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Concept of the facility for testing the wear of chain links in the aspect of synergism of environmental factors

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Abstract:

The article presents the concept of a test stand for laboratory comparative tests of the multifactorial wear of chain links used in scraper conveyors, the aim of which will be to improve the durability of chains by using more favourable materials from which the chain links are made. The tests will focus on the zones of links cooperation under load. The concept was preceded by a theoretical introduction illustrating the nature of the wear of chain links and the synergy of wear processes. 3D model of the test stand and proposals for technical solutions of each component were discussed. The test stand will enable testing the environmental factors increasing the intensity of the wear process in several arrangements. These include, among others mineral abrasive, mine water and dynamic forces acting on the chain. The method of verifying the concept of the test stand using the simplified prototype made in the 3D printing technology was also presented.

Keywords: increase of durability, link chain, wear

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Introduction

Cooperating components of machines are subjected to wear and tear. There are many external factors causing and/or increasing the wear degree of the machine nodes. There are the following most common forms of damage:

- separation fracture (decohesion),
- corrosion,
- plastic deformations,
- tribological wear [1,2].

All the above-mentioned forms of damage can be observed in the subassemblies of scraper conveyors operating in hard coal mines - this also applies to link chains. However, analysis of the state of the art shown that tribological wear is to a significant extent responsible for the total damage to the components of scraper conveyors. This wear often intensifies or accelerates all the above-mentioned forms of damage [1, 3-8].

Material and Methods

2.1. Basic forms of tribological wear

In the literature, tribological wear is defined as a type of wear caused by frictional processes. There is a change in the structure and physical properties of the outer contact layers, and thus a loss in the volume and weight during the processes related to tribological wear. The wear intensity can be defined as the total result of different types of destructive interactions. Tribological wear can be defined by several quantities. The most popular are the parameters defining the loss in volume, weight or some dimensions characteristic for a given wear (e.g. in the case of link chains it may be a pitch) [1, 2].

The main process causing destruction of cooperating components is a criterion for classification of tribological wear (Fig. 1). Here we can distinguish the following [1, 2]:

- adhesive wear caused by degradation of adhesive joints,
- abrasive wear caused by micro-cutting and micro-grooving processes through the interaction of the surface with the micro-roughness present,
- fatigue chipping of surface layers of cooperating components, caused by cyclic variable load or abrasive movement,
- corrosive wear.

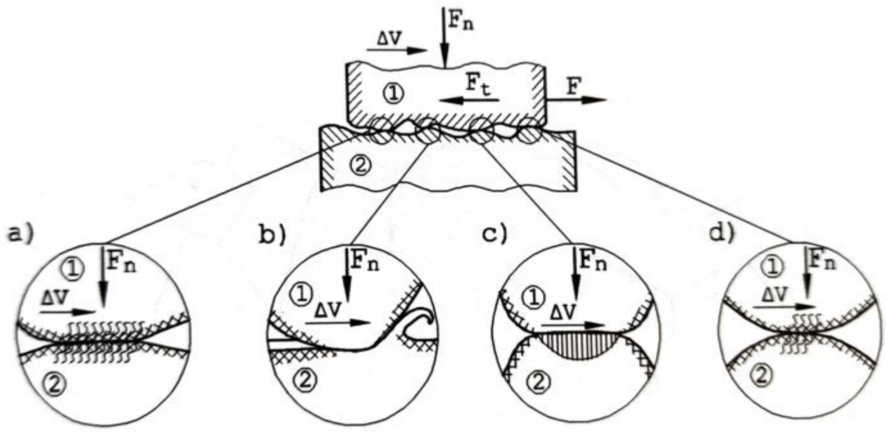

Fig. 1. Tribological wear mechanisms (a-adhesive, b-abrasive, c-fatigue, d-corrosion) [1]

Abrasive wear is the basic mechanism of damage in the tribological system of two cooperating chain links. In general, it consists in the separation of material particles of the abrasive surfaces as a result of micro-abrasion and micro-grooving processes. In the absence of additional abrasive material between cooperating surfaces, damage is caused by micro-roughness of the cooperating surfaces themselves. When there is additional abrasive between the cooperating surfaces, the degradation process is significantly intensified [1].

