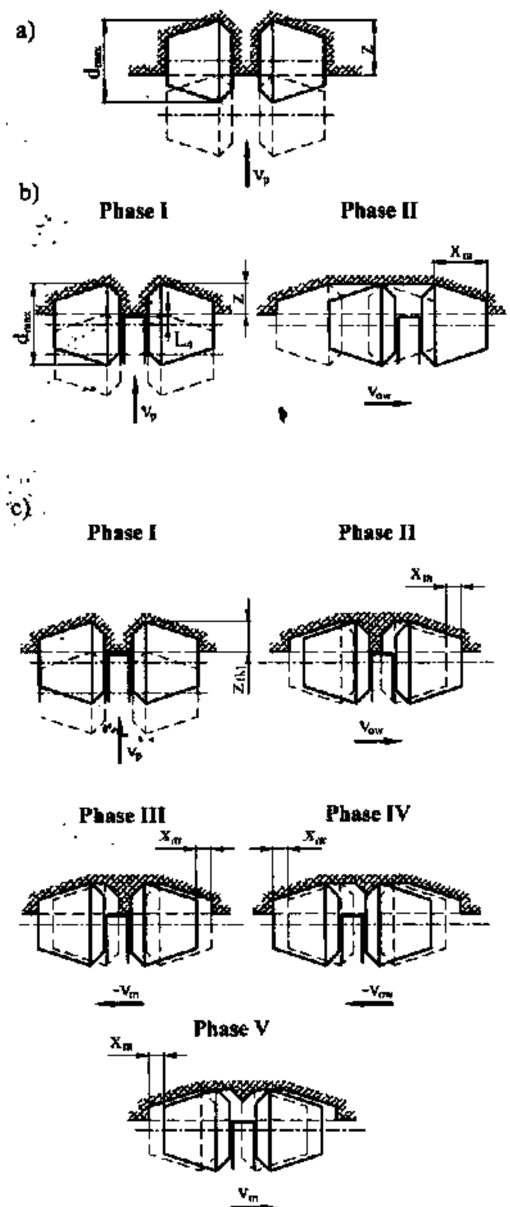

Figure 2. Sumping of transverse cutter heads in rock:
a) technological variant I, b) technological variant II.
c) technological variant HI.

an angular velocity GW The rock is then mined by slicing the layers of height *h* with web z (Fig. 4). The course of cutting done by means of cutting tools arranged on transverse cutter heads during the above movement of the boom has the form of screw lines (Gehring 1989; Haaf 1992; Knissel & Wiese 1981). When a longitudinal cutter head is used for mining purposes, cutting tools move along cycloids. The differences are attributed to the dissimilar models of operation of the two types of cutter heads:

- with transverse cutter heads in working motion, a vector of tangential velocity of the boom swinging is perpendicular to the plane of rotation of a cutting tool tip (plane perpendicular to the axis of rotation of the cutter head running through the cutting tool tip),
- in the case of a longitudinal cutter head, a vector of tangential velocity of the boom swinging İs parallel to the plane of rotation of a cutting too! tip.

The swinging of the boom in a plane perpendicular to the floor is an auxiliary movement which makes it possible to pass to the next layer. It is the determinant of the height of the layer extracted during the working movement. When cutter heads are displaced towards the roof or the floor of a roadway under drivage at the tangential velocity v_{pw}, the cutting tools of both the transverse cutter heads and longitudinal cutter head move along cycloids.

When cutting tools are in contact with the rock mined, i.e., in a zone of cutting, they take cuts when penetrating the rock. The shape and size of these cuts depend on:

- the mechanical properties of the rock mined (compression strength, breakability number, angle of side breaking),
- the geometry of the cutting tools,
- the position of the cutting tool taking a given cut in relation to the cutting *tool* taking the preceding cut,
- the operational parameters of the road header (angular velocity of cutter head, speed of the boom displacement, web, and height of the layer extracted).

In order to determine a run of load on particular cutting tools engaged in the process of the mining of a road head, it is necessary to make a projection of cuts taken by particular cutting tools. The projection of cuts resolves itself into the modelling of the shape of particular cuts and of the shape of the initial break cross-sectional area (before beginning the process of mining) and that of the final break cross-sectional area (after termination of the process of mining). With regard to cutter heads equipped with conical cutting tools, there are three kinds of cuts, distinguished as opening cuts, half-open cuts and open cuts (Wiese, 1982).

