Simulation tests of new solution of the longwall shearer haulage system

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Abstract. The article presents the idea of a new solution for KOMTRACK longwall shearer haulage system. Based on the analysis of test results of an earlier version of the FLEXTRACK haulage system, a new version of the KOMTRACK system was developed. Using the ANSYS LS-Dyna program, simulations of the longwall shearer's drive wheel mating with the selected elements of the toothed haulage segment were performed. The purpose of the analyzes was identification of contact stress value of the elements of the feed system as a function of geometrical parameters of various solutions of the toothed bar. The result of the simulation was the selection of the rack solution for further field and industrial tests.

1. Introduction

In polish underground coal mines currently hard coal is excavated in longwall system, using mainly shearers. The EICOTRACK system is a widely used longwall shearer haulage system. In this system, the shearer is moved by the interaction of the drive teeth wheels with the rack (ladder) located horizontally in the face conveyor gate. The segments of the racks (ladders) are fixed to the bracket supports with bolts in a rigid manner. The vertically positioned drive teeth wheel of the shearer tractor engages with its teeth with horizontally positioned pins of the ladder, forcing the change of the location of the shearer. The leading part of the shearer moves along the ladder in a sliding way, providing constant conditions for the cooperation of the meshing between the drive teeth wheel and the ladder [1, 2].

This results in accelerated wear of the drive wheel teeth and leads to frequent changes of drive wheels during the operation of the longwall work (3-4 times depending on the wall run and mining and geological conditions). This process generates additional costs for shearers producers and users and also creates the need to work of shearers servicemen in dangerous conditions. Downtime in mining, forced by maintenance work, negatively affects the economic result. The stress analysis carried out by ITG KOMAG shows that in the course of operation, the yield point of the material from which the wheel is made is exceeded. This is the result of a rigid attachment of ladders, which causes that in the case of transverse or vertical bending of the face conveyor, there is a so-called cutting the tooth of the drive wheel and disturbing of the pitch, i.e. the distance between the neighbouring teeth. The described problem is intensified by the increasing power of shearer tractors, which has now reached the value of 120 kW, causing a significant exceeding of the permissible surface pressure between the cooperating surfaces of the drive wheels and the ladder [3].
As a part of the project entitled “Innovative advance system of mining machine increasing the effectiveness of output and work safety in longwall systems”, realized by the KOMAG Institute of Mining Technology (leader), Faculty of Mechanical Engineering and Robotics at the AGH University of Science and Technology, Foundry Research Institute and Specodlew Enterprise of Foundry Innovation Ltd., new solution of haulage system for longwall shearsers was developed. It was called FLEXTRACK [1, 2, 3].

This solution eliminates mentioned above, unwanted collaboration conditions of the described kinematic pair. It is an innovative longwall shearer haulage system with flexible toothed segments. The toothed segments installed in guides, replacing the Eicotrack toothed bar (ladders), enable a more advantageous collaboration of the shearer driving wheel, in particular in the case of the curved conveyor line – it allows turning of flexible toothed segments both in the vertical as well as the horizontal planes. The operation principle of new haulage system FLEXTRACK and currently used system EICOTRACK is presented on the model in Figure 1 [4].

![Figure 1. Model of collaboration of tractor drive toothed wheel with: 1 - system FLEXTRACK, 2 - system EICOTRACK [4].](image)

The concepts of eight rack segment variants and five guides concepts were developed, which were subjected to strength, material and technological analysis.

In the rack segment variants (instead of the convex tooth profile used so far), a profile with a concave cylindrical lateral surface was proposed, whose radius was 5% larger than the largest radius of the driving teeth wheel. The results of the analysis allowed the selection and manufacturing of a prototype set of the most advantageous version of the rack segment and guide [4]. It has been subjected to field comparative tests with the ladders of the EICOTRACK system, using a longwall shearer and route elements of a longwall face conveyor. During the tests, for a comparable haulage length of the shearer, the qualitative and quantitative wear of drive wheels, ladders of the EICOTRACK system and rack elements of the FLEKTRACK system were measured, as well as the temperature of these elements. Selected results are presented below.

2. Selected field test results of the FLEXTRACK haulage system

The view of the test stand and the elements of the EICOTRACK and FLEXTRACK haulage system selected for testing are shown in Figures 2 and 3 [5]. The test stand allowed to simulate the bending of the longwall face conveyor route in a vertical and horizontal plane. In the case of FLEXTRACK haulage system shearer moved a total of about 7 km. In the case of EICOTRACK haulage system shearer moved about 1 km less. During tests with the EICOTRACK system, a significantly higher noise level was recorded, as well as greater vibration of the shearer and its load. In addition, several
shearer failures occurred during the tests. In the case of wear and temperature measurements of the EICOTRACK and FLEXTRACK system elements, selected results are shown in Figures 4, 5, 6 and 7.

