EXPERIMENTAL IDENTIFICATION OF THE DYNAMIC LOAD OF CONICAL PICKS DURING THE CUTTING PROCESS OF TRANSVERSE CUTTING HEADS OF BOOM–TYPE ROADHEADER

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ABSTRACT

The boom–type roadheaders are commonly used for drilling roadways in underground mines and tunnels in civil engineering. Rock cutting in the heading face of the roadways or tunnels is carried out on the principle of cutting with picks, most often conical. The cutting tools are subjected to strong dynamic loads that are the reaction of the rock-cut to the cutting picks. This applies in particular to the cutting of hard rocks. The high variability of the picked load has an unfavorable effect on the fatigue strength and the durability of picks and pick holders, the durability of the main roadheader components and the course of the cutting process. The article presents selected results of the R–130 roadheader (manufactured by Famur S.A.) obtained during simulated excavation of the heading face at the experimental stand in the Technological Hall of the Faculty of Mining and Geology at the Silesian University of Technology. During these tests, forces acting directly on the three conical picks of the cutting head were recorded. This enabled the identification of the size and nature of the actual load of the picks on the cutting head of the roadheader while cutting the rock mass with various workability in different conditions of this process. For the recording of components of the picks load, an innovative, autonomous measurement & recording system was used. This system has been built inside the cutting head of the tested roadheader. It has been equipped with specially designed pick holders (measuring devices) with built–in force sensors.

Keywords: *roadheader, cutting process, conical picks, dynamic load, experimental tests*

INTRODUCTION

The boom–type roadheaders (fig.1) are heavy-duty machines commonly used in underground mining and tunnelling for drilling of roadways, chambers and tunnels. Rock cutting is done here on the basis of cutting with picks installed in pick holders located on the side surface of the cutting head. One longitudinal or two transverse cutting heads are placed at the end of a movable boom, which is swung in a parallel plane and perpendicularly to the floor. The cutting heads are moving in this way on the surface of the heading face of the roadway or tunnel. It is, therefore, possible to drill roadways or tunnels of any shape and with a different size of its cross-section. This is a big advantage of this type of machines compared to TBM machines, which can only drill excavations of a circular cross-section of a given diameter [6]. The ability to move the cutting heads on any path allows for adapting of the heading face cutting technology to the geological structure of the rock massive, in order to ensure the optimal working conditions of the roadheader, maximize the drill speed and obtain the established shape of the excavation cross-section [9].

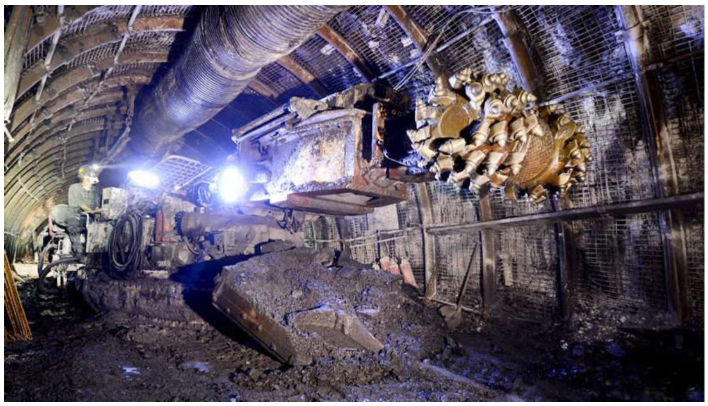

Fig. 1. A boom–type roadheader equipped with transverse cutting heads in the underground mine's roadway (www.mining-technology.com)

During mining, in particular of hard rocks, the cutting picks are subjected to strong dynamic loads. This is due, on the one hand, to the mechanical properties of the rock (the brittleness of the rock), the way in which the roadheader's picks interact with the cut rock and the process of the breakout of the grains of the excavated material. Due to the geometry, especially of the conical picks, the rock is subject to crushing, as well as elastic and plastic deformation at the bottom of the furrow made by the pick. The dynamic character of the process of cutting rocks with mining cutting machines' picks is confirmed by the results of many years of experimental research and theoretical work (e.g. [5], [8]). The large fluctuation of the pick load is the source of intense vibrations of the boom of the roadheader, transferred through construction nodes to other components of the roadheader, as well as the high dynamic loads of its drives. The dynamic nature of the picks' load is also one of the causes of their intensive wear and tear and even premature destruction (e.g. breakage) of an ad hoc or fatigue nature.

