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A tool for determining the number of bends and places of accumulation of potential wear of steel ropes operating in the luffing systems of basic opencast mining machines

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Abstract:

This article presents the issues of the wear of steel ropes operating in the lowering systems of the largest wheel excavators (BWE), type SchRs, Rs, KWK operating in KWB Bełchatów. Sudden degradation of these ropes may lead to the complete shutdown of the BWE-Belt-Stacker system from operation. However, this can be avoided by regular visual inspections of hoist ropes. Unfortunately, the rope systems in each excavator are different, and their availability is difficult. In order to simplify this task, the authors of this paper have developed an IT tool that allows the modelling of a given multi-pulley rope system and the indication of critical places on the rope for given working conditions. A simplified description of this tool is the subject of the article.

Keywords: opencast mining, steel ropes, rope modelling, rope wear

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1. Introduction

In the last few years, in the European Union, as well as in Poland, the discussion on thermal energy based on coal raw materials has definitely shifted towards low-carbon and renewable sources. In Poland according to the Central Statistical Office [1] and forecasting for the future [2], almost 50% of electricity is produced from lignite, including pprox. 24% in the Bełchatów power plant and mine complex. There is a clear retreat from these classic carriers, while the government of the Republic of Poland does not outline at least short development prospects how to do it.

The outbreak of war and the economic consequences of the Russian Federation's attack on Ukraine radically changed the European and global approach to the problems of energy production in general. The discussion on coal-based energy is no longer so radically negative. Nevertheless, several years of uncertainty regarding the future of lignite mining, the complete lack of investment and the inevitable ageing of the unique set of basic machines [3] for lignite mining may lead to various failures in the future.

This article presents the issue of wearing the steel ropes used in the lowering systems of the largest wheel excavators (BWE), type SchRs, Rs, KWK working in KWB Bełchatów mine. Fig. 1 shows one such a machine with a rigging system of the lifting system of the cutting wheel boom.

Fig. 1. Bucket-wheel excavator SchRs4600 of KRUPP

Degradation of the hoisting ropes may eliminate the excavator-belt conveyor-stacker (KTZ) system from operation. However, this can be avoided by regular visual inspections of the rope hoisting systems [4]. Fig. 2 shows the kinematic diagrams of such machines together with the rigging systems.

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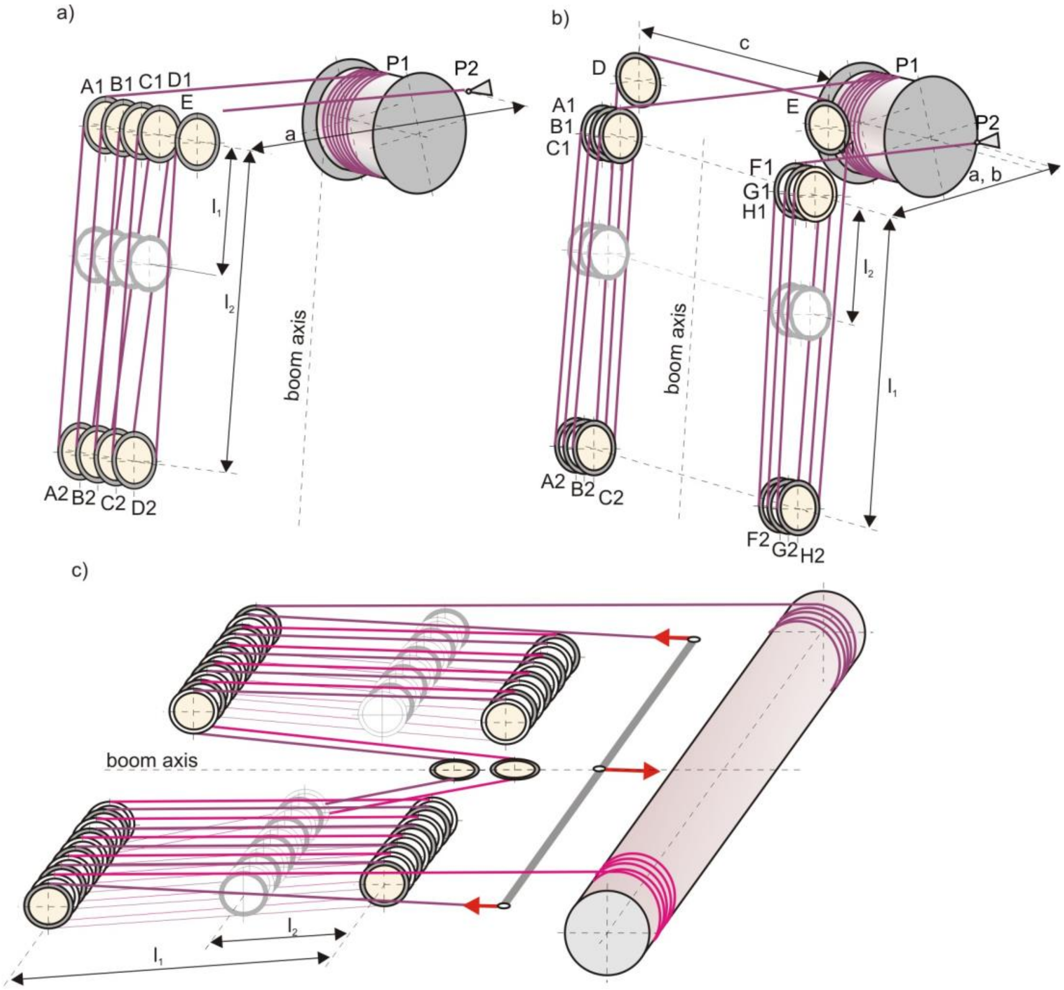