Dynamic effect is an another factor that intensifies the abrasive wear. In the literature, abrasive-dynamic wear is sometimes classified as a sub-category of impact wear, defined as a collision of solid bodies. Abrasive-dynamic wear is related to the presence of two following mechanisms:

– hitting the abrasive particles on the worn surface and further sliding movement of these particles on the worn surface,
– sliding against each other of two worn surfaces in the presence of abrasive particles with the interaction of external forces generating impact [1, 9].

Frequent starts, uneven load, hits of the transported material on the conveyor, constantly generate dynamic forces that can cause impact on the abrasive between the surfaces of the chain link.

Tribo-chemical wear is another wear mechanism mentioned in the literature, defined as the formation of surface reaction layers in a result of tribo-chemical reactions. These surfaces, in a result of the abrasive mechanisms, are removed, opening the newly-reacting surface with environmental components (e.g. mine water). This reactivity is explained by the plastic deformation of the friction surface, which generates local changes in density, causing the migration of electrons from the places with shear stresses to places with tensile stresses (where the potential is negative). Temperature differences resulting from warming up of friction surface is another catalyst for tribo-chemical reactions. Then, electrons flow from regions with higher temperature to the places with lower temperature. Within the tribo-chemical wear, a distinction is made between oxidative and corrosive wear. The first one consists in the cyclic removal and recreation of the oxide layer on the surfaces of the cooperating components, in the atmosphere of dry air. It is classified as a normal type of wear, and its intensity is insignificant under stabilized conditions. In turn, corrosive wear is the removal of the brittle oxide layer in a cyclical manner during the abrasion of the cooperating surfaces. This process is significantly intensified by the presence of wear products, which take the role of hard abrasive grains. In the literature, the concept of tribo-corrosive wear is used to describe the forms of combined wear intensified by the synergistic effect of abrasive and corrosive factors [1, 9-15]. The mechanism of tribo-corrosive wear is schematically presented in Fig. 2.

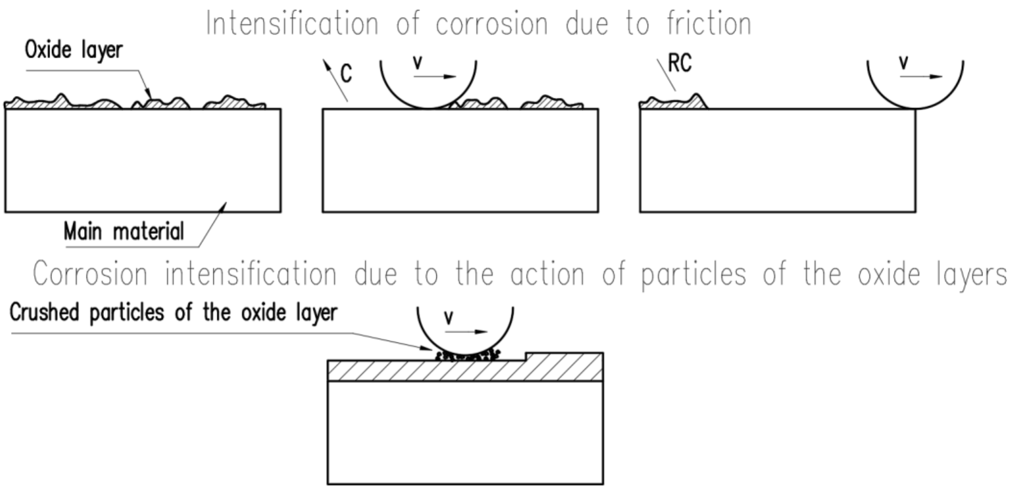

Fig. 2. Mechanism of tribo-corrosive wear (velocity vector, K-corrosion; R-repassivation) [11]

More broadly, tribo-corrosion is sometimes treated as the interaction of corrosion with various types of mechanical wear. On this basis, the literature defines the so-called tribo-corrosion system understood as a kind of tribological system, taking into account, along with mechanical inputs, material and environmental properties, also electrochemical inputs. This type of system is best described by the relationships influencing the wear of the chains in the area of contact of mine scraper conveyors components [1, 16-18].