**Figure 2.** View of test stand for EICOTRACK and FLEXTRACK haulage system testing [5].

**Figure 3.** View of the elements of the EICOTRACK (right) and FLEXTRACK (left) haulage system selected for testing [5].

**Figure 4.** View of the wear of elements for FLEXTRACK haulage system after the test: on top – drive wheel, bottom – rack segments [5].

**Figure 5.** View of the wear of elements for EICOTRACK haulage system after the test: on top – drive wheel, bottom – ladder [5].

Based on the analysis of the obtained results, it can be stated that for the FLEXTRACK haulage system the shearer adapted better during the passage on the bent sections of the longwall face conveyor. The temperature of the system components, both racks or ladders, and drive wheels, was lower in the case of the FLEXTRACK haulage system. However, the quantitative (volumetric) wear of both cooperating elements was for the FLEXTRACK haulage system by several percent higher. However, the form of this wear was very even [5]. These elements, primarily the drive wheels, were
mainly wearing off. In the case of the EICOTRACK haulage system on the drive wheels, there were signs of chipping.

Figure 6. View of the temperature distribution of elements for FLEXTRACK haulage system after moving around 50 m: on top – drive wheel, bottom – rack segments [5].

Figure 7. View of the temperature distribution of elements for EICOTRACK haulage system after moving around 50 m: on top – drive wheel, bottom – ladder [5].

Therefore, the new haulage system has proved its usefulness for work in difficult mining and geological conditions, when moved along a bent face conveyor route. However, the results of the study led to the conclusion that the proposed rack profile with a concave cylindrical lateral surface may be the reason for the increased wear of the elements of the FLEXTRACK haulage system. Therefore, as part of the new project "Innovative haulage system for highly productive longwall complexes" it was proposed to continue the topic and testing of the newly designed shearer haulage system called KOMTRACK.

A distinguishing feature of this system is also its flexibility enabling individual toothed segments (racks) to adapt to longitudinal and transverse curvatures of the longwall face conveyor route, which guarantees a correct cooperation with the drive wheel. The present knowledge, based on the results of the FLEXTRACK project, indicates that a flexibility of the racks, in relation to the rolling driving wheel, decreases a level of stresses generated during a longwall shearer displacement.

The following assumptions were accepted for reaching the project objective:

- the maximal force carried by a tooth of the toothed bar segment is 500 kN,
- the angle of rack turn in relation to each other is at least +/- 0.3 deg,
- values of stresses in each collaboration point of the frictional pair are below the material yield point,
- the shearer haulage system pitch is 151 mm.

Considering the above, it began to develop a construction form of a toothed segment (rack) adapted for a collaboration with the driving toothed wheel of a longwall shearer haulage unit.

However, it was proposed to change the shape of the rack. Instead of the concave surface, several versions of the convex or straight surface were selected.
To determine which version is the most favorable for further research, simulation tests were performed using the Ansys LS-Dyna program. The course and results of these tests are presented below.

3. Testing methodology
The physical model used in simulation was presented on Figure 8. The main assumption was to fix the drive wheel and to impose constant angular velocity \( \omega = 0.5 \) \( 1/s \). The feed system consists of the two racks. The constrains were imposed on the bottom surface of the racks. The configuration of the degrees of freedom is illustrated in figure below. As it is illustrated, the haulage system has capability to free displacement only in the X direction. On the front surface of the rack a horizontal force of 335 kN was applied. In this way resistance to motion of a longwall coal shearer were simulated. Between the elements of the haulage system the surface contact were assumed so as to ensure free interaction between the haulage system elements. The simulation tests carried out for linear material properties. Material properties used in the simulation were presented in Table 1. The three types of the rack design used in the simulation tests are shown in Figure 9. They have different teeth profiles - flat, trapezoid of 20° wall inclination, convex with two curvature radius and convex with flat intermediate area inclined at 20°.