The way in which cutting tools are displaced has an effect on the shapes of the cuts and their sequence as well as'influencing the run of their depth. As a result, it also determines the state of the load on the cutting tools and, thus, the character and magnitude of the dynamic load in a roadheader's cutting system (Frenyo & Lange, 1993; Mahnen et al., 1990).

- X

*-%

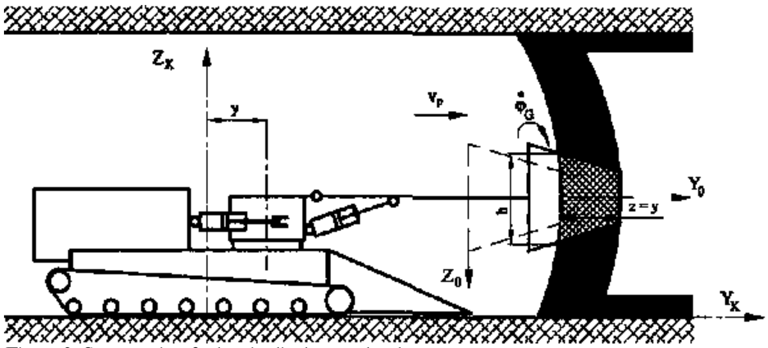

Figure 3. Sumpıng in of a longitudinal cutter head

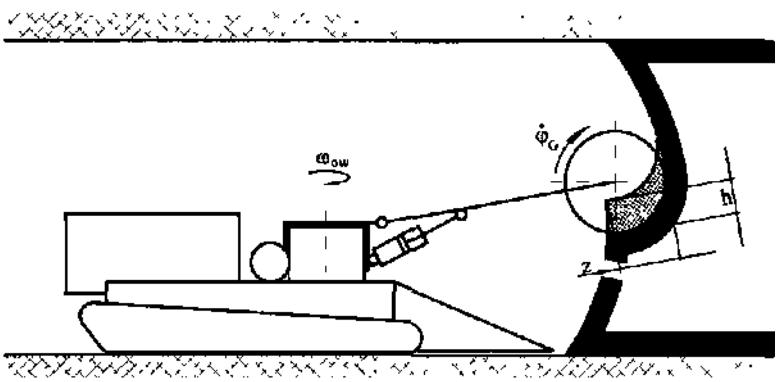

Figure 4. Extraction of a layer parallel to the floor

Whenever cutting tools are displaced along screw lines, the cuts taken by these tools are characterized by (approximately) constant depth (Dolipski & Cheluszka, 1993). A practically constant mean load is the effect. The depths of cuts taken when cutting tools are moving along cycloids vary as a function of the angle of rotation of the cutter head *(p*$_c$ (Dolipski & Cheluszka, 1995).

A cutting tool load, corresponding to the reaction of the rock to penetration of the tip of the cutting tool, is a vector sum of three components which are perpendicular to each other, i.e., of the cutting force P_s, holdmg-down force *Pd* and side force P/,. The spatial orientation of these forces depends on the shape of the movement trajectory of the tips of the cutting tools. Both the type of cutter head (transverse or longitudinal) and the mode of displacement of the boom in the course of the mining of the road head of the roadway under drivage have an effect on this orientation.

Depending on the depth of cut, the mean value of the cutting force is determined on the basis of Evans' theory of cutting with a conical cutting tool (Evans, 1984). From the analysis of the dynamic phenomena in a roadheader's cutting system, it appears that İt does not suffice to assume loading of a cutting tool with cutting resistances at the level of the mean value for a given depth of cut. In reality, it varies within a wide range, even when a cut of constant depth İs taken. Therefore, a method for determining a run of load on the cutting tools has been worked out for the purpose of investigation of the dynamic phenomena occurring İn a roadheader's cutting system (Dolipski & Cheluszka, 1998)

The overall moment of load forces of a cutter head is equal to a sum of moments of load forces on cutting tools in a zone of cutting at a given moment. In the case of transverse cutter heads, furnished with *N* cutting tools each, a moment of load forces is expressed by the formula:

- during displacement of a boom in a direction parallel to the longitudinal axis of a roadway:

$$M_{OB}(\varphi_G) = \sum_{i=1}^{N} W_i(\varphi_G)\left[P_{si}(\varphi_G)\cdot\cos(\sigma_i) + -P_{di}(\varphi_G)\cdot\sin(\sigma_i)\right]\cdot r_i \qquad (1)$$

wherein.

$$\sigma_i = arc\sin\left[\frac{v_p \cdot \cos(\varphi_G - \vartheta_i)}{v_{Si}}\right] \quad (2)$$