2.2. Wear and degradation of chain links

Cooperation of chain links with the drum and the conveyor route, cooperation between the links as well as difficult and complex environmental conditions in hard coal mining plants determine complexity of the wear processes of link chains in terms of friction, corrosion and fatigue. The most important factors increasing the degradation of links and components of scraper conveyors are the following:

– presence of rock and coal dust in the zone of cooperation of chain links and during their movement in the segments of the conveyor route
– corrosive effects of mine water coming from spraying systems and flowing out of the goaf (causing the so-called Rebinder effect),
– corrosive effect of aerosols of mine air and mine water,
– dynamic loads from start-ups of conveyor drives, their uneven loading, frequent reloading and blocking.

The above-mentioned degradation factors of chain links, most often lead to their breaking after a given operating period. Despite the production of chains from high-quality steel according to specialized technologies ensuring high durability and strength requirements, chain breaks are the most common failures of scraper conveyors, which, first of all, pose a great threat to working miners and generate significant economic costs related to breakdowns. This is especially disadvantageous when considering the serial mining system in coal mining, where the stopping of the haulage machine on the face or longwall heading usually stops the entire mining process. What's more, the chains break usually without any previous symptoms, that is why taking the preventive actions is not impossible posing a risk.

Results and discussion

3.1. Technical assumptions

Analysis of the possibility for designing a test stand, intended for laboratory comparative tests of chain wear (within the link contact zone), with particular attention to impact of environment in underground mining plants was the basic assumption of the conceptual work. Development of the stand design to a degree that would enable its construction, and then testing it was the authors objective. The following assumptions were made for the test stand:

– the stand should reflect the cooperation of two chain links, one fixed and the other moving in the range of the angle of turning one against the other by about 30˚,
– drive component of the stand based on an electric motor with a power of approx. 1.1-1.5 kW and a rotational speed of approx. 1420 rpm,
– load to the fixed link with an axial force of about 1000 N,
– 14x50 link chain will be tested.

3.2. Concept of the test stand

The first step in the conceptual work was to determine the kinematics of the test stand based on the adopted technical assumptions. Accordingly, the diagram as in Fig. 3 was adopted.

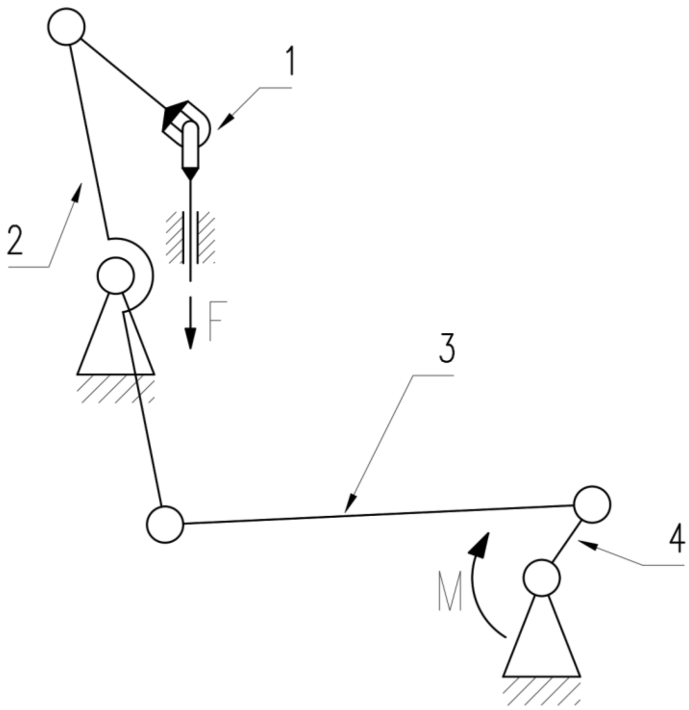

Fig. 3. Kinematic diagram of the conceptual test stand
(1-cooperating links, 2-rocker arm, 3-linkage, 4-crank, F-loading force, M-torque)

