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Krzysztof KOTWICA*

EFFECT OF SELECTED WORKING CONDITIONS OF CUTTING PICKS ON THEIR WEAR DURING THE MINING OF HARD ROCKS

SUMMARY

The article presents the influence of work conditions of rotary-tangential picks on their wear while compact rocks mining. There was mainly presented the influence of applying high-pressure support and spraying the tangent-rotary tools with water jets on their quantitative and qualitative wear during conducted laboratory tests in comparison to tools operating in dry conditions. There was suggested and presented a solution of holders lubricated with water under pressure to provide proper conditions of tangent-rotary tools work in the clamp. The results of laboratory tests of rotary-tangential picks fixed in the folders were presented and compared with results of picks only supported or sprayed with high-pressure water jets.

***Keywords**: hard rock, tangential-rotary pick, mining, wear, high pressure water jet assistance, lubrication*

WPŁYW WYBRANYCH WARUNKÓW PRACY NARZĘDZI SKRAWAJĄCYCH NA ICH ZUŻYCIE PODCZAS URABIANIA SKAŁ ZWIĘZŁYCH

W artykule przedstawiono wpływ warunków pracy noży styczno-obrotowych na ich zużycie podczas urabiania skał zwięzłych. Przedstawiono wpływ zastosowania wysokociśnieniowego wspomagania oraz zraszania strumieniami wody noży styczno-obrotowych na ich ilościowe i jakościowe zużycie podczas przeprowadzanych badań laboratoryjnych, w porównaniu z nożami urabiającymi „na sucho”. Zaproponowano i przedstawiono rozwiązanie uchwytów smarowanych wodą pod ciśnieniem dla zapewnienia prawidłowych warunków pracy noży styczno-obrotowych w uchwycie. Przedstawiono wyniki badań laboratoryjnych noży styczno-obrotowych mocowanych w tych uchwytach i porównano je z wynikami noży tylko wspomaganych lub zraszanych wysokociśnieniowymi strumieniami wody.

***Słowa kluczowe**: skała zwięzła, nóż styczno-obrotowy, urabianie, zużycie, wspomaganie wysokociśnieniowe, smarowanie*

1. INTRODUCTION

In recent decades the problems of mechanical hard rock cutting in Polish mining related to deeper coal seams and driving workings in harder rocks containing more highly abrasive inclusions, have become more intensive. It was related mainly to small-cutting advance rate and very high wear of the shearer picks, so the cutting process became not effective economically. The attempts directed for applications of the new type of cutting tools, mainly the tangential tools with sintered carbide inserts of increased diameter and disc cutters with small diameter, did not lead to successful results in hard rock cutting. Therefore, the steps to develop the new rock cutting technologies have been undertaken. At the Department of Mining, Dressing and Transportation Machines, of the AGH University of Science and Technology, Krakow, successful investigations of the rock mining with use of high-pressure water jet assistance and lubrication holders have been executed. During these tests first of all the wear of used tangential-rotary picks was measured. Results of these investigations are described below.

2. NEW SOLUTIONS OF TANGENTIAL-ROTARY PICK'S HOLDERS

The tangential-rotary picks with the sintered carbide blades that have been manufactured on a large scale found their wide application as cutting tools to be mounted on the mining units of the mechanical coal miners or modern drill bits. Due to their specific character of rock loosening and self-sharpening as a result of turning in a holder during operation, such tools are predisposed to mine hard and very hard rocks. When the cone tool blade enters into the contact with the rock it starts developing the triaxial hydrostatic stress, which plastifies the rock, accumulating its losses just near the tip (Evans 1984). The constant factors of a proper operation of tangential-rotary picks are as follows: their right setting (selection of the optimum cutting angles), the way they are mounted and the kind of bearing in the units or tool holders. Tangential-rotary picks tend to operate under quite difficult conditions, especially when during hard rock mining. Some substances (fine fraction of the rock and drilling fluid or water used for sprinkling) reach and contaminate the zone of "bearing" of tool holders and make it difficult for tangential tools to rotate in the holders or heads of mining devices, as depends on the kind of sliding friction. Dry friction usually occurs in the tool bearing constructions mentioned above and it is characterized by a relative displacement of collaborating elements with no participation of a lubricating medium and by cutting down the tops of uneven surface.

As it has been already mentioned both in Poland and abroad the bearing of tangential rotary tools in the mining

* Department of Mining, Dressing and Transport Machines, AGH University of Science and Technology, Krakow, Poland; kotwica@agh.edu.pl

units takes place either directly in the holders or in the holders with hardened exchangeable sleeves. The tools are set up in the holders at the given angles in order to maintain their proper operation (Jonak 1998). These angles are shown on the scheme in Figure 1. Such a mounting way of bearing generates the occurrence of dry friction that leads to seize tool handles in the holders, deteriorate their rotations and cause their premature asymmetric wearing. This situation applies for ca. 50% of tools used in the industry.