The function $W_i(\varphi_G)$ assumes values:

$$W_i(\varphi_G) = \begin{cases} 1, & \text{cutting tool is in a zone of cutting,} \\ 0, & \text{cutting tool is not in a zone of cutting} \end{cases} \quad (3)$$

- during swinging of the boom in a plane parallel to the floor:

$$M_{OB}(\varphi_G) = \sum_{i=1}^{N} W_i(\varphi_G) \cdot \left[P_{si}(\varphi_G) \cdot \cos(\rho_i) + - P_{bi}(\varphi_G) \cdot \sin(\rho_i)\right] \cdot r_i \quad (4)$$

wherein:

$$\rho_i = arctg\left(\frac{v_{ow}}{\dot{\varphi}_G \cdot r_i}\right) \quad (5)$$

- during swinging of the boom in a plane perpendicular to the floor:

$$M_{OB}(\varphi_G) = \sum_{i=1}^{N} W_i(\varphi_G) \cdot \left[P_{si}(\varphi_G) \cdot \cos(\xi_i) + - P_{di}(\varphi_G) \cdot \sin(\xi_i)\right] \cdot r_i \quad (6)$$

wherein:

$$\xi_i = arc\sin\left[\frac{-v_{pw} \cdot \sin(\varphi_G - \vartheta_i + \alpha_V)}{v_{Si}}\right]. \quad (7)$$

where: M_{OB} - forced excitation of torsional vibrations, N - number of cutting tools on a cutter head, P_s - instantaneous value of cutting force, Pa - instantaneous value of holding-down force, Pb - instantaneous value of side force, r, ϑ - coordinates of cutting tool tip in a polar system, v_p - speed of displacement of boom in a direction parallel to the longitudinal axis of the roadway, $v_{,m}$ - tangential velocity of swinging of the boom in a plane parallel to the floor, v_{pu}, - tangential velocity of swinging of the boom in a plane perpendicular to the floor, v_s - cutting speed, o> - angle of swinging of the boom in a plane perpendicular to the floor, φ_G - rotational coordinate of cutter head, and $\dot{\varphi}_G$ - angular velocity of cutter head.

3 COMPUTER SIMULATIONS OF THE PROCESS OF MINING WITH A ROADHEADER

Figures 5, 6 and 7 show computer simulation of the process of sumping of transverse cutter heads in the rock, carried out according to the second technological variant (Fig. 2b). The simulation has been performed for rock the compression strength of which is equal to *65 MPa*. In the first phase of sumping in, the cutter heads penetrate into the surface and road head until they reach a web of *0.075 m* İn this case (Fig. 5).

The speed of displacement of the boom in the direction parallel to the longitudinal axis of the roadway amounts to *0.05 m/s*. The dynamic load in the coupling of the cutting system initially increases and after reaching the maximum value, it decreases (Fig. 6). The peak value is *2615.9 Nm,* while the amplitude is equal to *2899.4 Nm.*

In the second phase of sumping in, the boom is swung from the axial position to the right at an angular velocity ω_{ow} = *0.031 rad/s* (Fig. 7). The distance covered by the cutter heads in this phase of sumping in results from the width of the rib between the cutter heads. The dynamic load in the coupling of the cutting system is here more stable in character. It ranges from *1323.1 Nm* to *+3488.4 Nm* (Fig. 6).

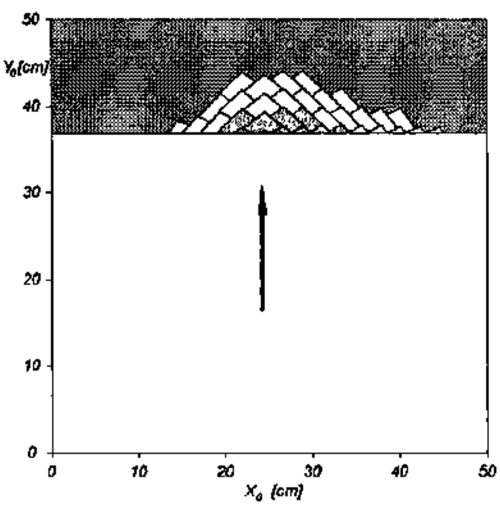

Figure 5. Break cross-sectional area made by cutting tools of the right—hand cutter head in the first phase of sumping İn.

