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Article

Development of Longwall Shearers' Haulage Systems as an Alternative to the Eicotrack System Used Nowadays

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Abstract: Longwall shearers' haulage system of the Eicotrack type, used most often nowadays, is presented in this article. Its disadvantages, causing problems with a correct operation of mechanized longwall shearer systems, are discussed. The concept of the innovative Flextrack, which should reduce the occurrence of the disadvantages mentioned above, is described. A course and research results, connected with rig tests of the Flextrack haulage system functionality, are presented. Measurement results of wear and stresses, obtained for the Eicotrack and Flextrack haulage systems, are compared and presented. Based on an analysis of the obtained results, a modified version of the Komtrack haulage system was suggested and manufactured. This haulage system was tested in the field conditions, similar to underground conditions in a mine coal longwall. The obtained results confirmed its full functionality and lack of problems experienced in the case of the Eicotrack and Flextrack systems. At present, the Komtrack system is tested in a coal longwall in Piast coal mine, where comparative tests with the Eicotrack system are conducted. The big part of the results presented in this article was developed as part of the research project KOMTRACK jointly implemented by KOMAG Institute of Mining Technology, AGH University of Science and Technology, Łukasiewicz Research Network—Cracow Institute of Technology, Specodlew Innovative Foundry Company and Polish Mining Group Inc., co-financed by the European Regional Development Fund (Contract No. POIR.04.01.04-00-0068/17).

Keywords: longwall shearer haulage system; toothed segment; toothed wheel; stress; flexible collaboration; wear

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1. Introduction

One of basic systems for a mechanical exploitation of hard coal in underground mining includes shearer longwall systems. Their application for mining hard coal started in mid-XX century. The first sharers were relocated along the longwall with use of pulling rope or chain haulage systems. They generated a very big hazard to the workers employed in the longwall, mainly caused by a possibility of strand break and so-called whipping, i.e., vibrations of the strand having a big amplitude. In the fifties of the XX century, a search for chainless haulage systems of shearers eliminating the abovementioned hazards [1–5] was started. The first trials were realized in semi-mechanized longwall faces in Germany and in Hungary, but the biggest development of this type of system started 10 years later in Great Britain [6]. The first chainless solutions such as Rackatrack, Peratrack or Dynatrack, after positive tests in British and French mines, became a thing of the past without their broader implementation in the abovementioned longwall systems [7–9].

In the seventies, the tests of chainless solutions of haulage systems with a drive wheel (gear wheel or pin) and different toothed bars were finished with a bigger success.

They were described in the literature [10–12], starting with the British Rollrack with the drive wheel and the toothed bar through similar solutions in Europe and China, with the vertical or horizontal rack in the form of toothed bar such as Powertrack, Eicotrack and Poltrack. Such a haulage system enables a relocation of a shearer along a coal longwall and a realization of its basic functions, i.e., cutting and loading coal on an armoured face conveyor.

Coal shearers, operated nowadays, are mainly equipped with chainless haulage systems, among which the Eicotrack system, together with its following versions, is most popular—e.g., Megatrack, Gigatrack. The Eicotrack system is composed of stiff toothed bars (racks) fixed to the conveyor line pans [1,10]. The teeth of the shearer drive wheel, situated vertically, gear with the rock pins positioned horizontally, forcing a change of the machine location.

A construction and operational principle of the Eicotrack haulage system (Figure 1) is broadly described in other publications [1–3,10]. Due to a stiff construction of toothed bars, on nonrectilinear sections of the armored face conveyor, a location change of the shearer drive wheel in relation to the axis of racks occurs. This leads to a local change of pitch between extreme pins of racks adjacent to each other and a change of distance between pins of rack segments and the axis of rotation of the drive wheel. Such a collaboration of the frictional pair leads to so called edging of teeth, due to which the values of permissible contact stresses between the collaborating surfaces are exceeded. Such a situation, in turn, causes an untimely wear of drive wheel surfaces (mainly the teeth of these wheels) and pins installed in racks [13–17]. In Figure 2, a view of wear of gear wheels, used in the Eicotrack haulage system and of one of the extreme rack pins, is shown as an example.

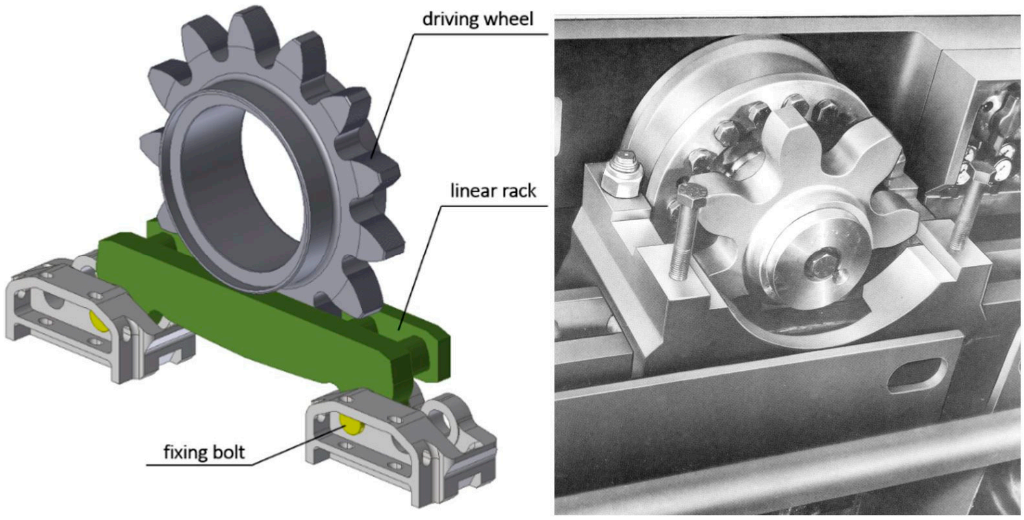

Figure 1. Model and view of the Eicotrack haulage system solution [18].

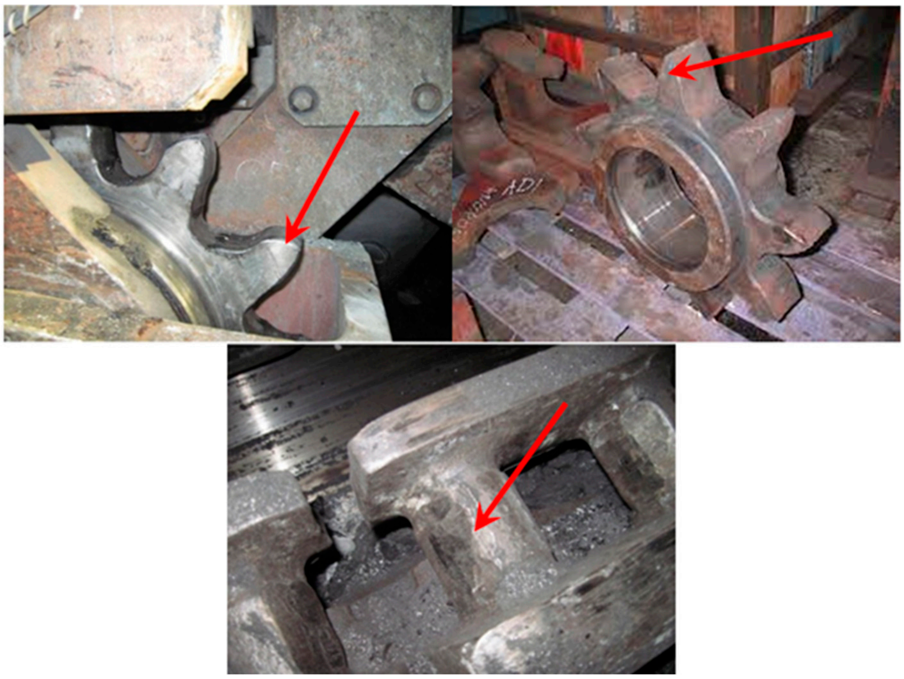

Figure 2. View of wear of gear wheels used in the Eicotrack haulage system of one of the extreme rack pins, (marked with red arrows).