According to the above diagram (Fig. 3), the torque will be transmitted directly to the crank system. The crank will be connected by a link to the articulated rocker arm. Movement of the crank will allow the rocker to rotate around the link to a limited extent, corresponding to the required range of rotation in the chain link. The rocker arm on the other side will be connected via articulated arm, on which the half of the link that will move in the link will be fixed. The second half of the link will be suspended on the movable "half-link", loaded with the force F in the direction coinciding with the longitudinal axis of the fixed link. The load will be fixed on a guide which will be free to move in the direction of the force.

After the analysis of the kinematic scheme, the components of the drive assembly were selected. Three-phase electric motor of a body size IEC 90, foot-mounted (B3) and with the possibility of flange-mounting (B14) type 90LP/4 TF 180E by Nord was selected. As standard, the motor is equipped with an inverter (type SK 180E), which enables setting the rotational speed of its shaft. The speed control does not require an additional control system and will be controlled by a knob already mounted on the inverter [19]. In addition to the motor, a Kacperek HM-202/90B14 worm gear was selected [20]. With the assumed gear ratio i=11.42, the test stand will be able to make maximum 123 friction cycles (back and forth) on a one sample (177,120 cycles per 24 hours).

The conceptual model of the test stand is shown in Fig. 4.

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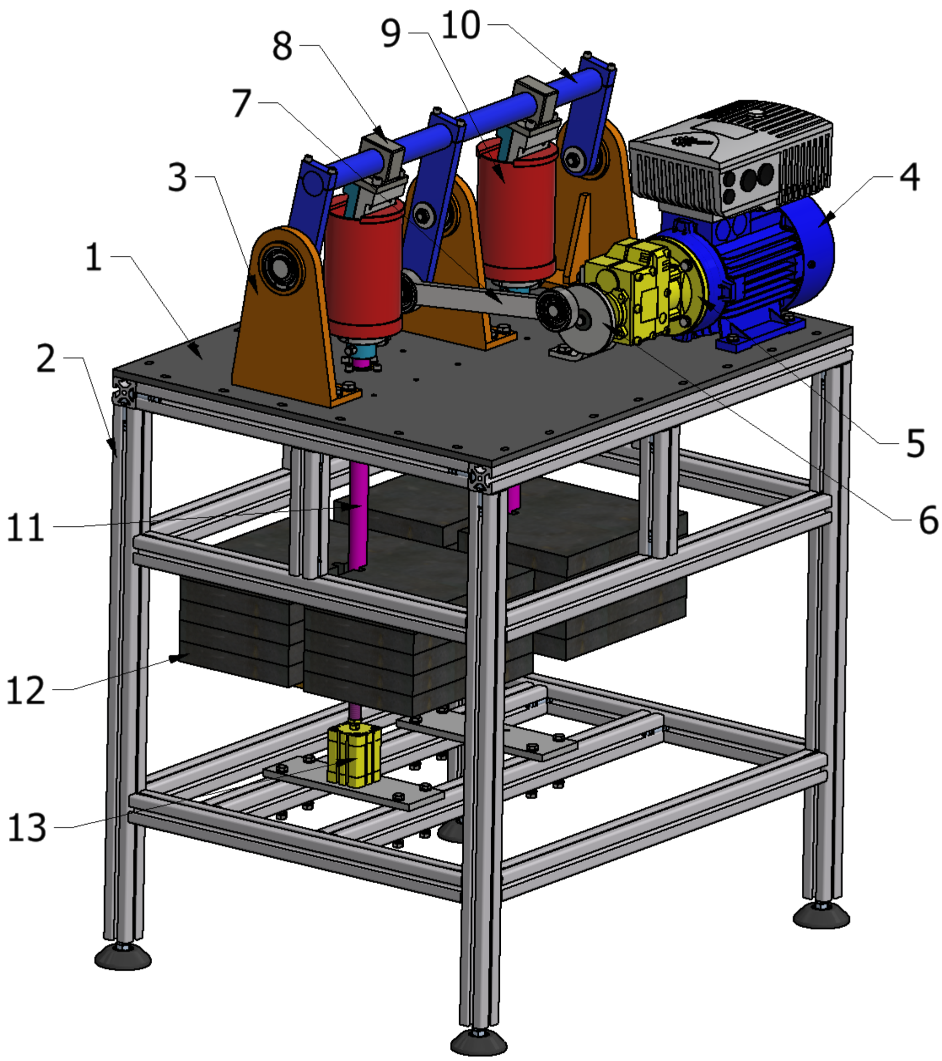