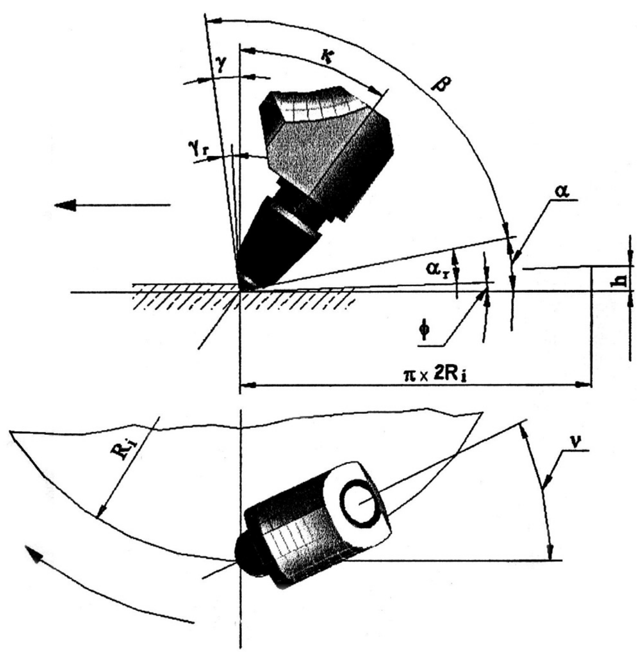

Fig. 1. Parameters of cutting and tool setting angle of the rotary tangential tool (Jonak 1998): α – tool clearance, α_r – tool auxiliary clearance, β – blade angle, γ – tool rake angle, γ_r –auxiliary tool rake angle, ν –tool side setting angle, κ – tool setting angle, *h* – depth of cut, R_i – radius of *i* – tool

In the first laboratory tests with high-pressure water jet in the place of contact pick's blade with the rock was introduced. Quantitatively reduce the amount of pick's blade was obtained, but further a problem with the rotation of the tools in the holder was observed

In the Department of Mining, Dressing and Transportation Machines, of the AGH University of Science and Technology, Krakow have then taken some attempts aimed at bearing of the rotary tangential tools' handles in the holders towards changing dry or semi-dry friction for mixed or semi-fluid friction in order to make the tools rotate and self-sharpen. Due to the limited constructional space, which is determined by the size of tools, their holders and bodies of the units, as well as low rotational speed, fluid friction cannot be acquired in any case. Such a situation is also related to the fact that the requirements for Somerfeld number So are not likely to be met, even when very viscous lubricating media are applied (Janecki *et al.* 1969).

$$So = \frac{\eta \cdot \omega}{p \cdot \Psi^2} \quad (1)$$

where:

- η – viscosity of a lubricating medium [Pa·s],
- ω – tool angular velocity [1/s],
- *p* – surface pressure in the bearing sleeve [MPa],
- Ψ – relative clearance for slide bearings on fluid friction should range from Ψ = 0.0006 to 0.015 as depends on the bearing load and pin rotational speed.

Thus there have been made some efforts to apply exchangeable slide bearing sleeves. Due to the difficulty in sealing of bearing joint operating in very tough conditions, standard abrasive wear index was taken into account. It is defined as a relation of the volume of ground material to the friction road [6].

$$W = K_A \cdot S \cdot \rho \ [\mathrm{m}^2] \quad (2)$$

where:

- K_A – standard abrasive wear index, so-called Archard constant for a given material, which is a function of pressure (thrust) according to the Figure 7 [MPa^{-1}],
- *S* – friction face (contact surface) [m^2],
- ρ – pressure (thrust) [MPa].

The bearings of rotary-tangential picks tend to operate under unfavourable conditions, where the sliding speed is very low and thrust – high. It is then difficult to provide proper lubrication, and additionally the output and abrasion products press themselves between frictional surfaces (Fuller 1960; Hirst 1955). Therefore the alternative solution for bearing of rotary-tangential picks was prepared at the Department of of Mining, Dressing and Transportation Machines. Dry friction was replaced by semi-dry or mixed friction. The figure of the modernized solution of the RM8 system holder with forced lubrication of the sleeve is shown in Figure 2 (Bęben *et al.* 2001; Kotwica 2003, 2005). In such a solution a lubricating agent (low-percentage oil-water emulsion) is distributed under the pressure through the hole of ferrule 2 to four grooves made in the sleeve 3, mounted in the tool holder 1.

Going further to the next step was to find methods of replacing sliding friction with rolling friction at the bearing of tool handles in the holders. Suggested rolling bearing is a pioneering solution on a world scale; no company has applied such a type of bearing of tangential rotary tools so far. The way of rolling bearing is determined, in a limited constructional space, by a rest load-carrying ability of the rolling bearings or their combinations possible to be mounted, as well as their packing. Taking into consideration strength analysis of the tools and holders being at exploitation, as well as the findings of the own research, the alternative methods of rolling bearing for tangential rotary tools were prepared. Their sample constructional solution is presented in Figures 3. This solutions is based on the application of needle bearings as the elements transmitting the load transverse to the tool axis (Bęben *et al.* 1999).