2. Flextrack Haulage System—Results of Stand Tests, a Comparison with the Eicotrack System

A solution, eliminating above mentioned undesired results of collaboration of the frictional pair: a gear wheel-rack is an innovative haulage system of a longwall shearer with flexible toothed segments developed at the KOMAG Institute of Mining Technology within the framework of the FLEXTRACK project. The toothed segments are installed in a way that enables their mutual relocation in the guides. Replacing the Eicotrack rack, they contribute to a more advantageous collaboration of the drive wheel of the shearer haulage system and toothed segments, in particular in the situation of the conveyor line pan contraflexure both in the vertical plane, as well as in the horizontal one [19]. A model of the Flextrack haulage system, showing a layout of toothed elements in the guide, as well as a comparison of the Flextrack and Eicotrack haulage system elements, collaborating with the track wheel are shown in Figure 3.

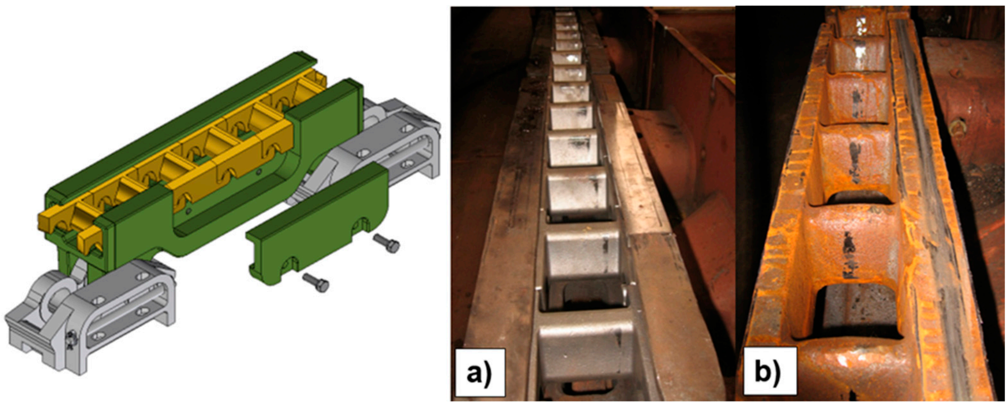

Figure 3. Model of the Flextrack haulage system with a layout of toothed elements in the guide and a comparison of elements collaborating with the track wheel: (**a**) Flextrack haulage system, (**b**) Eicotrack haulage system.

A special test rig, enabling the carrying out of comparative tests of wear of components of individual haulage systems, stresses generated in these components during a pass of the track wheel, resistances to haulage and vibrations, was elaborated and manufactured. This rig, shown in Figure 4, enabled about 15-metre of pass along the armored face conveyor line pan at its rectilinear position or contraflexure in the vertical and horizontal planes. A set of two pairs of rams enabled the generation of load resistances simulating cutting during the shearer passes.

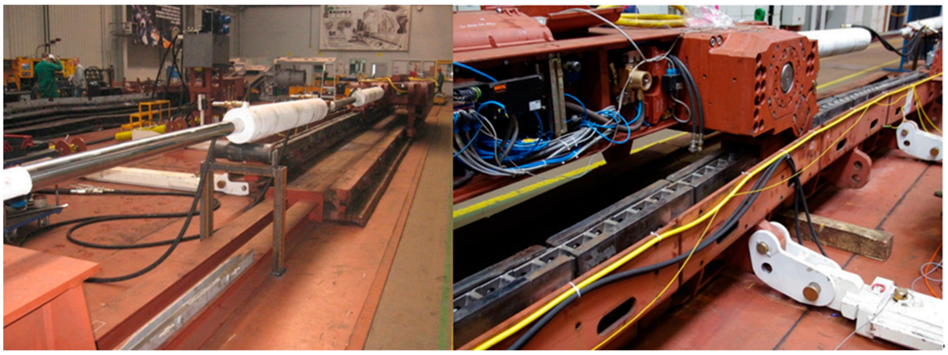

Figure 4. View of the special test rig for conducting comparative tests of the Flextrack and Eicotrack haulage systems.

We planned to perform tests in the same operational conditions in the case of both systems; however, in the case of the Eicotrack haulage system, very big values of haulage load resistances, generated by this system, did not render it possible to conduct tests with a comparable value of the force simulating load resistances to cutting generated by rams. It was about 1/3 smaller. For the measurements the transducers of vibrations of 4507 B 005 type produced by Bruel and Kjaer, installed above the shearer haulage system (above each track wheel), were used. Average and maximum values of vibrations acceleration, significantly bigger (of about 40–50%) in the case of the Flextrack system where obtained, respectively, Eicotrack a_{med} = 2.5–4 m/s^2, a_{max} = 45–78 m/s^2, Flextrack a_{med} = 4–6.5 m/s^2, a_{max} = 75–105 m/s^2.

Moreover, different conditions of conducted tests had an impact on the measurement results of track wheels wear. The geometry of the wheels under testing, of new manufacture for each of the tested haulage systems was measured with use of the 3D scanner, HDI Advance, LMI Technology. A digitalization of the objects was carried out with use of the structural light method. A comparison of measurements, taken before and after the tests, enabled to determine quantitative and qualitative wear of track wheels for both systems. The obtained result of qualitative wear of wheels is shown in Figure 5. It is from 30 to 45% bigger in the case of the Flextrack system, however the form of wear is very uniform, and it is caused mainly due to abrasion of the wheels flanks. In the case of the track wheels, used in the Eicotrack system, an irregular wear, in a form of chippings on the edges of teeth, can be seen.

Measurements of stresses in the selected components of the Flextrack and Eicotrack systems were realized with use of an indirect method through measurements of deformations in these components using light pipe sensors with a Bragg net. These sensors, as measurement transducers of small dimensions lacking in sensitivity to the external electromagnetic field, enable the carrying out of noninvasive measurements in many branches of industry. Due to their sensitivity to temperature and stress, Bragg nets are often used as measurement sensors of these physical quantities. Most often, the phenomenon of relocating the wavelength of the Bragg resonance due to an impact of temperature of stress is used. Only the knowledge of the Young's modulus value of the material, from which the components under measurement are made, is required for an assessment of stresses. The applied measurement method is described in detail in the publications [20–23]. The light pipe sensors with Bragg net SC-01 and the optical interrogator FBG Scan 800 were used for measurements.

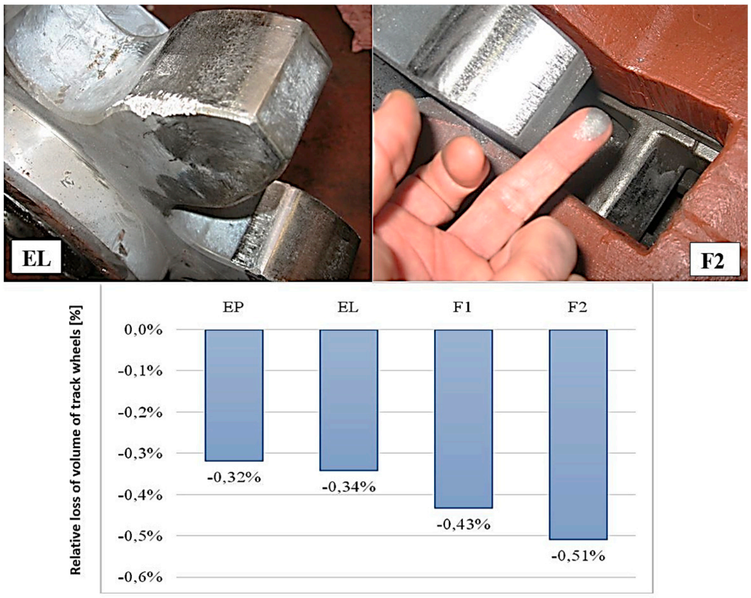

Figure 5. View of track wheel wear and graph of the relative volume loss of individual track wheels: EP and EL—right and left track wheel in the Eicotrack system, F1 and F2—right and left track wheel in the Flextrack system.