Fig. 4. Model of the test stand - general view (1- table top, 2-table frame, 3- stands, 4- electric motor with inverter, 5- reducer, 6-eccentricity (crank), 7-connector, 8-upper link holder, 9 - container for abrasive, 10-rocker arm, 11-load bar, 12-weights, 13-pneumatic cylinder)

The assembly is driven by a three-phase electric motor. The selected motor has a body that contains both the legs and the connection flange. This allows the motor to be screwed to the table through the legs and to fix on it the reduction gear flange. On the input side, the gearbox is equipped with a hub with a key (for connection with the motor), and on the output side with a shaft, also equipped with a key. An eccentricity (crank), made as a pipe (with a groove) with a disc containing an eccentric opening, will be mounted directly on the shaft. The eccentric sleeve acts as a crank mechanism, converting the rotary motion into a reciprocating motion.

A pin assembled with the connector will be installed in the eccentric opening. The connector is the component that transmits the reciprocating movement to the rocker arm, which in turn converts it back into a rotary movement around the link, but limited to about 30°. A steel rod, ending on both sides with bearing hubs will be the connector– on one side for connection with the drive, and on the other side with the middle arm of the three-armed rocker arm, installed on three legs to make swinging possible. So-called movable links will be attached to the rocker arm, cooperating with fixed links, which are loaded by a weight. Both movable and fixed links are located in containers to which abrasive is dosed.

The containers cover precisely the abrasive and possibly the water added with it, due to the need to limit the amount of abrasive needed for testing, and also the need to reduce dust, which is particularly dangerous for the operators working in the presence of carbon abrasive. A cross-section through the abrasive tank is shown in Fig. 5.

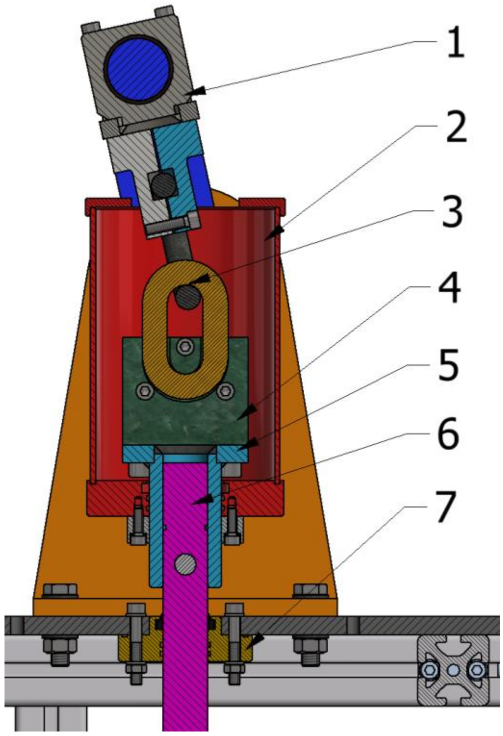

Fig. 5. Cross-section of the tank for abrasive
(1- grip of upper link, 2 – tank for abrasive, 3 – cooperation point between links,
4- grip of bottom link, 5- sealing sleeve, 6 – loading rod, 7 – guiding sleeve)

The load that simulates the longitudinal forces in the chain will be installed on a bar attached to the bottom link. The bar will require displacements restriction in directions perpendicular to its axis. For this purpose, a guide screwed from the bottom of the table will be introduced (Fig. 5), allowing only the axial displacement of the bar. At its end, a set of weights (Fig. 4, item 12) will be installed, simulating the tensile force occurring nominally in the chain. Weights will be made of rectangular pieces of metal sheets, and their number will depend on the assumed load. At the bottom of the table, it is possible to install auxiliary devices, e.g. a relief jack, as well as a unit responsible for generating dynamic loads. It was initially assumed that this role would be played by a pneumatic actuator axially connected to a loading bar.