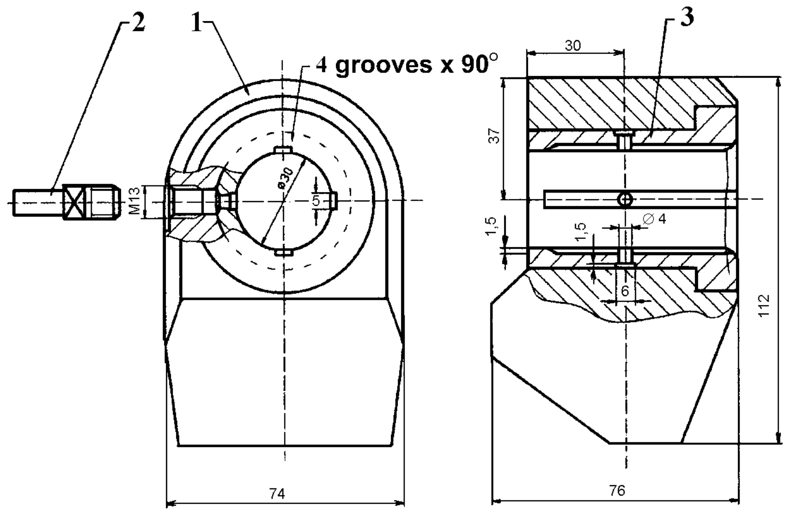

Fig. 2. Modernized, lubricated holder for the tangential rotary tools of the RM 8 system (Bęben *et al.* 2001; Kotwica 2003, 2005): 1 – tool holder, 2 – delivery ferrule, 3 – sleeve

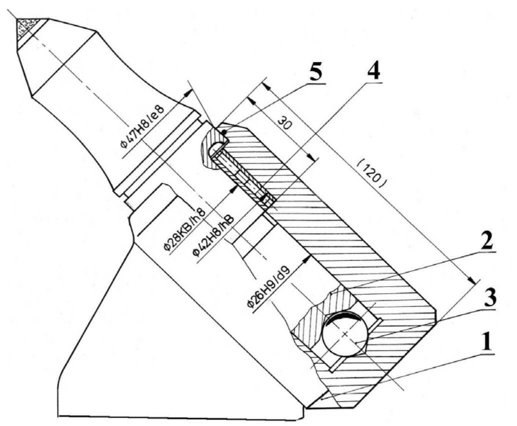

Fig. 3. Bearing of the tangential rotary tools with the supportive bearing globule in the holder (Bęben *et al.* 1999)

At the rolling bearing of tangential rotary tools it is not required to select bearings as regards mobile load-carrying ability, because they rotate slowly, their life is limited, so the relationships resulting from the Hertz contact pressures i.e. $\sigma_H < k_{dh}$ seem to be sufficient. Therefore rolling elements may be much more loaded, and thus the rolling joints – miniaturized.

In order to assess the effectiveness of new constructional solutions for the holders of rotary-tangential picks, there have been made copies of both holders with forced lubrication and with rolling bearing . Such solutions were examined on a special laboratory stand designed for testing individual mining tools. For comparison, the first tests on this laboratory stand were performed during the mining of artificial samples of rock with different types of tangential-rotary picks with and without high-pressure water jest assistance.

3. TEST STAND AND MEASUREMENT PROCEDURE

The measurements were taken on the test stand for single picks, which have been subjected to some modifications in order to create similar to real pick edge working conditions. The stand (Fig. 4) consists of a frame along which a traverse is moved vertically. A slide support with a cutting tool-holder of *L* shape is mounted on the traverse. The support can move along the traverse. The measuring head enabling an independent measurement of cutting force components: tangential P_s, radial P_d and lateral P_b is mounted on the tool-holder, on the lower part of the longer arm. The replaceable Boart Longyer RH8 standard tool-holder on which a cutting tool is directly mounted is used. The holder is installed in such a way that the picks can cut in the layout which is close to that occurring on the cylindrical part of traverse organs, i.e. at setting angle κ – 45^o and lateral angle ρ = 8^o. There is also a clamp for fitting the nozzles to assist the cutting with high-pressure water jet at 75 MPa in front or at the rear of the

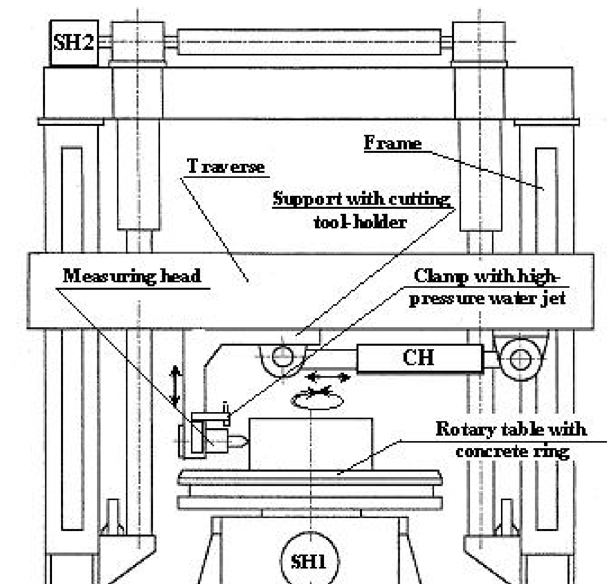

Fig. 4. Scheme of the test stand for single picks (Kotwica 2003)

pick. To generate water jets the Saphintec sapphire nozzles of ∅ 0.30 ÷ 0.80 mm have been used (Kotwica 2003).