The measurements were taken for three elements: Flextrack—type 1, made of cast steel I; Flextrack—type 2, made of cast steel II and Eicotrack—the rack of the Eicotrack system. On the selected previously prepared components light pipe sensors were installed by their flooding. The sensors were placed in a vertical hole of 6 mm dimeter drilled in the selected components (Figure 6).

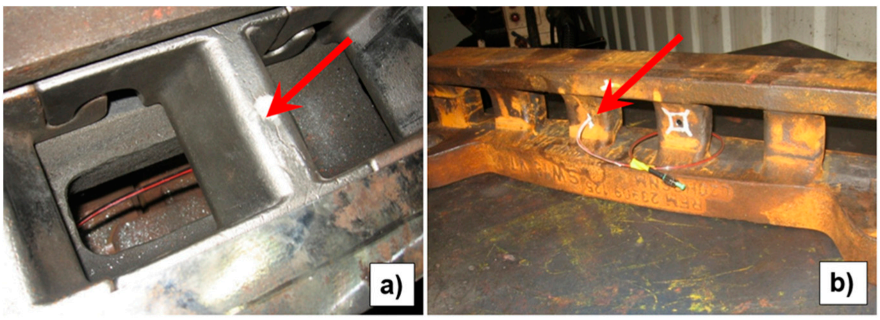

Figure 6. View of one of the toothed bar segments of the Flextrack system (**a**) and of the rack of the Eicotrack system (**b**), with a glued-in optoelectronic sensor with Bragg net for measurements of strains, (marked with red arrows).

The measurements were taken during a pass along a rectilinear conveyor section and along a deflected section both in the vertical plane and in the horizontal plane. A view of exemplary recorded courses for the toothed segments of Flextrack haulage system of type 1 and type 2 are shown in Figure 7. A deformation is caused in the first phase due to a compression of these components—a negative strain—but in the second phase when the wheel performs the proper work resulting from a transmission of the shearer haulage force to the toothed bar or the rack, it causes bending of the tooth or of the rack, i.e., a tension of the sensor (positive strain).

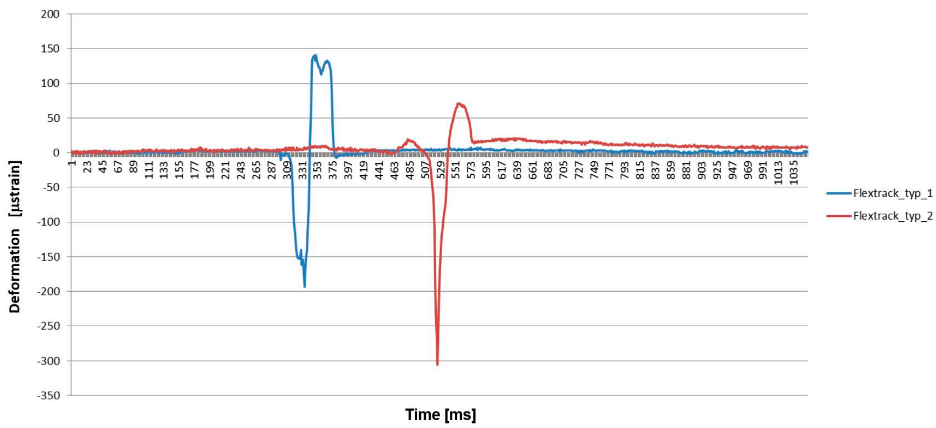

Figure 7. A course of the deformation value of the toothed segments of the Flextrack haulage system with the conveyor route curved in the horizontal plane.

Comparing the obtained results, it can be stated that a contraflexure of the conveyor line pan has an impact on increasing the values of strains and stresses, even several times greater, in particular in the case of the route bent in the vertical plane. The results obtained for the segments of the toothed bar—Flextrack type 1, made of cast steel I—were most advantageous. Not much bigger values, or in some cases comparable ones, were obtained in the case of the Eicotrack rack, whereas in the case of the toothed bar segments—Flextrack type 2, made of cast steel II—the obtained results are much higher in comparison with the toothed bar—Flextrack type 1—in relation to the configuration of the conveyor route, from 250% to even 550% (the route bent in the horizontal plane). It shows a big impact of the kind of material, from which the toothed bars were made, on the values of strains and stresses. The scope of measurement values of stresses is presented in Table 1.

Table 1. Scope of measured stress values in Flextrack and Eicotrack haulage system elements.

	Compressive Stresses (MPa)	Tensile Stresses (MPa)
Toothed segment—Flextrack—type 1	−2.2 to −7.2	4.3 to 7.2
Toothed segment—Flextrack—type 2	−6.5 to −55.6	6.7 to 29.6
Eicotrack rack	− 4.2 to −9.5	3.8 to 18.2

Analyzing all the obtained results of tests it is, however, possible to state that the innovative Flextrack system, subject to tests, is a more advantageous solution in comparison with the Eicotrack system used at present, despite the fact that an expected decrease in the track wheels' wear was not achieved in the new system. This might be caused by the fact that initial analyses concentrated on solving a problem of reducing contact stresses during a collaboration of the wheel with the toothed bar segment. To achieve this objective, the outline of teeth in the toothed bar was changed for a concave one. An analysis, enabling the determination of an impact of the second factor such as a slip connected with a collaboration of the pair: wheel–toothed bar, should be carried out again. A resignation from the meshing model of an involute outline could cause an increase of the slip share in the contact of the wheel tooth with the tooth of the toothed bar, which resulted in increased wear [24–26]. Comparative tests of noise measurements of the systems, subject to tests, confirm obtaining an effect of reducing contact stresses. However, the wear measurements indicate that a share of friction in the contact of the collaborating pair is significant, and the meshing requires an optimization. In the case of gears, it is difficult, and in practical life impossible, to optimize a collaboration of elements if one of them is subject to a modification. Thus, a conclusion was drawn that the following step should include an analysis and synthesis of the mesh pair based on the involute outline of the wheel tooth and an adaptation of the toothed bar to it, which in this case should have straight teeth or an involute outline.

Such tests and computer simulations were conducted, and their results are described in the publications [27,28].

3. Solution of the Komtrack Haulage System and Field Tests

The results of tests of the Flextrack system, conducted on the test rig, as well as the results of an impact analysis and the tooth outline of track wheel and of the flank of the toothed segment on a correctness of collaboration, were used in the design process of an innovative Komtrack haulage system, mainly of the toothed segment intended for an application in highly productive longwall systems of big power [28,29]. The toothed segment was designed with a bigger pitch of 151 mm and an innovative outline of the tooth flank. It reduced a number of segments installed in the guides to five. The 3D model of the guide and toothed segments, installed on the conveyor line pan, the 3D model of a new version of the Komtrack toothed segment and the model of collaboration of the shearer drive wheel with toothed segments are shown in Figure 8.