So far, the experimental research of cutting rock with mining cutting machines' picks has focused mainly on the implementation of this process with a single pick. Specially constructed test stands or adapted metal-working machines were used for this purpose. Moreover, the research of the cutting process is carried out on samples of natural rock or of equivalent materials such as cement-sand masses. From the point of view of the dynamics of the rock cutting process, such kind of bench tests don't give a full picture of the actual nature and size of the load of the cutting picks. The dynamic properties of the stands for testing the cutting process with a single pick, and often also the parameters at which the cutting process is carried out at the workstation differ significantly from the real conditions that we deal with in the case of cutting machines. What is more, the actual rock cutting process is carried out with multi-pick cutting heads, not a single pick. The interaction that occurs in the system: the cutting machine – the cut rock, the interaction between neighbouring picks of the cutting head and stochastic variability of mechanical properties of the cut rock, make the course of the picks' load obtained in laboratory conditions differ from the actual ones. In many cases, these tests are limited to determining only the cutting force, assuming that this force has the most important meaning [4], [5], [10]. From the point of view of the analysis of the mining machine's dynamics, this is a far-reaching simplification.

Identification of the actual course of the dynamic load of the cutting picks by means of measurement is basically possible only directly on the roadheader, while cutting the rock with it. This is an extremely difficult undertaking, especially in operational conditions. It requires a design of the measuring and recording system that could be installed in the cutting head and an adaptation of the cutting machine to these needs.

The article presents the selected results of the measurements of the conical picks' dynamic load on the cutting head of a R–130 roadheader (manufactured by Famur S.A.) with transverse cutting heads. These measurements were carried out in laboratory conditions during a simulated excavation of the heading face. The experimental roadheader cut the surface of the cement-sand block. This block consisted of five layers of varied uniaxial compressive strength (UCS), ranging from 33 to 69 MPa. The cutting was carried out while moving the cutting heads parallel to the floor. Time courses of dynamic load components of three selected picks were recorded, with which one of the cutting heads was equipped. The cutting process was carried out at different values of the parameters characterizing it: the web of cut z, cut height h, the angular velocity of the cutting heads $\dot{\varphi}_G$ and the speed of their movement v.

MEASURING SYSTEM

The measurement of the dynamic load of roadheader picks in the conditions of simulating the cutting of the cement-sand block included time courses of three mutually perpendicular components, i.e. cutting force (F_C), normal force (F_N) and sideway force (F_S) – fig.2 – for three selected conical picks on the cutting head of the tested roadheader. These picks are positioned in different places of the cutting head. An innovative, autonomous measurement & recording system was used for this purpose. It was installed in the cutting head and moved with it. Due to the fact that during mining the cutting heads of the roadheader make a rotational movement around their axis of rotation and are moved along the surface of the heading face as a result of the deflection of the roadheader's boom parallel and perpendicular to the floor, the measurement & recording system could not be connected in any way to the stationary elements of the test stand via power and signal cables. Hence, the measuring system developed for these tests was equipped with its own battery power system. The recording of data was carried out on the memory card of the recorder built inside the hub of the cutting head.

Measurement of the three components of the dynamic load of individual conical picks was carried out with the use of the three-axis force sensors type 9077C of a Swiss company KISTLER. They were built into specially designed pick holders (measuring devices) (fig.3) attached to the side surface of the cutting head in place of standard pick holders. The design of the measuring pick holders allows the use of conventional roadheaders' picks, so that they don't disrupt the rock cutting process. The type of force sensors and their metrological characteristics were selected on the basis of a computer simulation of the load to which the conical picks are subjected during the cutting of rocks with mechanical properties corresponding with the test conditions.