Fig. 2. Kinematic diagrams of rigging systems for machines with a cutting wheel:
a) excavator SchRs1200, b) excavator SchRs4000, c) excavator SRs2000 [5]

Unfortunately, the hoisting rope systems in each excavator have a different geometry and number of pulleys [4], and the accessibility of ropes in the hoisting systems for visual assessment is difficult. Periodic magnetic tests are not carried out, and the condition of the ropes is assessed on the basis of random visual inspection of a foreman or a person authorized by the surveillance unit. But this inspection is made only from easily accessible locations, and these do not always include high-loaded parts which are subjected to wear and tear. A simplification of this task is an IT tool developed by the authors of this article in the form of a calculator, which allows modelling the given pulley system on the basis of identified critical places on the lines for the given working conditions. A simplified description of this tool [6] is the article subject.

2. Testing methodology

2.1. Reasons for the wear of hoisting ropes in the luffing systems of excavators in the opencast mining industry

Roller pulley systems are the systems for lifting or lowering masses suspended from movable pulley blocks, moving with the use of steel ropes, wound on driving drums and rolling on rope sheaves (wheels). In these systems, the steel ropes, while rolling on the rope sheaves, contact the sheave through the raceway of the appropriately shaped groove. In these systems, we deal with the action of longitudinal forces in the ropes, bending of the rope on the pulleys and phenomena in the area of the rope contact with the pulley groove raceway. In addition, there are loads, mainly of a random nature, from vibrations that are damped at the entrance of each rope section to the pulley. Such action gives rise to three wearing symptoms. The most important is the mass loss wear of the rope, characterized by a local change in the rope cross-section area. In fact, these are the abrasions of its external wires due to friction against the raceway of the rope sheave. The abrasion is visible as an ellipse formed on the wire surface, which affects the strength properties of the wire [7]. Abrasive wear also occurs inside the rope as a result of the movement of strands and wires with the simultaneous occurrence of point contact pressure (Hertz pressure). This process is largely influenced by the cleanliness and quality of the lubricant [8]. The second extremely important cause of the wear of lifting ropes are plastic deformations caused by increased pressure between the rope and the groove of the rope pulley. The pressure leads to abrasive wear and also to plastic deformation wear, leading to wire breakage (crushing). These deformations in specific contact conditions can also lead to the formation of such high pressures that martensitic structures are formed on the outer layer of the outer wires. Due to their brittleness, these structures can cause premature fatigue cracks in the outer wires of the rope. This damage has a different effect on the weakening of the rope. The loss in the metal rope cross-section area due to the abrasion processes may not exceed 2% of the original rope cross-section area [9]. Abrasive wear is closely related to the operating conditions of the ropes and to the pulleys linings. The process of abrasive wear is more noticeable on hard and abrasion-resistant wires [10]. In opencast mining excavators, due to their short operation and good lubrication, no corrosive mass losses nor excessive fatigue wear leading to premature disqualification of the rope were observed.