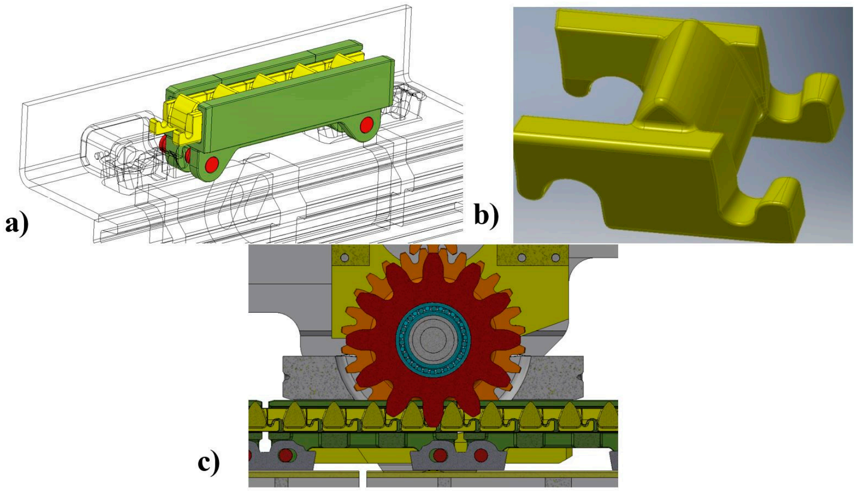

Figure 8. Komtrack haulage system: (**a**) 3D model of the guide and toothed segments installed on the conveyor line pan, (**b**) 3D model of a new version of the Komtrack toothed segments, (**c**) model of collaboration between the shearer drive wheel with toothed segments.

The developed Komtrack haulage system was subject to functional tests on the rig situated at the stacking yard of the Piast–Ziemowit, Mine Piast. Their objective was a verification of functionality of newly developed longwall shearer haulage system and of the wear degree of haulage system components, including toothed segments, on the field test rig simulating real conditions of loading the track wheel and of the toothed route. The prepared test rig of the length of about 50 m, with the installed Komtrack system, enabled a realization of the shearer passes under loading along a rectilinear route and deflected in the horizontal and vertical planes. A model of this rig is presented in Figure 9.

An armored face conveyor of the nominal length of line pans 1500 mm, in the number of 33 units, was mounted in the hardened base. A powered roof support unit was connected to every second line pan of the armored face conveyor to stabilize the conveyor position and enable its advance in a mechanized way, simulating contraflexures of the route in the horizontal plane.

The test rig enabled an assembly of the Komtrack haulage system guides in the existing seats on each line pan of the armored face conveyor. Toothed segments, blocked on both ends of the route with controlled hydraulic blocking, were placed inside the guides along the whole route length. The task of the blocking devices was an elimination of clearances occurring between toothed segments and a transmission of longitudinal loads generated by the longwall shearer moving along the armored face conveyor route.

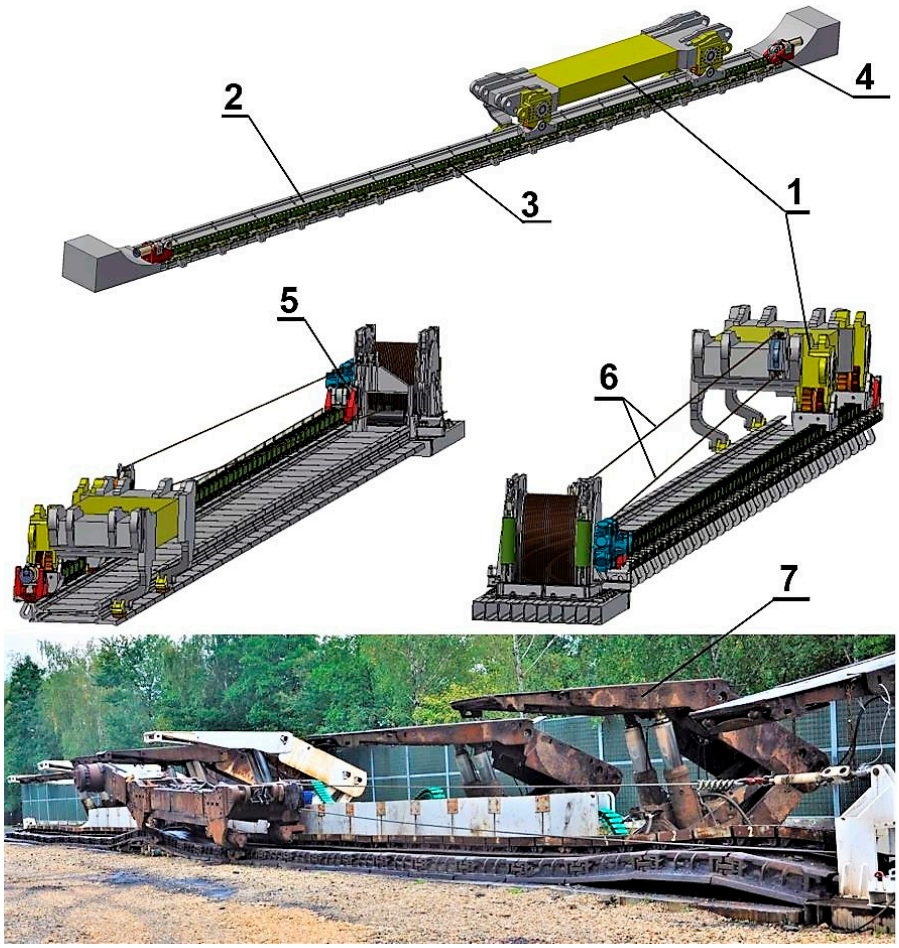

Figure 9. Three-dimensional model and a view of the field test rig for conducting functional tests of the Komtrack haulage system: 1—coal shearer, 2—armored face conveyor, 3—Komtrack haulage system, 4—tensioning system of toothed segments, 5—hydraulic winch, 6—braking rope, 7—powered roof supports.

The KSW-1140E longwall shearer (made by FAMUR S.A.) with haulage units equipped with track wheels, collaborating with the toothed segments of the Komtrack haulage units and shoes adapted to a collaboration with the guides, were installed on the rig.

The KHT-6 hydraulic transport winch was used for loading the longwall shearer (simulation of load resistances resulting from cutting). The braking force was transmitted to the shearer frame with a steel rope. Due to an application of a driving pulley (pulley block), it was possible to obtain twofold higher values of forces loading the shearer in the result of braking the winch. A view of the rig, ready for conducting functional tests of the Komtrack haulage system, is shown in Figure 9.

4. Functional Verification of the Komtrack System

The elaborated test rig enabled to conduct functional tests of the Komtrack system on three trough alternatives of the armored face conveyer, simulating underground conditions, occurring during cutting the coal mass (Figure 10):

- "P" straight route reflecting a rectilinear route of the armored face conveyor;
- "S" route reflecting the route deflected in the horizontal plane by 800 mm simulating the conveyor advance;
- "G" route of the hill type reflecting the route deflected in the vertical plane by about 300 mm, which enables to obtain an angular contraflexure of 5°.

Figure 10. Three alternatives of situating the trough of the armored face conveyor simulating the conditions of underground operation: P—straight route of the conveyor, S—the route of the conveyor deflected in the horizontal plane by 800 mm, G—the route of the conveyor deflected in the vertical plane by about 300 mm.