![Figure 8. Schematic arrangement of testing model.](image)

| Element     | Young’s modulus | Poisson ratio | Yield strength |
|-------------|-----------------|---------------|----------------|
| Drive wheel | 207000 MPa      | 0.3           | 1080 MPa       |
| Rack        | 210896 MPa      | 0.286         | -              |

4. Results of simulation tests
Simulation tests has been conducted in Ansys LS-Dyna program. The results of the simulation tests was presented on Figures 10÷12. To simulate dynamic interaction between elements of the feed system the implicit algorithm was used. The aim of simulation tests was to identify the maximum equivalent stress, that occurs at the contact between the drive wheel and the racks, as a function of geometrical parameters of the rack construction. On figures below the stress concentration on the rack construction are shown. The location of stress concentration is changing because of dynamic operating between the drive wheel and the rack construction. In order to better show the stress distribution the equivalent stress above 1000 MPa has been marked in pink color. For the first type of the rack the maximum equivalent stress appears on the top edge of the second rack and the level of stress
significantly exceeded the value of 1000 MPa. The tooth profile modification for type V2 and V3 allowed to reduce level of the equivalent stress, as shown in Figures 11 and 12.

**Figure 9.** Types of rack segments of different teeth profiles used in simulation: Type V1 - flat, trapezoid of 20° wall inclination, Type V2 - convex with two curvature radius, Type V3 - convex with flat intermediate area inclined at 20°.

**Figure 10.** Equivalent (H-M-H) stress distribution for type V1.

**Figure 11.** Equivalent (H-M-H) stress distribution for type V2.
Figure 12. Equivalent (H-M-H) stress distribution for type V3.

Analyzing the stress distribution on the flank of the racks it can be concluded that the level of equivalent stress for type V3 is lower than in the case of type V2. The maximum equivalent stress on the flank of the rack V2 reached 1103 MPa. In the case of type V3 the equivalent stress reached 988 MPa.

5. Summary
The conducted research allowed to compare the impact of the tooth profile on the equivalent stress in the racks construction. In the field of dynamic computation, the three type of racks have been verified. The purpose of the study was to identify the stress concentration, that occurs at the contact between the drive wheel and the rack. The final results of the research was the recommendation of the selected rack design to the future laboratory test. The rack segment type V3 with convex and flat intermediate area inclined at 20° has been recommended. On the basis of designed CAD model the first prototype of the rack segment was manufactured. It is shown in Figure 13. This solution will be checked in the future during field and industrial tests. It is assumed that the working conditions of the examined system will be as close as possible to the conditions prevailing in the underground coal mines.

Figure 13. View of the first prototype of the rack segment type V3 with convex and flat intermediate area.

Acknowledgements
The article was created as part of project “The innovative haulage system for highly productive longwall complexes”, according to the Contract No. POIR.04.01.04-00-0068/17 with the National Center for Research and Development, co-financed by the European Union from the European Regional Development Fund under the Intelligent Development Program.
References

[1] Zachura A et al. 2014 Projekt Program Badań Stosowanych - Innowacyjny system posuwu maszyny wydobywczej podnoszący efektywność wydobycia oraz bezpieczeństwo pracy w kompleksach ścianowych - Zadanie 5. Kryterialny wybór z pola możliwych rozwiązań oraz opracowanie postaci konstrukcyjnej elementów systemu posuwu maszyny wydobywczej. Instytut Techniki Górniczej KOMAG, Gliwice (not published)

[2] Zachura A and Żuczek R 2014 System posuwu Flextrack zwiększający trwałość i niezawodność napędu kombajnu ścianowego. [w:] Monografia: KOMTECH 2014, Innowacyjne techniki i technologie dla górnictwa. Bezpieczeństwo - Efektywność - Niezawodność, Instytut Techniki Górniczej KOMAG, Gliwice s. 151-161.

[3] Zachura A 2014 Quasi-statyczna analiza współpracy koła napędowego i zębatki w systemie posuwu kombajnu ścianowego Mechanik R. 87, nr 10, s. 842—848

[4] Zachura A et al. 2015. Flextrack - innowacyjny system posuwu kombajnu ścianowego, cz.1 i 2. Nowoczesne metody eksploatacji węgla i skał zwięzłych: Monografia. Kraków: Wydawnictwa AGH, s. 185-204

[5] Kotwica K, Stopka G, Gospodarczyk P et al. 2016 Projekt Program Badań Stosowanych - Innowacyjny system posuwu maszyny wydobywczej podnoszący efektywność wydobycia oraz bezpieczeństwo pracy w kompleksach ścianowych - Zadanie 13. Badania stanowiskowe odlewów w warunkach laboratoryjnych. Akademia Górniczo-Hutnicza w Krakowie (not published)