Another important factor leading to rope wear in the hoisting system of an excavator cutting wheel is cyclical deformation of the rope geometry during lifting the cutting wheel, when the length of each rope branches between the upper and lower pulleys is shortened during lifting. The stroke length of the working rope is reduced. This reduction may lead to the occurrence of a torque moment which, by eliminating the frictional forces on the pulley, may transfer to the next rope branch outside the pulley. As a result, these changes accumulate, and in some sections of the rope there may be accumulations of changes in the length of the stroke. This phenomenon is shown in Fig. 3. This applies to practically all double lay rope designs operating in a pulley system. This mechanism influences the changes in the angle of inclination of the wires in the strands and also introduces additional variable tangential stresses, which accelerate the fatigue wear process.

The main disadvantage of the pulley system are large dimensions and masses of components, depending mainly on the diameter of the ropes used. The design of the ropes has a great impact on the service life of the entire rope system [11].

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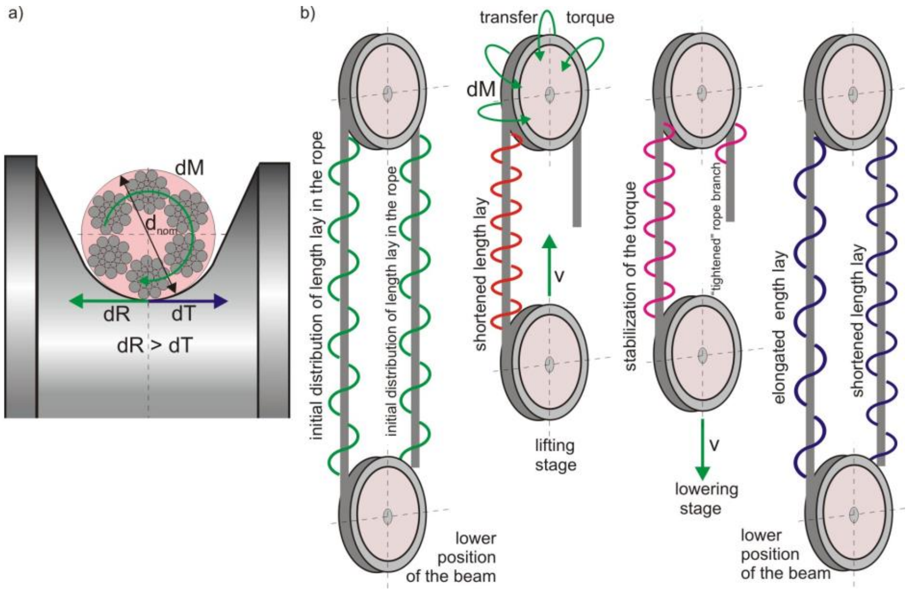

Fig. 3. Phenomenon of differentiation in stroke length of ropes operating in pulley systems:
a) friction forces and torque of the turn-off moment,
b) variation in rope stroke length during lifting and lowering [5]

Therefore, the cyclic change in the stroke length has a significant impact on the local fatigue damage. The change in the stroke length in a given branch is dynamic and results from the operating range of the pulley system. This leads to local damage on the sections where the stroke length changes most [12].

As in excavators' lowering systems, ropes with a steel core coiled in the opposite direction to that of the rope are most often used, this may lead to the formation of a large torque in the layers inside the rope. This moment is cyclical. In the phase of lowering the cutting wheel, the stroke lengths of the outer strands are lengthened and the stroke lengths of the core strands are shortened. In the lifting phase, the phenomenon is opposite. This creates a fatigue machine which, in the event of high friction between the core and outer strands, can lead to twisting of the inner rope layers. Unfortunately, this happens in such a way that it is invisible to an outside observer. Such phenomena were observed multiple times and always when the inner part of the rope was practically destroyed due to fatigue. Fig. 4 shows such an extreme situation.