The tests of the newly developed Komtrack haulage system were divided into three equal time periods, in which the tests were carried out on the straight route "P", on the route deflected in the horizontal plane "S" and on the route deflected in the vertical plane "G". On the route of type "P", 196 passes were made; on the route of type "S"—167 passes and on the route of type "G" altogether 172 passes were realized. In total, the Komtrack haulage system was subject to the loads resulting from the total number of longwall shearer passes reaching 535 passes. One pass consisted of covering the length of the conveyor one way and back, highlighting the fact than one way the shearer was slowed down with use of the winch and on the way back it returned at the neutral gear. Assuming the web depth of one cut on the level of 0.8 m, it was calculated that in the simulated conditions of the field test rig the shearer mined out the longwall of the panel length of nearly 430 m in the case of unidirectional cutting and twice the length in the case if bidirectional cutting.

During the conducted field tests, the following aspects were measured or subject to verification:

- Assembly technology of the haulage system;
- Collaboration correctness of the frictional pair: toothed track wheel—toothed segment;
- Strength of toothed segments;
- Operational correctness of tensioning system of toothed bars;
- Wear degree of individual components of the haulage system.

The realized work showed that the assembly and disassembly technology and an operation of the Komtrack system are simple by intuition, and they only require a short training of the miners' team in the scope of the system tensioning. A construction of guides of the haulage system enables their installation in the places, where the Eicotrack system racks have been installed up till now. An installation of toothed segments inside the guides results in getting a route flexible in all the planes, self-adjusting to a current position of the shearer track wheels. Conducted observations showed a correct character of operation of the frictional pair whose strength is not lower than in the case of the Flextrack system of comparable dimensions.

5. Verification of Wear Degree of Toothed Segments

The conducted functional tests enabled to determine the wear degree of the Komtrack toothed segments. The most visible form of the toothed segment wear was grinding of the tooth tip (Figure 11a), which occurred on the teeth of exceeded nominal height in the situation when a segment of the toothed bar was in the top zone of the guide. In the case of maintaining nominal overall dimensions, this phenomenon did not occur (Figure 11b).

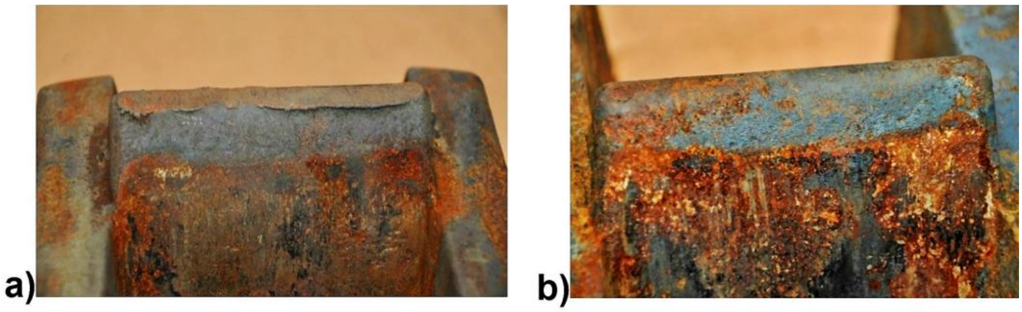

Figure 11. View of the top surface tooth of the Komtrack toothed segment: (**a**) damaged, (**b**) without any signs of damage.

The following form the toothed segment wear included indentations on the side walls of the keeps of these segments (Figure 12), caused by the pressure of the track wheel tooth in the situation of the toothed bar torsion in the horizontal plane. It was a proof of flexibility occurring in the haulage system, enabling a relocation of the toothed segments in relation to each other (tension). In extreme cases the above mentioned damages led to breaking off of keeping parts or resistance surfaces of toothed segments.

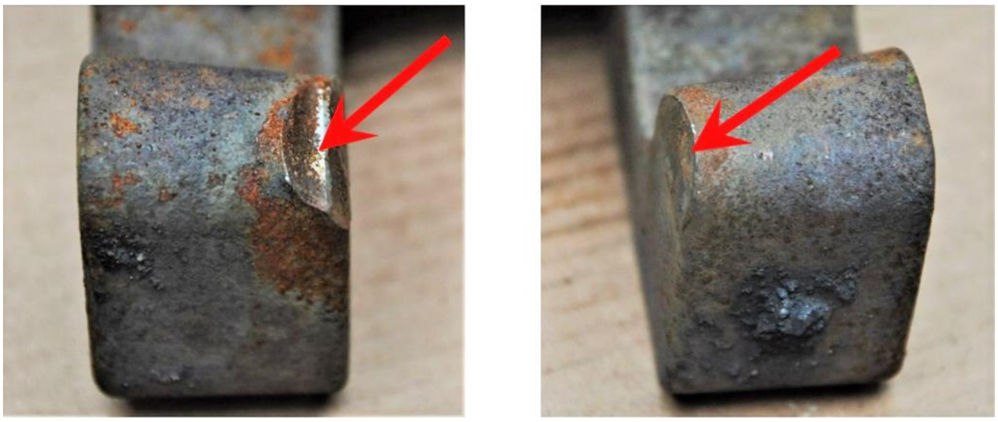

Figure 12. Damages of keeps of the Komtrack toothed segment, (marked with red arrows).

The most essential aspect, from the point of view of functioning of newly developed haulage system, was the wear degree of the tooth side surface of the toothed segment collaborating with the track wheel flank. Detailed digital data, indicating the wear degree of toothed segments, are presented in the further part of the article dedicated to a qualitative assessment of the toothed segments wear, based on the 3D scanning results. In the result of a visual inspection, it can be stated that the wear of the tooth flank is dependent on a position of the segments in the conveyor route. The toothed segment flank wear is distributed uniformly on its whole width (Figure 13a) in rectilinear conveyor section. In turn, in the places where the rectilinearity disturbances of the conveyor occur, the maximum flank wear moves towards the side wall of the toothed segment closer to the side wall (Figure 13b). Spherical load bearing surfaces of toothed segments, responsible for flexibility of the haulage system and maintaining its pitch, were also subject to a visual inspection. No forms of wear were identified on the above mentioned surfaces.

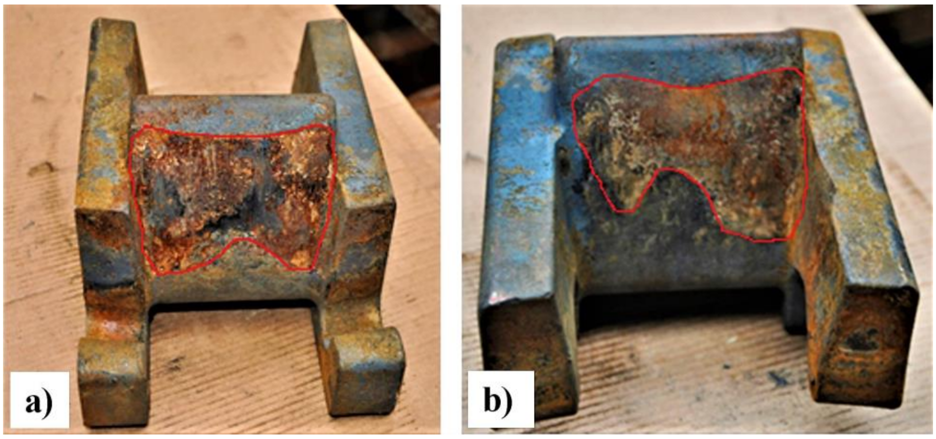

Figure 13. View of the wear of the tooth surface of the toothed segment, (marked with red frames). installed in the section: (**a**) rectilinear, (**b**) with disturbances of rectilinearity.

To assess the wear degree, the selected segments, before starting functional tests, were marked in a fast way and subjected to a process of weighing with accuracy of 0.5 g. Knowing the weight of individual specimen before starting the tests and after their ending, the wear degrees of individual segments were determined. They are presented in a form of weights differences and percentage wear. The results are presented in Table 2. In Figure 14, a graph of values measured before and after the tests of weights of individual toothed segments is shown.