The force sensors in the measuring pick holders are connected with cables to the power source and the recording unit. These elements have been installed in a cylindrical housing with dimensions adapted to the diameter and the depth of the hub in the cutting head (fig.4). The data logger used allows the recording of time courses of 10 parameters (three load components of each of the three picks and a synchronization signal) with a frequency of up to 1000 Hz. The capacity of the memory card and the capacity of the batteries supplying the measuring devices and the data logger allow to measure the load of picks for up to 24 hours. By recording the synchronization signal (generated with every rotation of the cutting head) it was possible to synchronize the data with a stationary recorder, in which the position of the cutting head on the surface of the cut block was recorded. This was the basis for determining the conditions of cutting. The transmission of the measurement data to a PC computer for further processing and analysis was carried out via a wireless network after stopping the data logging. The ongoing control of the measurement system is possible with the use of dedicated software installed on a PC, laptop, tablet, or smartphone. The remote communication with the data recorder is carried out via WLAN.

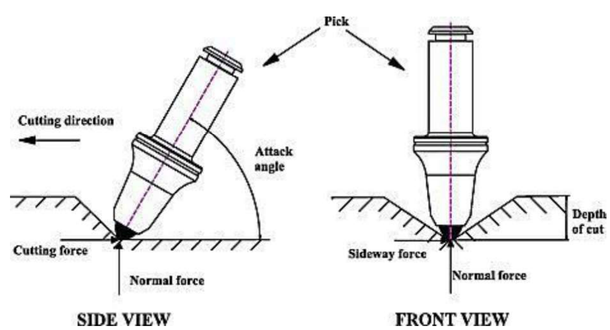

Fig. 2. The components of the loads of conical picks of mining machines [11]: the cutting force, the normal force and the sideway force

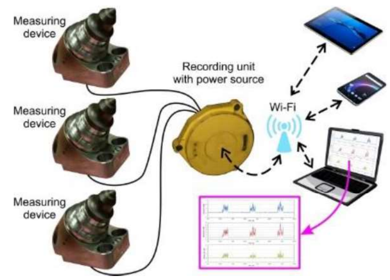

Fig. 3. The measurement & recording system of the dynamic load for three picks placed on the cutting head of a roadheader

Fig. 4. The measurement & recording system mounted on the cutting head of the roadheader

THE REAL-TIME COURSES OF THE DYNAMIC LOAD OF PICKS DURING THE CUTTING PROCESS – SELECTED EXAMPLES

Figure 5 shows an example of the dynamic load components of one of the roadheaders' picks (No. 28) generated by the cutting process when making the uppercut with a height of h = 125 mm and a web of cut of z = 200 mm. The cutting head was moved with the speed $v \approx 35$ mm/s, and its angular velocity $\dot{\varphi}_G$ was equal to 5.5 rad/s. During the presented fragment of measurement, the cutting head was cutting the layer with UCS σ_C = 50 MPa. During the 10-second measurement period the cutting head made nine revolutions. As we can see, the load of cutting picks is characterized by a high variability. For example, the cutting force F_C acting on the conical pick No. 28 in the analysed nine revolutions of the cutting head reached peak values ranging from 3.3 to 6.3 kN. Mean values of this force in subsequent cutting cycles were, however, in the range from 1.2 to 2.2 kN. The peak value of the normal force F_N for this pick was in the range from 4.5 to 9.2 kN, and its average value ranged from 1.8 to 3.2 kN. The average value of the sideway force F_S was close to zero, and the peak values didn't exceed 3 kN.