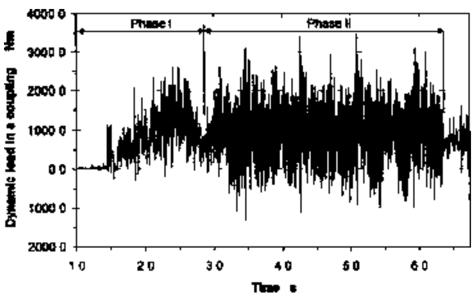

Figure 6 Run of dynamic load in coupling of the cutting system during sumping of transverse cutter heads in rock

The course of the process of mining by means of the longitudinal cutter head during swinging of the boom m the plane parallel to the floor is shown in Figures 8 and 9 The mining of a rock layer of *60 MPa* in compression strength with a web of $z = 0\ 30\ m$ was simulated The longitudinal cutter head was then displaced at the tangential velocity $v_{ow} = 0\ 04\ m/s$ The run of the dynamic load in the coupling of the cutting system is characterized by great variability (Fig 9) The peak value of dynamic load in the coupling of the cutting system reaches *3100 Nm*, while the amplitude of this load is equal to *4270 Nm*

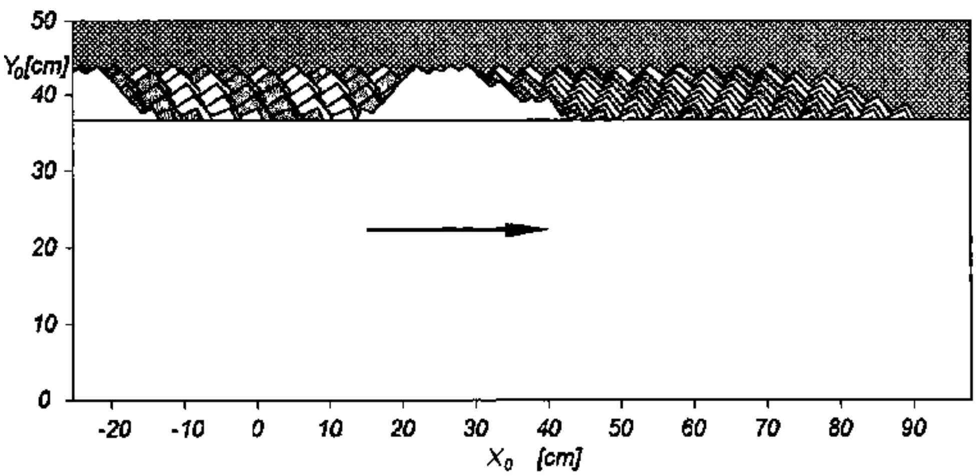

Figure 7 Shapes of cuts taken by cutting tools of the nght-hand and left-hand cutter head in the second phase of sumping in

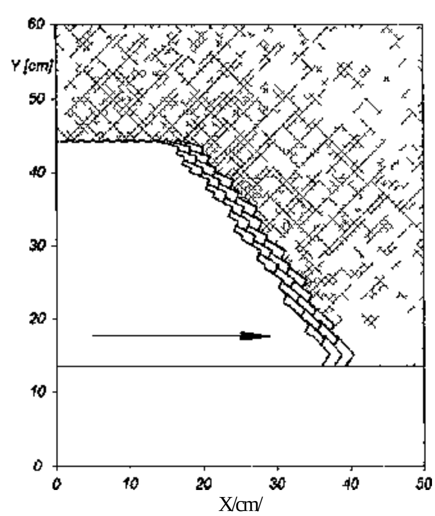

Figure 8 Break cross-sectional area made by cutting tools of longitudinal cutter head displaced parallel to the floor

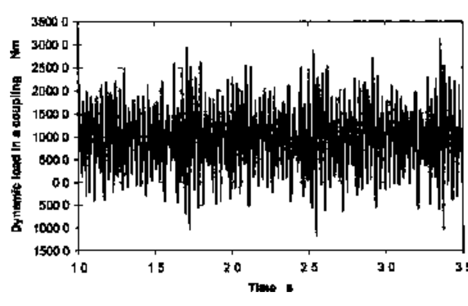

Figure 9 Run of dynamic load in coupling of the cutting system dunng mining by means of longitudinal cutter head displaced parallel to the floor

4 CONCLUSIONS

The dynamic model of the roadheader's cutting system developed has been experimentally verified on the basis of dynamic characteristics recorded under real operating conditions Having been accepted, the model has successful application in research and design practice. In particular, it allows:

- graphics of break cross-sectional areas made by a cutter head to be computer generated in order to determine the depths and sectional areas of cuts, the volumes of the material cut and the performance of mining;
- dynamic loads in all elements of the cutting system to be determined when taking any technological variant being realized into consideration;
- dynamic phenomena occurring in the cutting system of roadheaders produced at present to be investigated by means of computer so that conclusions resulting from experiments can be facilitated;
- computer investigation of the process of mining to be carried out, while making it possible to change freely the values of particular parameters of the roadheader and of strength properties of the rock to determine the optimum parameters relating to mass, elasticity, damping of the cutting system as well as the operational parameters of the roadheader;
- computer analysis to be performed at the stage of the designing of roadheaders which incorporate cutting systems of the new generation, without the necessity of building expensive prototypes;
- the design of cutter heads for roadheaders and the selection of them for definite mining and geological conditions to be computer aided;
- the demand for energy in the process of mining the rock to be stated when designing the technical equipment of a road head to be suitable for the given mining and geological conditions;
- the process of mining to be automatically controlled in respect of reducing the dynamic loads and specific energy consumption of mining as well as allowing work safety to be enhanced.

The dynamic model presented finds successful application in the process of designing the cutter heads and subassemblies for roadheaders made by the REMAG Company - a leading manufacturer of these machines in Poland. The development of novel cutter heads for the R-100 roadheader, characterized by the arrangement of cutting tools along screw Unes with a small helix angle, is, among others, a result of many years of comprehensive computer investigations (Fig. 10). The rock is here cut by the tips of cutting tools of successive groups entering the zone of cutting. Cutting is realized so that in each successive group of cutting tools, the tip of the cutting tool situated on the smallest radius starts me process and the tip of the cutting tool situated on the greatest radius finishes it. In this case, the load of the cutting tools is visibly lower due to the additional area of exposure. This leads to reduction of the dynamic load and to a decrease in the specific energy consumption of mining. The comparison tests carried out in underground workings of coal mines show that a roadheader equipped with the new cutter heads, characterized by screw lines with a small helix angle, consumed less energy than the conventional solution. The average specific energy consumption of mining by means of the new cutter heads was 5% lower than the average specific energy consumption typical for mining with the aid of standard cutter heads, although the compression strength of the rock being mined increased by 60%.

Figure 10. Novel cutter head with screw lines characterized by small helix angle.

REFERENCES

Dolipski M, 1993. Dynamic model of coal plough. *Archives of Mining Sciences* 3:315-330.

Dolipski M, Cheluszka P. 1993. Belastungsmoment des Schneidkopfes einer Teilschnittvortriebsmaschine. *Bergbmi* 5:198-202.

Dolipski M-, Cheluszka P. 1995. Vergleichende Untersuchungen an Längs- und Querschneidköpfen in einer Vortriebsmaschine. *Bergbau* 4:154-159.

Dolipski M., Cheluszka P. 1998. Bestimmung der Form des Schnittkraftverlaufs an Kegelmeifleln von Vortriebsmaschinen. *Glückauf-Forschungshefte* 4:123-127.

Dolipski M., Cheluszka P. 1999. Dynamic model of a roadheader's cutting system which incorporates transverse cotter heads. *Archives of Mining Sciences* 1:113-146.

Dolipski M., Cheluszka P. 2000. Dynamik des Einschneidevorgangs einer Teilschnittmaschtne mit Querschneidkopf. *Glückauf-Forschungshefte* 2:53-65.

Evans I. 1984. Basic Mechanics of the Point-Attack Pick. *Colliery Guardian S:* 189-193.

Frenyo P., Lange W. 1993. Die Auslegung von Schneidköpfen für optimale Löseleistungeo. G/wc*flw/7:524-531.

Gehring K..-H. 1989. A cutting comparison. *Tunnels and Tunneling* 11:27-30.

Haaf J. 1992. *Das Verschleiß- und Drehverhalten von Meißeln für Teilschnitt-Vortriebsmaschinen.* Diss. TU Clausthal.

Kmssel W , Wiese H-F 1981 Möglichkeiten zur Verbesserung des Losevorgangs von Teilschnitt-Vortriebsmaschinen *GlückauflO* 1360-1366
Mahnen U , Gerhardt H , Bellman A 1990 Rechnergestutzte Optimierung der Arbeitsweise von Schneidköpfen an Teil-Schnitt-Vortriebsmaschinen *Glückauf-Forsch ungsh efte* 6 277-282
Wiese H -F I982 *Grundlagenuntersuchung zur Optimierung der Losearbeit von Teilschnttt-Vortrtebsmaschinen mit Querschneidkopf* Diss TU Clausthal