Table 2. Measurement results of weights of individual toothed segments specimens.

Specimen	Weight before Test (g)	Weight after Test (g)	Difference of Weights (g)	Percentage Wear of Individual Toothed Segments (%)
K1	9578.0	9553	28.0	−0.26
K2	9441.5	9413	31.5	−0.30
K3	9394.0	9372	25.0	−0.23
K4	9608.0	9585	26.0	−0.24
K5	9358.0	9331	30.0	−0.29
K6	9685.5	9647.5	41.0	−0.39
K7	9589.5	9562.5	30.0	−0.28
K8	9422.5	9398.5	27.0	−0.25
Average	9509.63	9482.81	29.8125	−0.28

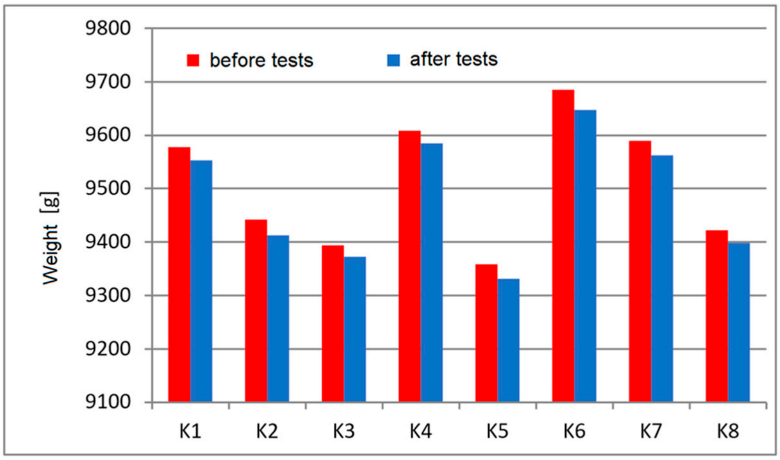

Figure 14. Weight value of individual specimens of toothed segments before and after functional tests.

An assessment of qualitative and quantitative wear degrees of the toothed segments was carried out with use of 3D scanning technology. Scanning was performed with use of the 3 DEINSCAN PRO 2 manual scanner made by the SHINING Company. Based on the 3D scans, comparative tests of the toothed segments surfaces, before and after functional tests, were realized. The measurements were taken with use of GOM Inspect 2019 software. Exemplary measurement results, in a form of the surface change deviation for selected segments, are shown in Figure 15. These segments are marked as:

- K1—toothed segment installed on the rectilinear route section before the contraflexure zone of the armored face conveyor;
- K3—toothed segment installed on the primary section of the conveyor contraflexure;
- K8—toothed segment installed on the rectilinear route section after the contraflexure zone of the armored face conveyor.

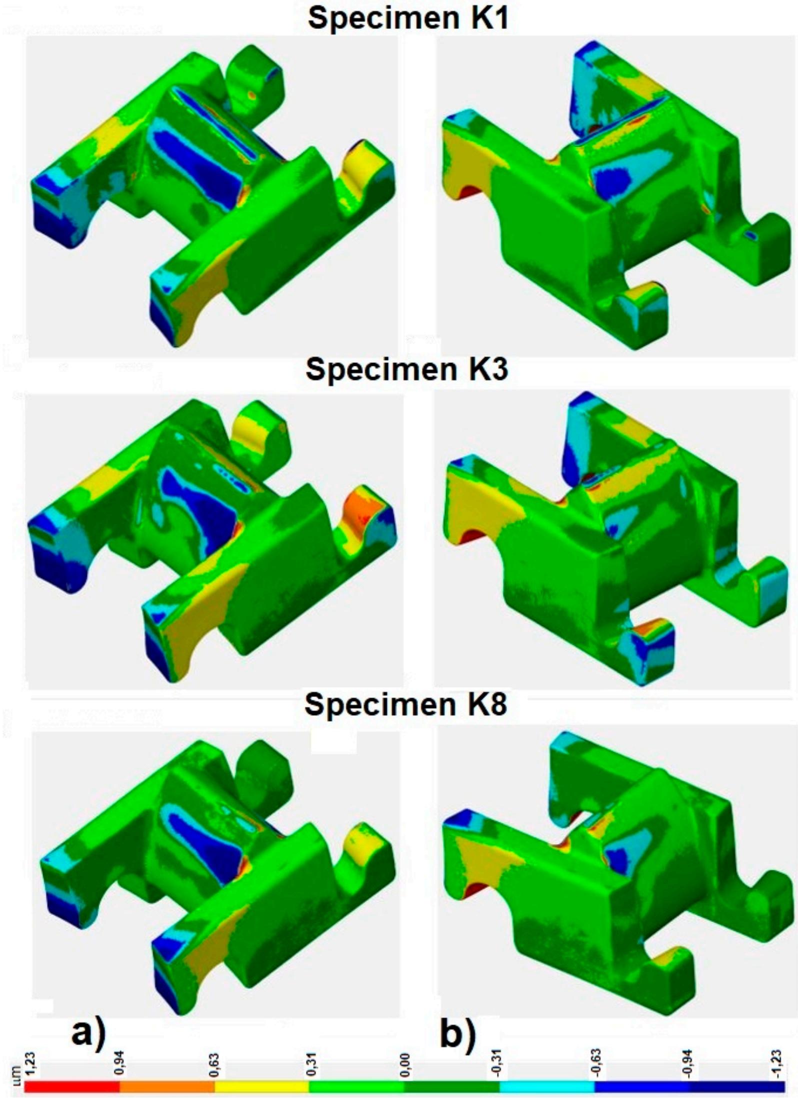

Figure 15. Measurements results of changes deviation of surfaces for selected segments, a comparison of scans of toothed segments models made before tests and after tests: (**a**) at loading caused by the shearer braking force, (**b**) at loading caused only by the shear pass.

The average deviation of surface changes before and after the tests for sample K1 was 0.1717 mm. The maximum upper deviation of the above mentioned specimen after tests, related to the scan made before tests, was 1.14 mm and for the lower deviation this value was −1.16 mm. Both flanks of the teeth collaborated asymmetrically with the track wheel teeth (i.e., bigger wear from the side of the coal mass). The loss is also visible in the tooth top part. Local plasticization of the material and relocations of compressed ends of catching keeps were identified as well.

For the K3 specimen, an average deviation of surface changes before and after tests was 0.2032 mm. Maximum upper deviation was 1.24 mm and the lower one −1.29 mm.

In turn, the average deviation of surface changes before and after tests for the K8 specimen was 0.1273 mm. Maximum upper deviation was 0.99 mm and the lower one −1.02 mm. Similarly, as for the K1 and K3 specimens, the increased wear on the tooth side collaboration during the shearer pass under load was stated.

In the case of all the specimens, maximum wear was identified on the tooth side corresponding to the shearer pass under load. On average, the deviation value between the reference model (before functional tests) and the models obtained in the result of 3D scanning of toothed segments after tests was 0.17 mm. Average values of deviations of model surfaces of all the toothed segments under analysis are shown in Figure 16.