Fig. 4. Degradation of the metal core of the lifting rope of the SchRs excavator lifting system as a result of the torque (photo A. Tytko)

The figure shows a metal-core rope removed from the excavator, in which the steel core has practically been ground. The only effect visible on the outside was a change in the diameter of the rope over a short distance, and the two outer strands collapsed. As the rope was well covered with grease, the damage was hardly visible. The effect of all these wear factors is the reduction of the rope diameter. In Polish conditions, for ropes in opencast mining, a decrease in the rope diameter by 7% in relation to the nominal diameter disqualifies the rope for further operation. This moment is very difficult to observe. Moreover, this degradation occurs on a very short, difficult-to-find section of a rope that is several hundred meters long. The wear mentioned above occurs on the sections of the rope that are most often bent, therefore the information about the number of bends that the rope (or, in fact, its sections) makes during one work cycle is crucial for the correct diagnosis of these devices. Rope reliability and reducing the likelihood of its sudden failure in operation are important issues in rope inspection and testing [13].

Rope may also be damaged as a result of improper design or operation of rope pulleys. This applies in particular to the geometry of the grooves of each rope pulley, seizure of the bearings and the wrong angles of the rope slope on each pulley. The correct geometry of the pulley system structure and diagnostics of the rope condition during its operation always lead to the extension of the rope operation time, and thus the operation time of the entire device.

2.2. Rope operation cycle in a multi-pulley system of bucket-wheel excavators

In the case of opencast mining machines, the pulley systems are the key mechanical unit determining the quality and safety of their work. The operation of ropes in these systems is cyclical, but in each case it is determined by the design of a given pulley system. Parameters characterizing a given pulley system include: the number of pulleys of the movable and stationary pulleys, the distance of the rope section between the drum and the first pulley, and the rope distance between the last pulley (so-called dead pulley) and the rope attachment. However, the basic parameter determining which sections of the rope are most loaded are the distances by which each rope branch moves. Depending on the lifting and lowering height of the multi-pulley system (for each configuration of the system), a characteristic course can be determined during one cycle. This is the number of bends that each section of the rope experiences during the full work cycle to the height of lifting and lowering the cutting wheel. The work is the result of geological conditions in which a given machine works. Characteristics of the number of bends as a function of rope length is a basic indicator that can be used to indicate places on the rope that are potentially subject to wear. Opencast mining machines used in Poland have very large dimensions, and access to each rope section is difficult. Therefore, for a given machine, with a specific design of a multi-pulley system, operating in a specific work regime, access to particularly sensitive places is difficult. Main disadvantage of the pulley system are large dimensions and masses of components, depending mainly on diameter of the ropes used. Design of ropes has a great impact on service life of the entire rope system [14]. Nevertheless, the characteristic function of rope wear (number of bends as a variable of the rope length) makes it possible to set the pulley system in such a way that a foreman or another person assessing the condition of the rope during its operation could be in the immediate vicinity of the given rope.

2.3. Modelling the operation of steel ropes used in multi-pulley systems

It is possible to determine the number of bends affecting the hoisting ropes as a function of their length using a model describing the geometry and configuration of a given lifting rope. This model assigns to each rope section a number of bends during the complete cycle of lifting and lowering the cutting wheel. This modelling is based on the assumption that each bend made by the rope on a specific pulley adds up to the successive bends that this section of the rope makes during the entire work. Based on the tests of ropes in operation, it has been proven a number of times that the maximum wear of steel ropes operating in multi-pulley systems is concentrated in several characteristic places. These are: the sections of the rope that made the greatest accumulation of the number of bends, the sections of the rope lying on the pulleys and subjected to loads due to small rope displacements in the form of fretting oscillations, and the ends of ropes. This applies to both the rope attachment in the so-called dead end and on the drum. Therefore, in the opinion of the authors of this paper, rope condition assessment should focus on those places where the potential wear may be greatest. Therefore, a special algorithm (model) was developed that allows for the given geometry of the pulley system and specific, but real, conditions of its operation to calculate the actual numbers of bends performed by each part (sections) of the rope.