Initial nominal load resulting from the suspended weights was determined on the basis of FEM analyses, which showed the stresses ~ 40 MPa in the contact area at a load of 1000 N. It seems to be enough to emphasize the processes of micro-cutting and micro-grooving, however, this value will be finally verified empirically on the constructed test stand. In the case of selecting and determining the operating parameters of the pneumatic actuator, dynamic tests of the scraper conveyor will be carried out to determine the simplified characteristics of dynamic excitations. This characteristic will be implemented into the control system of the test stand.

The test stand is relatively small (Fig. 6). The height of the table top, approximately 860 mm from the floor, creates favourable ergonomic conditions for testing.

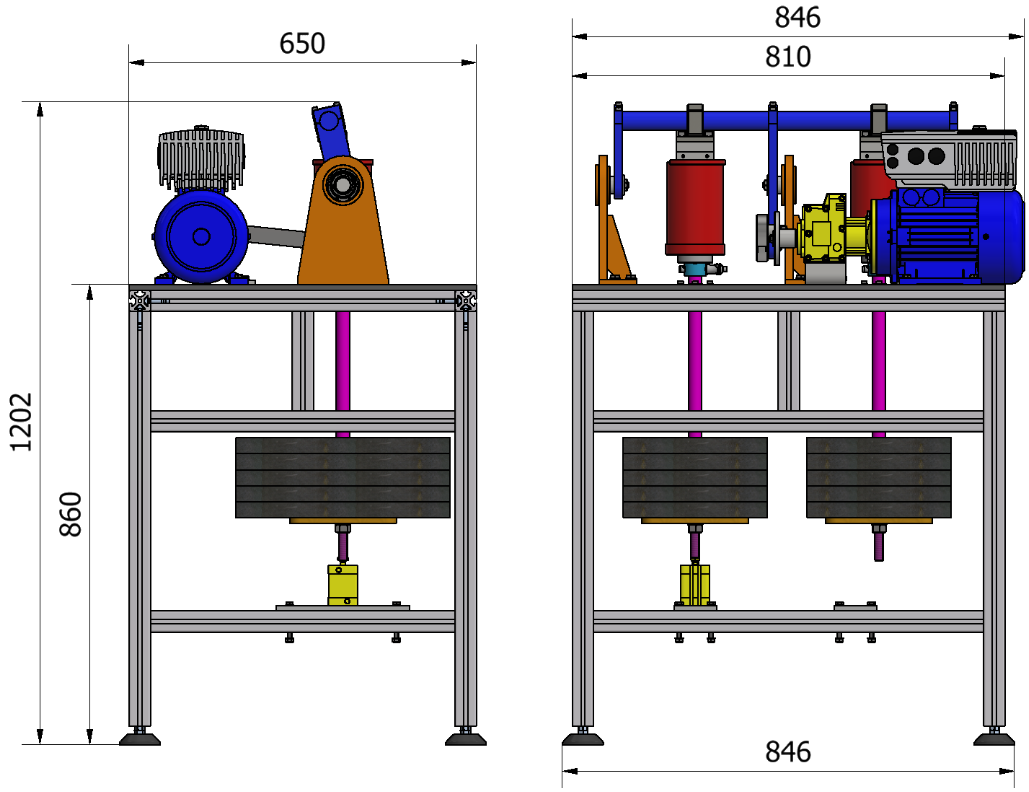

Fig. 6. Test stand dimensions

The test stand will be used for testing the wear of chain joints, taking into account the synergy of combination of environmental factors. The selected technical solutions will enable testing in the following configurations:

- chain wear tests without the presence of factors increasing corrosion and abrasive wear,
- chain wear tests in the presence of abrasive,
- chain wear tests in the presence of abrasive and demineralized water,
- chain wear tests in the presence of abrasive and saline water,
- chain wear tests with dynamic forces without the presence of abrasive,
- chain wear tests in the presence of abrasive with dynamic forces,
- chain wear tests in the presence of abrasive and demineralized water with dynamic forces,
- chain wear tests in the presence of abrasive and saline water with dynamic forces.