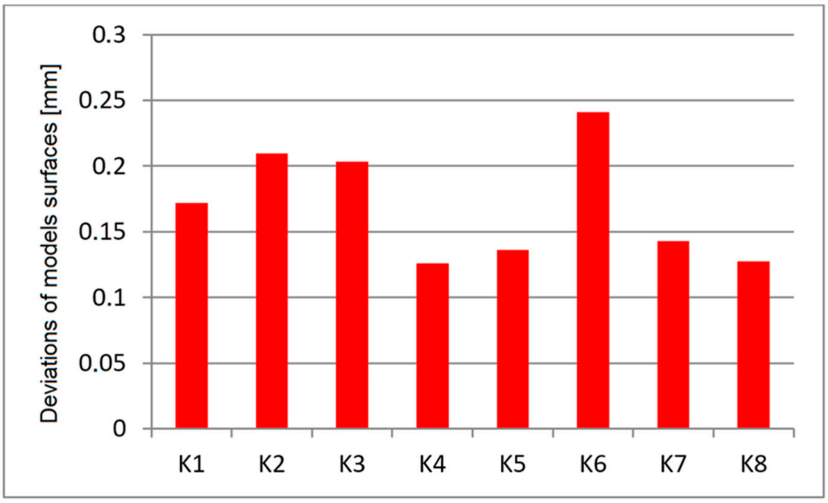

Figure 16. Value of the surface average deviation of the scanned model after tests in relation to the model before tests.

Analyzing the wear values of individual toothed segments, subject to functional tests in relation to their position on the conveyor route, it was spotted that the biggest wear occurred in the segments located in the zone of the armored face conveyor contraflexure. Based on the elaborated maps of deviations of surfaces of individual toothed segments, the following relationships were noticed:

- Visible increased flank wear of the toothed segment from the side of loading the shearer;
- Toothed segments characterized by positive tolerances of manufacture have damages in the tooth top part;
- Bigger wear of a part tooth flank of the tooted segment was stated from the side of the coal mass.

6. Verification of the State of Stresses in Toothed Segments

Within the framework of tests, also unique tests, oriented to a determination of the state of stress of the toothed segments due to a contact with the track wheel, were conducted. These tests were carried out with use of electric resistance strain gauges. A dozen or so special toothed segments, on which two, four and six strain gauges (Figure 17) were glued, were prepared. The strain gauges were glued in the pockets, also including the contact area of the toothed segment flank with the track wheel flank enabling to avoid their damage during a collaboration with the guide and the track wheel.

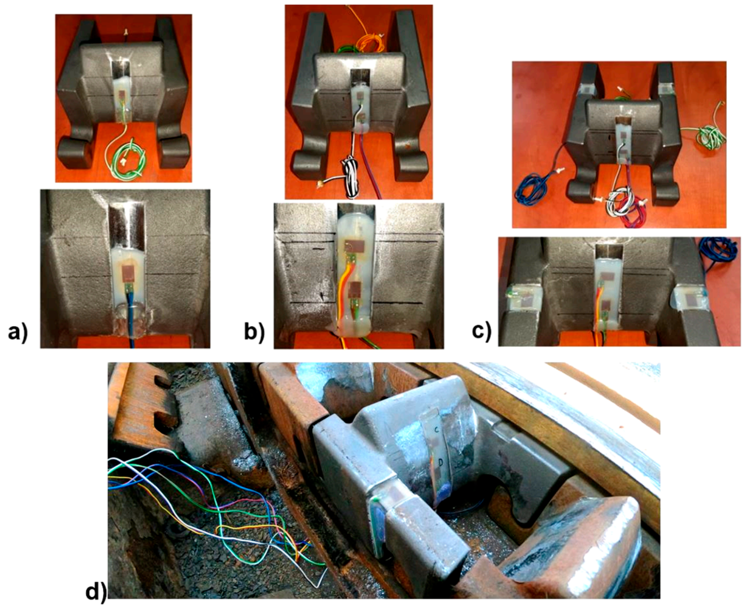

Figure 17. View of toothed segments prepared for tests with use of electric resistance strain gauges with glued strain gauges in the number: (**a**) two, (**b**) four, (**c**) six and (**d**) view of one segment with glued strain gauges installed in the guide.

After having installed toothed segments in the guides, the following longwall shearer passes were performed, recording current signals as reactions from the individual toothed segments. Collected data enabled to determine stresses in the place, where a strain gauge was glued in. In parallel with the strain gauge tests, the FEM numerical simulations, reflecting the conditions of the conducted strain gauge tests, were carried out. The exemplary result of conducting strain gauge tests and the results of the FEM simulations corresponding to them are shown in Figures 18 and 19.

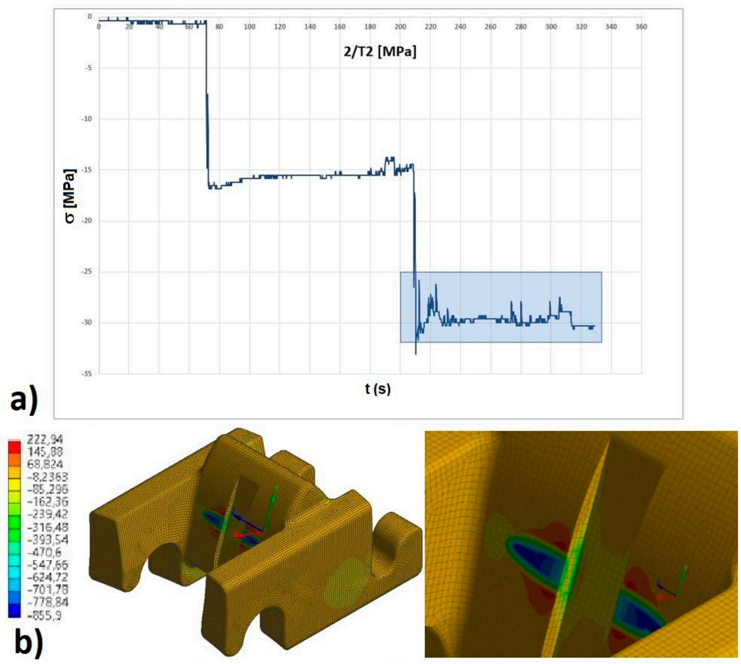

Figure 18. Values of main stresses in the contact place of the track wheel with the toothed segment with two glued strain gauges: (**a**) result of conducting strain gauge tests, (**b**) result of the FEM simulation.

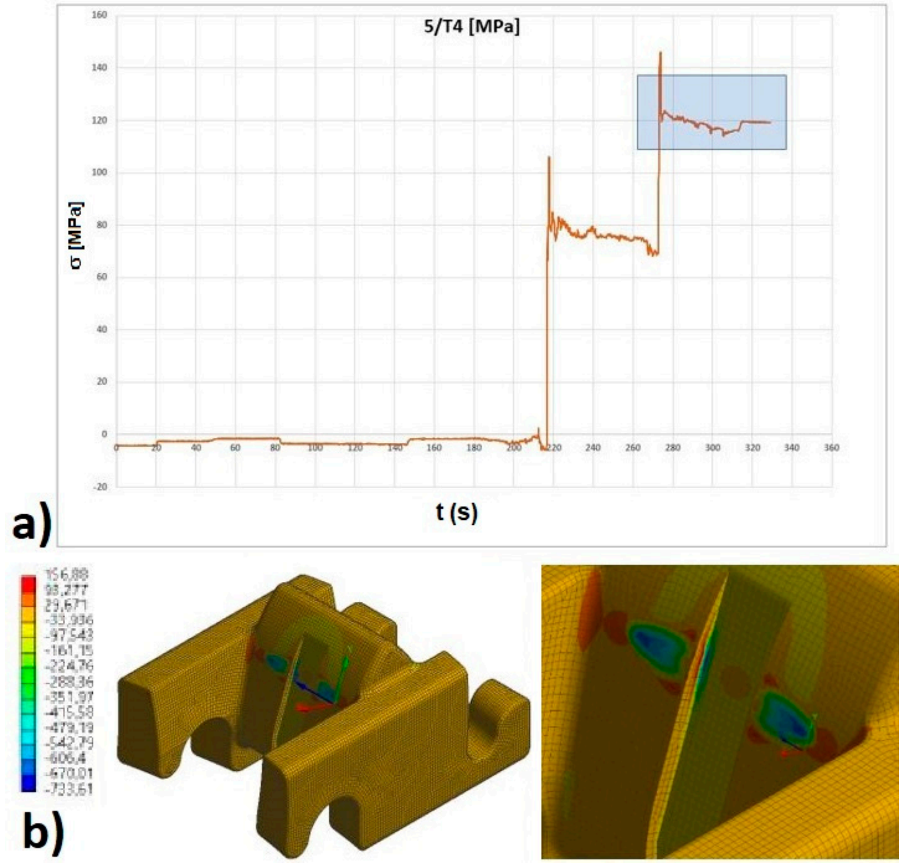

Figure 19. Values of main stresses in the contact place of the track wheel with the toothed segment with four glued strain gauges: (**a**) result of conducting strain gauge tests, (**b**) result of the FEM simulation.