3. Results - calculator of the number of bends of steel ropes working in multi-pulley systems

The program (algorithm [6]), the main screen of which is shown in Fig. 5, is the calculator of the number of bends of steel ropes operating in multi-pulley systems.

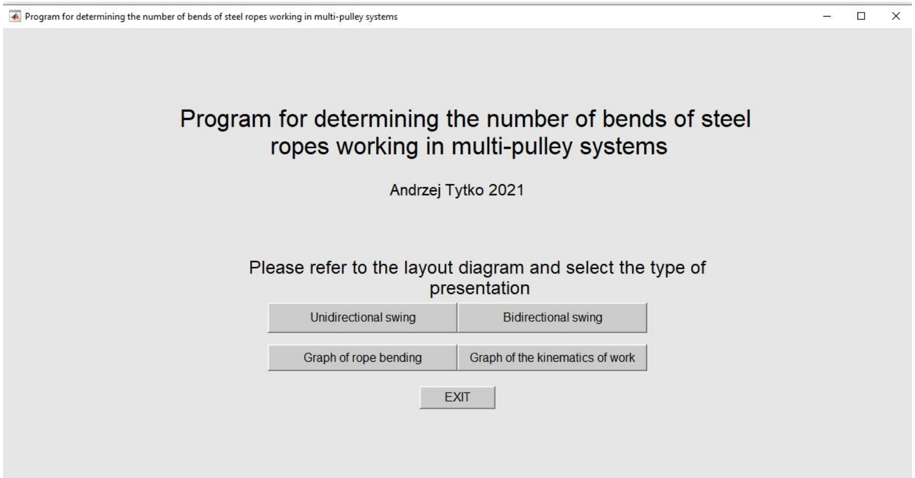

Fig. 5. Screen of the program for determining the number of bends in multi-pulley systems [6]

It enables modelling the real kinematic diagram of the working ropes by taking into account the number of pulleys of stationary and movable pulleys, the length between these pulleys in the lifting and lowering cycle. This is possible due to the active program screen shown in Fig. 6.

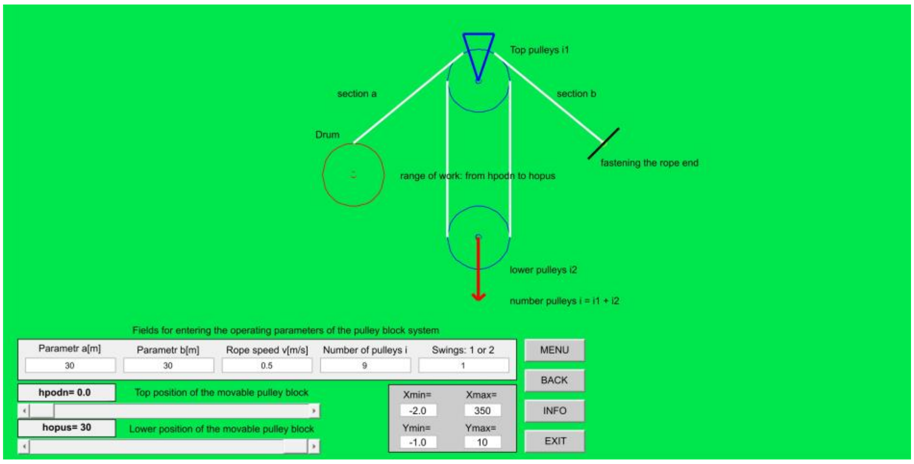

Fig. 6. Active program screen for entering geometrical parameters of the multi-pulley system as well as lifting and lowering heights of the multi-pulley system [6]

The program takes into account the lengths of rope sections between the drum and the first pulley, and the last pulley, and the rope fixation. The calculator draws a graph of the number of bends affecting each rope section during the work cycle. The cycle includes an optionally adjustable top and bottom position of the pulley system. The input data are the number of pulleys and the length of each section of the rope, as well as the method of bending the rope on the pulleys: unidirectional or bidirectional. Changing each of the parameters results in generating a different diagram of bends. An example of such a diagram is shown in Fig. 7 for the parameters of the pulley system in Fig. 6.