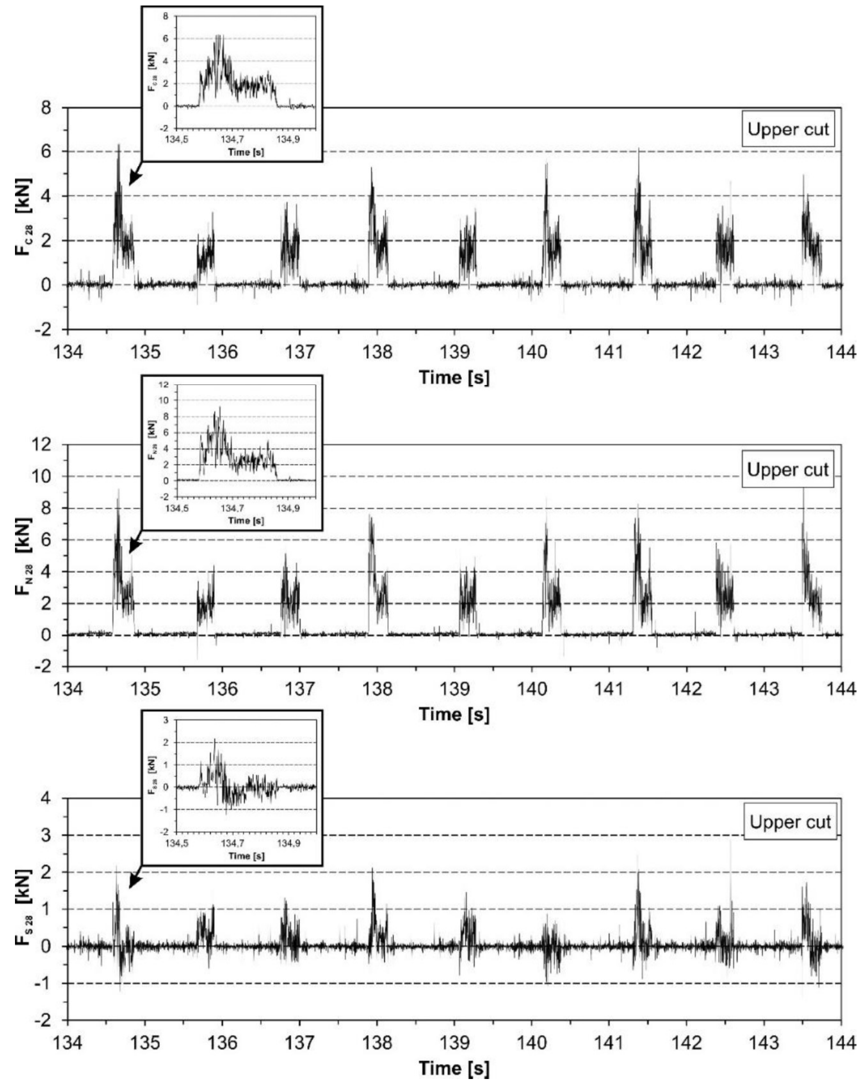

Fig. 5. Sample time courses of the components of pick load during making the uppercut (nine revolutions of the cutting head)

Although it is assumed that the depth of cut performed by a given pick is roughly constant when cutting with the transverse heads of the roadheader parallel to the floor, the courses of the components of the pick load are characterized by high variability. This applies in particular to the cutting force (F_C) and the normal force (F_N). When the pick comes in contact with the cut rock, the strength increases. This effect is particularly noticeable when making the upper cut. The entry of the pick into the cutting zone is accompanied by a hit to the surface of the excavated rock. The influence of the pick on the cut rock causes the grains of the spoil to break away. Due to the brittle properties of natural rocks and the cement-sand masses cut during the discussed studies, the size of grains of spoil following the moving pick is strongly diversified. This is one of the important sources of high variability of the pick load, leading to high dynamics of the mining machine. The character of the normal force course F_N is similar to the nature of the cutting force F_C. This can be seen on enlarged excerpts of the time courses shown in fig.5. The course of sideway force F_S differs from the course of the other two components. This force essentially oscillates around zero.

ANALYSIS OF THE DYNAMIC LOAD OF THE ROADHEADER' PICKS

The observations of time courses of dynamic load components of picks during the cutting process indicate the existence of mutual relations between them. It can be expected that these relations will depend to a large extent on the mechanical properties of the rock being mined. The relationship between forces: the normal F_N and the sideway F_S from the cutting force F_C for cut material is well described by the linear regression (fig.6). The carried out statistical tests confirmed the significance of the correlation coefficient of the studied relationships (the test probability p was lower than the assumed significance level α = 0.05, which allowed to reject the null hypothesis about the lack of correlation [2]). The values of the correlation coefficients r were respectively: 0.95 – for $F_N=f(F_C)$ and 0.8 – for $F_S=f(F_C)$. The significance tests of coefficients of regression equations of the dependences studied here showed that the slopes significantly differ from zero (test probability p <0.05). The obtained linear regression model of the dependence $F_N=f(F_C)$ passes near the point (0,0) – the intercept differs slightly from zero (p = 0.2). In the case of the sideway force dependence on the cutting force, the regression model doesn't pass through the point (0,0), since the intercept differs significantly from zero (p <0.05). The obtained mean values of the ratio of pick load components F_N^m / F_C^m and F_S^m / F_C^m for the cutting layer with UCS σ_C = 62 MPa were respectively: 3.2 and 0.4. This means that on average the normal force was slightly more than 3–times greater than the cutting force, while the average value of the sideway force constituted only 40% of the average cutting force value. From the point of view of the load of the cutting head, its drive and the body of the roadheader, the two components of the pick load, that is: the cutting force and the normal force, are therefore of significant importance. Due to the relatively small values of the sideway force acting on the picks during mining, it is often ignored.