In the case of the toothed segment with two glued strain gauges, maximum values of main stresses were in the range of 20–25 MPa, whereas the equivalent FEM simulations in this case showed the stresses on the level of 30 MPa. In turn, the values of stresses for the toothed segment with four glued strain gauges varied in the range of 115–120 MPa, whereas the values determined in the FEM simulations reached 130 MPa.

7. Modernization of Design Form of the Komtrack Toothed Segments

Based on the analysis of obtained results of the field tests, identified configurations of the toothed segments location inside the guide and their collaboration with the track wheels, some conclusions concerning a modification of the design form of the Komtrack toothed segment were formulated. The most essential ones are as follows:

1. Load-resistant and catching surfaces of the toothed segments, entering into a collision with the teeth of asymmetrically operating track wheel, are subject to damage (they break off), which in extreme cases can lead to a significant disturbance to the haulage system pitch.
2. Top surfaces of the tooth of the toothed segment, in relation to current position and tolerance of manufacture, entering into collision with a relocating shoe of the shearer, are subject to frictional wear; they introduce unwelcome resistances to motion and may cause a generation of disturbances in the haulage system pitch.
3. During slackening of the toothed route, the elements of keeps at the length of about ten meters enable pulling of the following toothed segments. A stroke of the cylinder of the tensioning system makes it impossible to eliminate backlash occurring among individual toothed segments along the whole route. To slacken the route completely, it is indispensable to move individual toothed segments manually in relation to the installed guides.

4. In the result of conducted tests and operational observations, as with regard to the Komtrack toothed segments, it was decided to modernize them through a removal of keeping parts (catches) due to the load-resistant surfaces gaining on the whole segment's height. Additionally, load-resistant surfaces, symmetrical in relation to the tooth axis, are subject to a collision with the track wheel teeth to a minimal extent. A reduction in the tooth height and an introduction of additional chamfering around the load-resistant surfaces decrease possibilities of abrasive wear of the toothed segment. The 3D model of the toothed segment, which was subject to field tests, and its modernized design are shown in Figure 20.

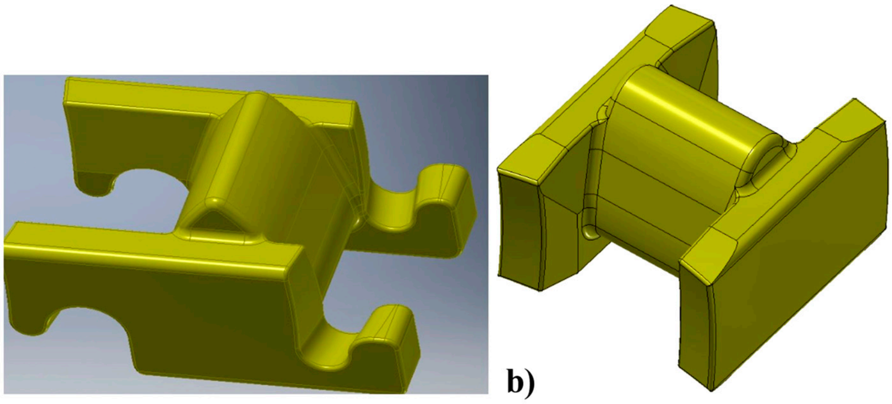

Figure 20. Three-dimensional model of the Komtrack toothed segment: (**a**) used in the field tests, (**b**) in the modernized version.

8. Summary

In the KOMTRACK project, realized by the authors, one of the stages included a verification of operational correctness of newly developed haulage system of highly productive longwall systems based on field tests. The tests were realized on the test rig, elaborated at the KOMAG Institute and constructed by the PGG S.A. Company. The test rig was located in the stacking yard of Piast–Ziemowit, Mine Piast. It enabled a simulation of operational conditions of a longwall system in underground conditions with regard to the equipment, loading and parameters characterizing the armored face conveyor with a chainless haulage system.

The results of tests and their analysis enabled, among others, answering the question of if a disadvantageous phenomenon of edging of track wheel tooth occurs in the newly developed haulage system. An analysis of films and photos, as well as of observations enables us to state that the developed Komtrack haulage system is characterized by flexibility resulting from design features of toothed segments. An analysis of the film material, in particular in the places, where disturbances of the route rectilinearity occur, indicated that a self-adjustment of collaborative surfaces of the frictional pair occurs in the result of a track wheel's single tooth acting on the tooth surface of the toothed segment. Due to this phenomenon, no durable, repeatable damage on the surface and on the edges of the track wheel occur.

Identified wear concerns both toothed segments, as well as the guide surfaces. The conducted analyses indicate that an average wear of toothed segments, in the results of tests, is smaller than differences in the tolerances of manufacture of new toothed segments. Thus, it can be concluded that the wear of individual toothed segments does not have any significant impact on functionality of the haulage system.

During a realization of tests, a few breakdowns were experienced, mainly regarding the shearer supply, but they did not have any negative impact on the scope and rate of conducting tests. Apart from some damage to the catching parts of toothed segments, the tests ran efficiently without any perturbations in the shearer's operation.

In the result of conducted functional tests, a modified design of toothed segments and guides of the Komtrack system were elaborated. These changes should increase, to a more significant extent, the operational reliability of the developed Komtrack system.

In the next stage of work in the KOMTRACK project, the newly developed haulage system was subjected to comparative tests with the Eicotrack system in in situ conditions in a longwall located in the Piast–Ziemowit mine. It was the last testing stage before preparing the haulage system for implementation on an industrial scale. The view of the shearer during the underground tests with the Komtrack haulage system is shown in Figure 21. The preliminary results of the tests showed that the shearer with the Komtrack system moves more smoothly along the conveyor route, with 2–3 times lower value of the vibration amplitude. In addition, thermal analyses have shown over 30% less heating of the cooperating system components.

Figure 21. View of the shearer during the underground tests with the Komtrack haulage system in Piast–Ziemowit coal mine.

On the other hand, in the case of wear of the cooperating components, very slight and even wear of the gang wheels and toothed segments was observed. In the case of the Eicotrack system, the wear of the cooperating components was higher and, especially in the case of rack pins, very uneven. The advantage of the Komtrack system is also lower by about 35% of volumetric unit consumption (cm^3/10,000 Mg of coal extracted from the longwall). A complete analysis of the results will be made after the end of the underground tests. Their completion is estimated in the second quarter of 2023. However, preliminary results confirm that the Komtrack shearer haulage system with modernized toothed segments can be successfully used in mechanized shearer longwall systems in coal mines. The obtained results of underground research will also be published and will be a continuation of and supplement to the article in question, in addition to the article that has already been published.

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