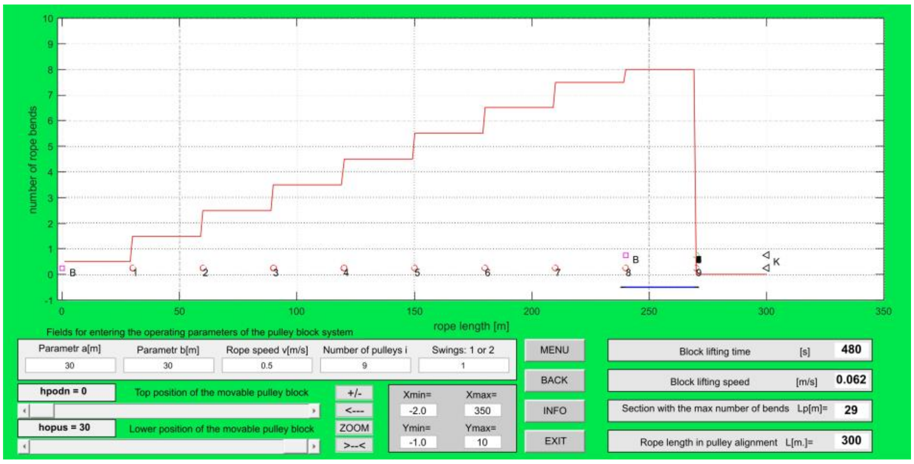

Fig. 7. An example of a diagram for the number of bends of a rope operating in a pulley system for the parameters of the system shown in Fig. 6

The calculator is a helpful tool used to determine the places of potential damage and the length of sections with a given number of bends. This tool, enables determining the places with the greatest number of damages.

On the basis of the analysis and model calculations made with the use of a calculator, it is possible to determine the sections of ropes potentially the most exposed to wear and deformations in the any pulley system. The section of the rope exposed in Fig. 7 is located near the entrance to the rope drum at the maximum lowering of the cutting drum. The drawing shows the results of the rope bends on the sheaves for individual sections of the rope during the lifting cycle of the cutting wheel boom from the position of 0 m to the position of +30 m. The presented example, for which simulations were made for various boom lifting heights, are not presented in this work, prove that the maximum level of wear, sections where damage may occur after a certain number of cycles (determined rope durability) of a rope with a length of approx. 300 m occur between pulleys 8 and 9 when the boom is raised to the level of +30 m. For the rope, it is a section of approx. 220-280 m from the fifth sheave on the side of the dead end of the rope.

The calculator is a helpful tool to indicate the places of potential fatigue damage, e.g. in the form of wire breaks.

4. Conclusions

The user of the calculator can model operation of the rope in any range of movement, both up and down. The calculator determines the rope sections with potentially greatest number of bends and shows the position of the sections, when the cutting system is in the highest or lowest position. Using the calculator's indications, the person who assesses the condition of the hoisting rope may adjust the position of the cutting wheel, so that the interesting section of the rope is within the range of observation. Opencast mining machines, as mentioned earlier, have very large dimensions and this tool allows to selecting the position of the boom in such a way that when lifting or lowering the wheel in front of the inspecting person, the rope with the potentially most worn part is wound. In the rope diagnostic practice of opencast mining machines such as multi-bucket or single-bucket dragline type, there is no similar diagnostic tool. The tool is not complicated, but it makes it possible to pinpoint potentially troublesome sections along the length of the rope. The rope examiner can focus on assessing these safety-critical several metres, rather than the entire length of the rope. This is the purpose and idea for the creation of the discussed tool. It was developed as a graphical interface in MATLAB [6], but it is possible to transfer the code to any other application and run it on any type of laptop or personal computer. The use of such a calculator should extend the working time of ropes operating in the luffing systems of opencast machines, due to identification of places on the ropes with the highest wear and on planning, through regular checks, convenient dates of tests, repairs and possible replacement of the ropes with new ones.

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