The concrete rings modelling a rock have been placed on the rotary table of continuously adjusted speed within the range from 0 up to 20 rpm. The samples have been made as concrete rings of outer diameter ∅ 1200 mm and 450 mm in height, reinforced with steel rings from the inside. The rings have been made of special concrete of guaranteed uniaxial compression strength R_c = 105 MPa. Large arenaceous shale pieces of R_c = 119.2 MPa taken from the one of coal mines in have been installed in the rings. This material has been characterised by relatively very high abrasive resistance.

The tests were carried out with three types of rotary-tangential picks: RM8 V5-25 and RM8-520 manufactured by Boart Longyear and equipped with sintered carbides of ∅ 25 mm and ∅ 22 mm and Alpine rotary pick of carbide diameter ∅ 18 mm. The picks have been especially chosen for test purposes in order to obtain a relationship between the insert diameter and the pick wear which could be achieved by selecting the picks of similar profile and the same edge angle guaranteed by the manufacturer, but of increased insert diameter. View of test picks with holder is shown in Figure 5.

Fig. 5. View of RH8 tool-holder and tangential picks RM8 V5, RM8-520, Alpine (Kotwica 2003)

The aim of the tests was to compare the wear for cutting tools of different sintered carbide insert diameters by mechanical cutting of a concrete sample being an imitation of hard rock. In addition, an effect of high-pressure water jet assistance and new solutions of lubrication holder on picks wear has been investigated.

The wear measurements were made for "dry" cutting by using all three pick types described above as well as for "wet" cutting by using RM8 V5-25 picks. The measurements were taken both for mechanical and "wet" cutting at the same working parameters: cutting depth g = 9 mm, pitch t =10 mm and cutting velocity v = 1 m/s. Water jets at pressure p = 20 MPa were applied in front or at the rear of the pick. The jets have been generated by the Saphintec nozzles of 0.40 mm in diameter. In the case of the front assistance a nozzle was placed at a distance of about 55 mm from the pick corner and the water jet was directed tangentially to the plane of shear at a distance of 2 mm before the pick corner. In the case of rear assistance a nozzle was placed at a distance of about 95 mm from the pick corner and the water jet was directed tangentially to the plane of shear at a distance of 2 mm behind the pick corner. For the first type of pick RM8 V5-25 during the mining of rock sample occurred the blurring of the holder. This led to very rapid and unsymmetrical wear of the pick blade. This was also the cause of the spark generation. The view of the pick during the mining of rock sample is shown in Figure 6. Only cleaning of the pick handle and holder before each test made it possible to generate a turnover during the mining. Views of "dry" and "wet" cutting by using the others RM8 V5-25 picks are shown in Figure 7.

The measurement of picks' wear was made before cutting and then every 500 m of pick run over the sample circumference until the total cutting length of 2500 m was obtained. The differences in total length for individual measurements did not exceed ±40 m.

Then the pick was removed from the tool-holder and after allowing its cooling down to ambient temperature the actual pick height h_n from the pick shank base surface was measured. In addition the pick edge profile was taken using an optical microscope. Measurements were performed in three planes at 120 degrees. before and after testing. Using Matlab Computer Programm for different profiles, we can calculate the volume of solid of revolution limited profile before and after the measurement. In calculating the volume of the profiles obtained in three planes, after subtracting the volume of the solid measurement of the volume of solids with the measurement and averaging the values can be determined with high accuracy volumetric wear of pick's blade. This method also allows to specify the nature of tool wear, his uniform or increased wear on one side of the blade. The linear edge shortening h_n was determined by measurements made with the height optimeter. The edge volume wear was determined by comparing the consecutive volume measurements.

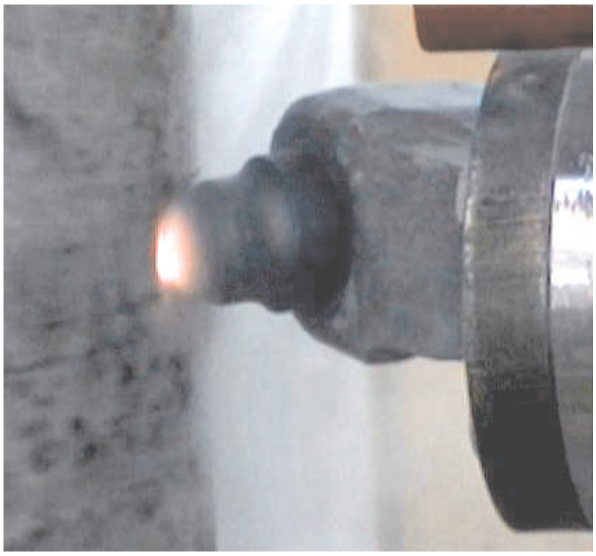

Fig. 6. Artificial sample cutting using RM8 V5-25 pick without high-pressure water jet assistance – blurring pick's handle