With the increase of UCS of the material being cut, the value of the load ratio of the picks increased (fig.7). This concerned in particular the ratio of the normal force to the cutting force determined for mean values F_N^m / F_C^m (solid line) and peak values $F_N^{\max} / F_C^{\max}$ (dash-dotted line) of the course of components of the pick load. As we can see, this is a nonlinear relationship, which can be approximated with a polynomial of degree 2. In the tested range of UCS of cement-sand masses, i.e. from 33 to 62 MPa, the ratio of average values of the normal and the cutting forces varied from about 1.5 to 3.2. The ratio of peak values of these forces ($F_N^{\max} / F_C^{\max}$) was slightly lower. With the increase of UCS of the excavated material, it varied from 1.3 to 2.9. The range of variation in the ratio of average values of the sideway and the cutting forces (F_S^m / F_C^m) was in the range from 0.1 to 0.43 (dashed line). Slightly higher values were obtained for the ratio of peak values of these loads ($F_S^{\max} / F_C^{\max}$). However, they didn't exceed 0.6.

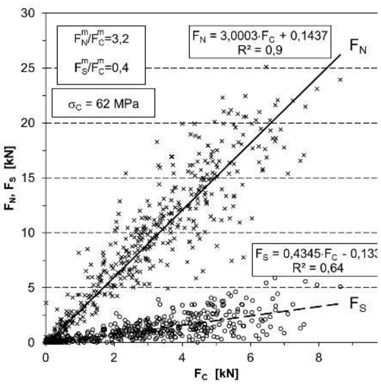

Fig. 6. The dependence of normal F_N and sideway F_S forces on the cutting force F_C

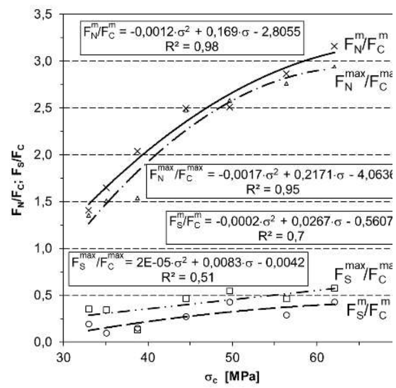

Fig. 7. The dependence of the ratio of pick load components on the UCS

As the publications show (e.g. [1], [7], [11], [12]), the ratio of the normal force to the cutting force for rocks of natural origin can also be of a wide range – usually of the range of about 1 to 2. However, it may exceed the value of 3. Such high values of the F_N/F_C force ratio may take place during mining of very hard rocks, such as sandstone [3].

The average values of the ratio of the normal force to the cutting force obtained during the cutting process of the cement-sand masses correspond to the values obtained during the excavation of hard rocks of natural origin.

CONCLUSION

The presented in this work results of experimental investigations carried out in the conditions of simulated excavation of the cement-sand block with the R–130 roadheader are a source of valuable knowledge about the state of real dynamic load of conical picks of a mining machine. Thanks to the use of an innovative measurement & recording system, it has been possible to register the course of forces acting on selected picks arranged on the cutting head of the tested roadheader. The registered characteristics, after the confrontation with the conditions of the mining process, allowed to identify the size and nature of the dynamic load of conical picks and to link it to the mining process parameters, including, inter alia, mechanical properties of the excavated material (cement-sand masses with different UCS). The recorded load patterns reflect the real response of the cut rock to the penetration of the picks. In this case, not only the mechanical properties of the rock and the geometry of the picks used are taken into account, but also the dynamic properties and the technical characteristics of an actual mining machine (roadheader) as well as interactions occurring in the system: the machine – the cut rock. The obtained pick load conditions are therefore the real answer of the tested object to the pursuance of the mining process with given values of the parameters of this process. Such possibilities are not provided by laboratory stands commonly used in the research of the rock cutting process with a single pick or even a group of picks.

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