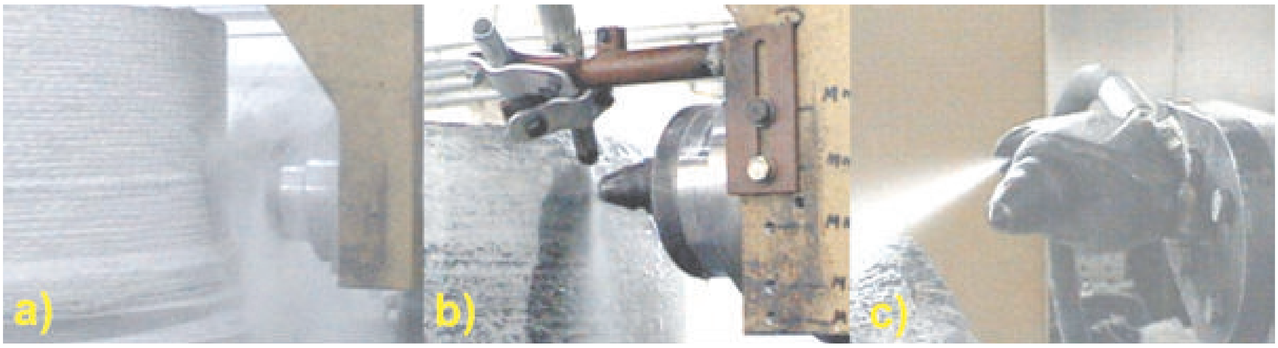

Fig. 7. Artificial sample cutting using RM8 V5-25 pick: a) "dry" cutting; b) cutting with high-pressure water jet assistance of the front; c) cutting with high-pressure water jet assistance at the rear

The last tests have been carried out using the new solutions of lubricated holder, holder with rolling bearings and standard holder RM8 with RM8 V5-25 picks. Views of new holders, used for laboratory tests, are shown in Figures 8 and 9 (Bęben *et al*. 2001; Kotwica 2003, 2004). The sample was cut along its total width and special marking gauges positioned on the tool handles or toolheads what made it possible to count number of rotations over 1 minute. The cutting depth was also changed, in first part of tests it was 9 mm and in the next one 12 mm. The lubricating holder was fed either with 1.5% water-oil emulsion (first case) or with pure water (second case), and the value of supply pressure was p = 1.5 MPa for both cases. In the Figure 10 there are shown the views of cutting the concrete ring sample used both holders. The views of the lubricated holder are shown every 0.5 second since the beginning of lubrication with lubricant. We may have noticed that as soon as we turn of the lubrication of holder, pick begins to rotate in the holder. The results obtained during the tests are presented bellow.

4. RESULTS OF LABORATORY TESTS

In the first part the results of tests of "dry" and "wet" cutting of rock sample with three different types of picks were presented. The measurement results of tool shortening and wear measurements are shown in Figures 11 and 12. It is clearly evident that the edge volume wears decreases with the increasing diameter of sintered carbide insert. Comparing to the Alpine pick of smallest sintered carbide insert of ∅ = 18 mm the volume wear decreased by 68% for RM8-520 (sintered carbide insert diameter ∅ = 20 mm) and by 84% for RM8-V5-25 (sintered carbide insert diameter ∅ = 25 mm), while the edge shortening was reduced by 28% and 36% respectively. When comparing the wear va-lues obtained for the high-pressure water jet assistance, the tool wear decreased by 82% was observed for the front application and by 18% only for the rear application. Similar figures were obtained for edge shortening, which was decreased by 48% and 8% respectively (Kotwica 2003).

Fig. 8. View of modernized, lubricated holder for the tangential rotary tools of the RM 8 system used for tests (Bęben *et al*. 2001; Kotwica, 2003, 2005)

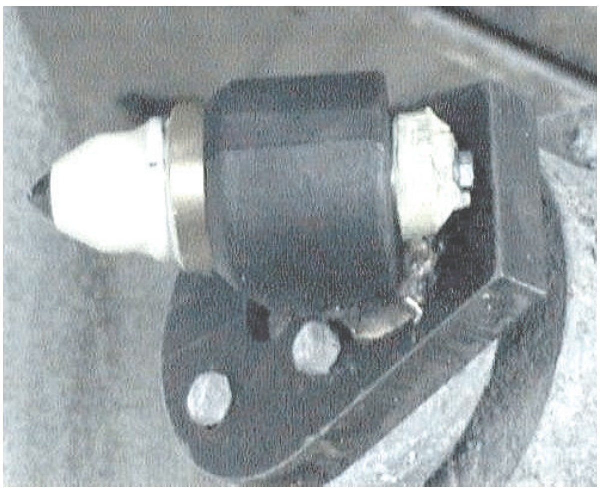

Fig. 9. View of bearing holder with the supportive bearing globule in the holder used for tests (Bęben *et al*. 2001; Kotwica 2005)

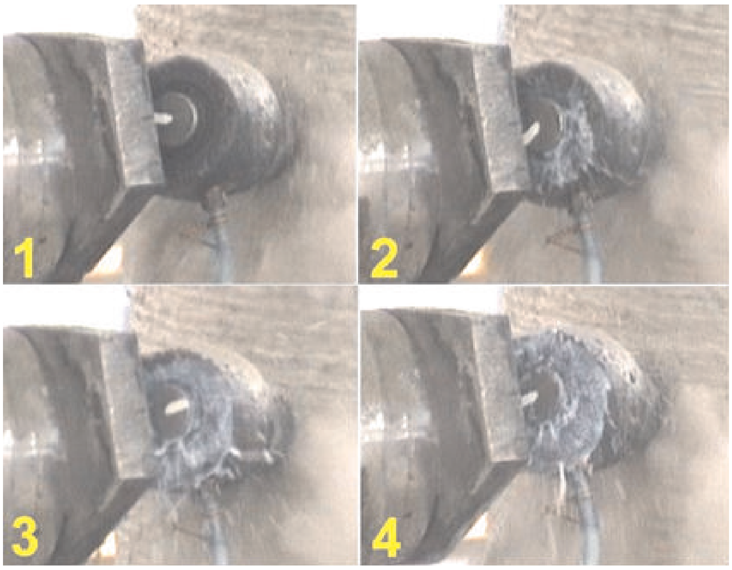

Fig. 10. View of modernized, lubricated holder during the cutting of rock sample every 0.5 seconds since the beginning of lubrication with lubricant

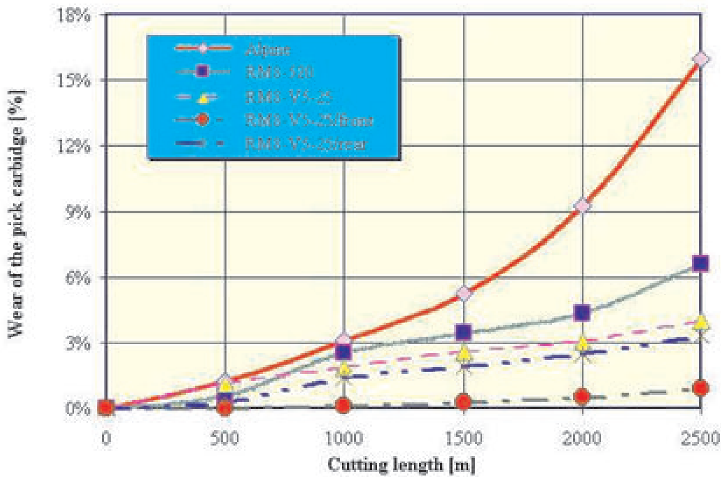

Fig. 11. Wear of the pick carbide in the function of the cutting length (Kotwica 2003)

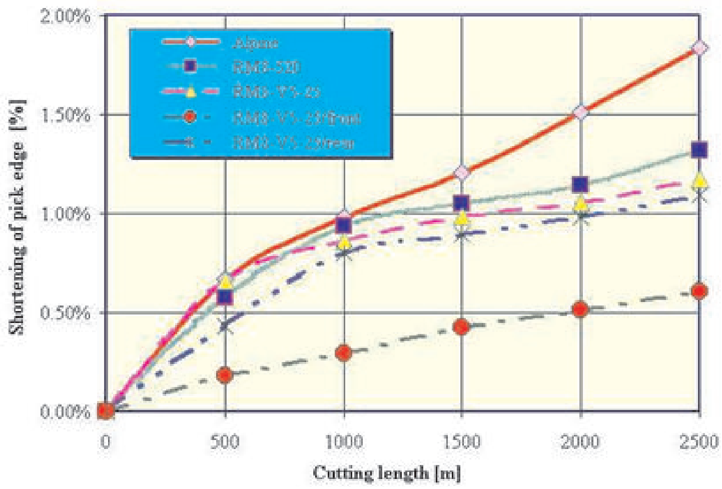

Fig. 12. Shortening of the pick edge in the function of the cutting length (Kotwica 2003)

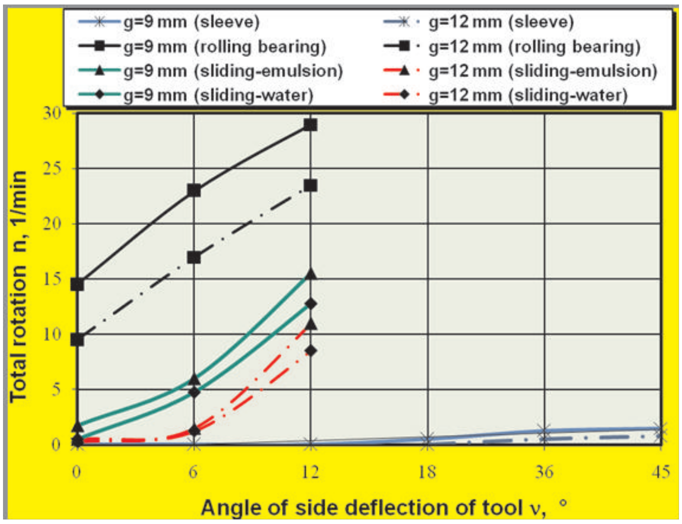

Fig. 13. Impact of side angle of tool deflection n on the number of its rotations in the function of cutting depth and the kind of holder (Kotwica 2003)

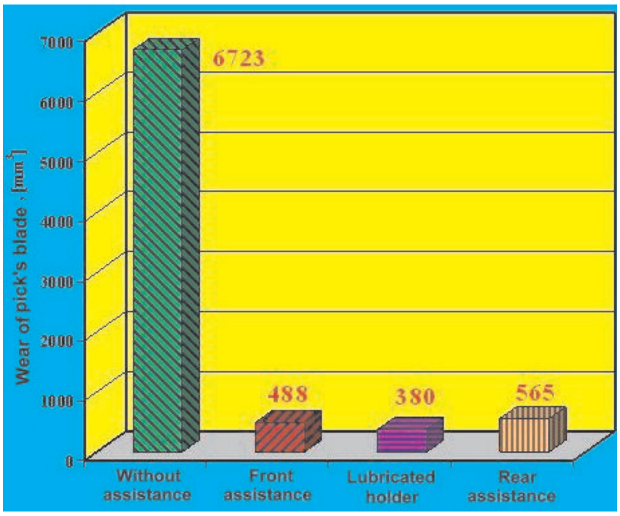

Fig. 14. Wear of the rotary-tangential picks' blades after the test along the length of ca. 2500 m: "dry" cutting, cutting with high pressure water jet assistance and cutting in the lubricated holder (Kotwica 2005)

More interesting were the results of the effect of pick's rotation on his wear. The number of rotations in the case of fixed the pick in standard, lubricated and bearing holders are shown on the diagram in Figure 13, whereas the wear of rotary-tangential picks' blades is shown in Figures 14, 15 and 16 (Bęben *et al.*, 2001, Kotwica, 2003, 2005).

The tests proved that for the rolling bearing, even when the tools are deflected at zero angle, they rotate in the holder – it seems to be of great importance on the uniform wearing and self-sharpening of the tools. This is crucial for drilling or expanding deep bore-holes with both vertical and horizontal modern drill bits with using dead movement (return trace) in the process of drilling. Good, but definitely not so favourable results were also obtained for the holder with forced lubrication. However, the angle of side deflection must have been at least 6^{o} or more, whereas, for the bushed holder, tool deflection up to 45^{o} did not lead to its greater, even irregular rotations. Increasing the depth of cutting from 9 to 12 mm affected the number of rotations, especially in the bushed or lubricated holder. High thrusts at greater cutting depths distinctly increased the strengths and hampered the tool rotation, what could have been expected from the point of view of the theory of friction and wear.

The occurrence of regular tool rotations, as it has been mentioned above, had great impact on the inconsiderable and uniform wear of the tool blades. The bushed tool, just after having a cut a rock sample on the length of about 2500 m, was asymmetrically grounded off (Fig. 15a), whereas the wear of tools fixed in new solutions of the holders was rather small and very regular, at the comparable way of cutting (Fig. 15d and 16). Comparing it to the high pressure water jet assisted picks, we can see the beginning of asymmetrical wear (Fig. 15b and c). This can also be seen

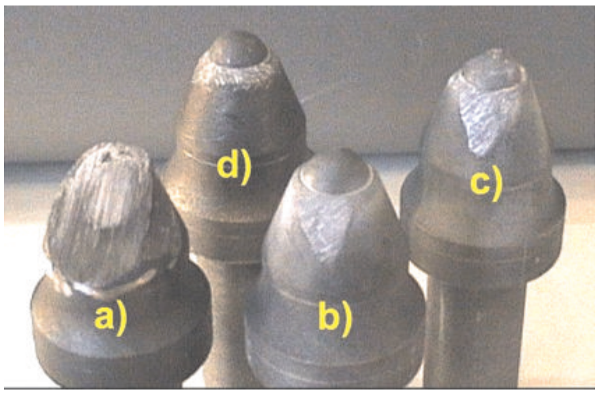

Fig. 15. The view of the rotary -tangential picks after the test along the length of ca. 2500 m (Kotwica 2004): a) "dry" cutting; b) cutting with high pressure water jet assistance from front; c) cutting with rear high pressure water jet assistance; d) cutting in the lubricated holder, cutting depth 9 mm

on profiles made before and after cutting. In the Figure 17B there is shown a profile of pick fixed in standard holder with front assistance and in the Figure 17A a profile of pick fixed in lubricated holder. Wear of picks' blades is not only quantitatively but also qualitatively better in the case of the pick fixed in lubricated holder.

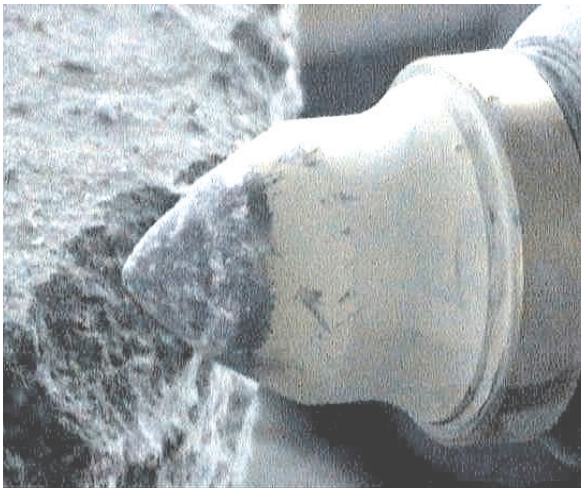

Fig. 16. The view of the blade of the rotary-tangential tool mounted in the rolling bearing holder after the cutting trials along the length of ca. 2500 m (Kotwica 2005)

5. CONCLUSIONS

Both the analysis of references and the results of the own tests proved that the rotation of tangential rotary tools is affected not only by the angle of side deflection ν, blade and cutting angles as depending on the properties and lithology of the rocks to be mined but also by the way of their bearing, and first of all on the kinds of holders and catches fixing the tools at their slide bearing. That is why the authors suggested some constructional solutions, which after they had been laboratory tested, gave satisfactory results. However, they can be verified when the large scale industrial research is carried out.

It must be mentioned that sample holder solutions with the lubrication of rotary-tangential tools, applied in the units of shearers and roadheaders, may be additionally fitted with ejector internal sprinkling with water stream under the pressure. It reduces the level of dustiness to be breathed in, protects against explosion of coal dust or me-thane and additionally allows to increase the life of cutting tools.

Pre-industrial test carried out in the ZG „Janina" in Libiąż, using the AM-50 roadheader has shown the usefulness of the new holder solution for rotary-tangential picks with pure water as the lubricant. Application of pure water lubricated holders increased almost twice working time of picks, as well as reduced the dustiness. The view of the "dirty" cutting head of AM-50 roadheader with standard holders after mining is shown in Figure 18a, and the "clear" cutting head with lubricated holders is shown in Figure 18b.

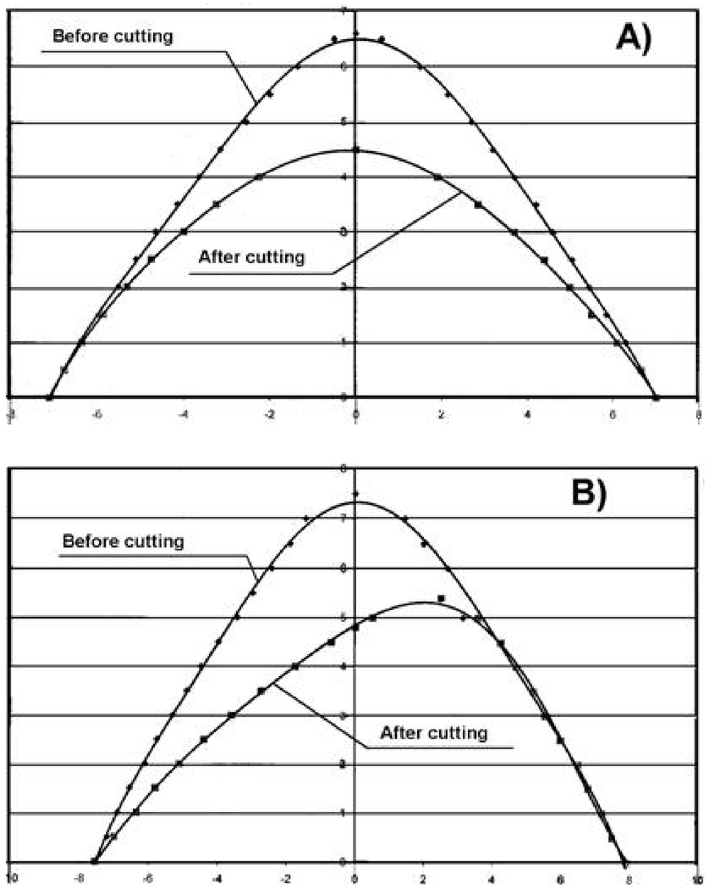

Fig. 17. The profiles of rotary-tangential picks' blades before and after cutting: A) cutting with high pressure water jet assistance from front; B) cutting in the lubricated holder (Kotwica *et al.* 2004)

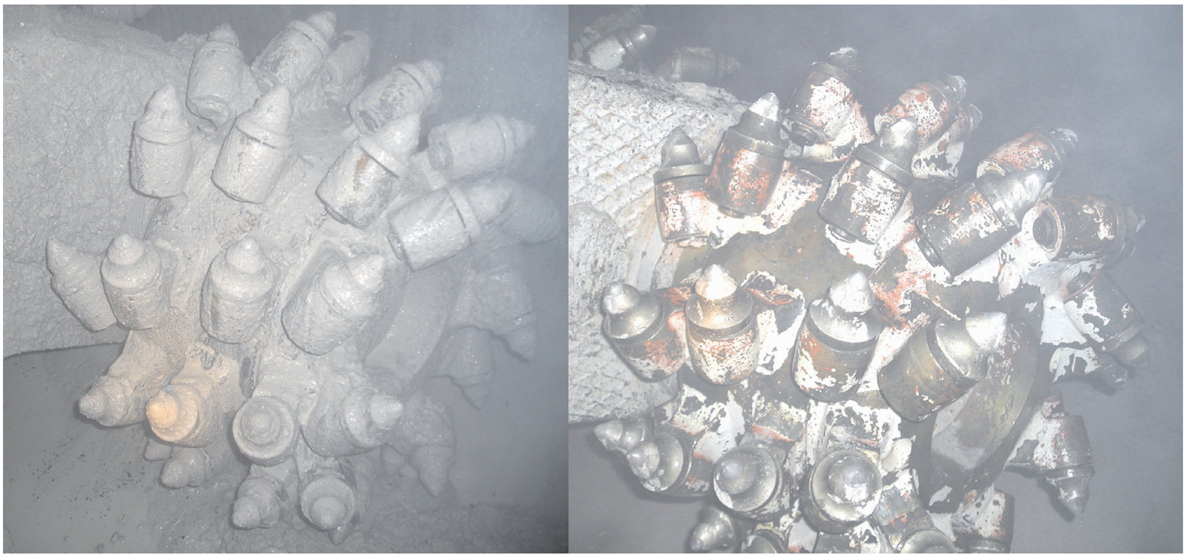

Fig. 18. View of the “dirty” cutting head of AM-50 roadheader with standard holders after mining (left) and the “clear” cutting head with lubricated holders after mining (right)

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