Mine links of size 14x50 will be tested due to the expected faster wear of the abrasive nodes (compared to larger sizes). Moreover, it is possible to test the samples made of potentially more wear-resistant materials, the introduction of which into the chains production could improve their durability. They are intended to be unconventional (e.g. nanocrystalline) steels or conventional steels subjected to novel processing methods. Such materials would be used to make test specimens in the form of rollers with an internal rounding corresponding to the radius of cooperation of the two joints. The shafts will be mounted in a special holder enabling, on the one hand, their replacement, and, on the other hand, assembly in the cell holders without making any structural adjustments. The structure and mounting of the sample in the holder are shown in Fig. 7.

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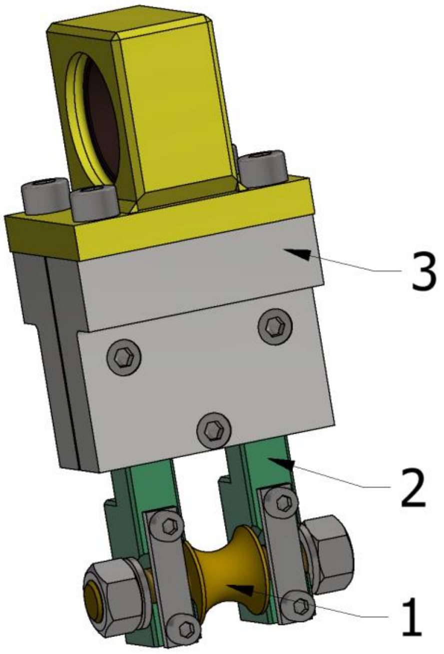

Fig. 7. Concept of assembly of a special sample
(1-universal sample, 2-sample holder, 3-upper link holder

3.3. Verification of design assumptions

Verification of design assumptions in form of a mechanism model and production of its components using the incremental 3D printing method was the final stage of the conceptual work. Components of the stand were fixed on the OSB board with the standard connecting components (also used to adjust the clearances between the components). A small 12VDC geared motor was the driving component of the stand mechanism. Rotational speed control was based on the supply voltage change using a simple converter with a potentiometer. The model and the first prototype are shown in Fig. 8 and 9.

Tests of the model made in 3D printing technology proved correctness of technical and construction assumptions.

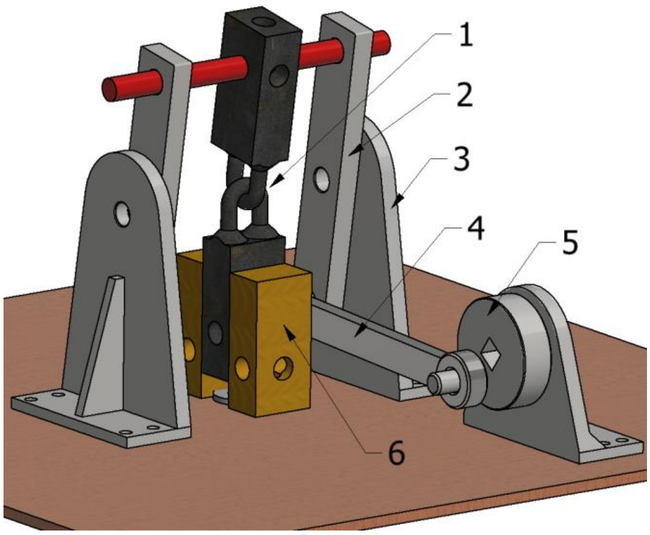

Fig. 8. Model of the stand for 3D printing
(1-cooperating links, 2-rocker arm, 3-stand, 4-connector, 5-eccentricity (crank), 6-guides)

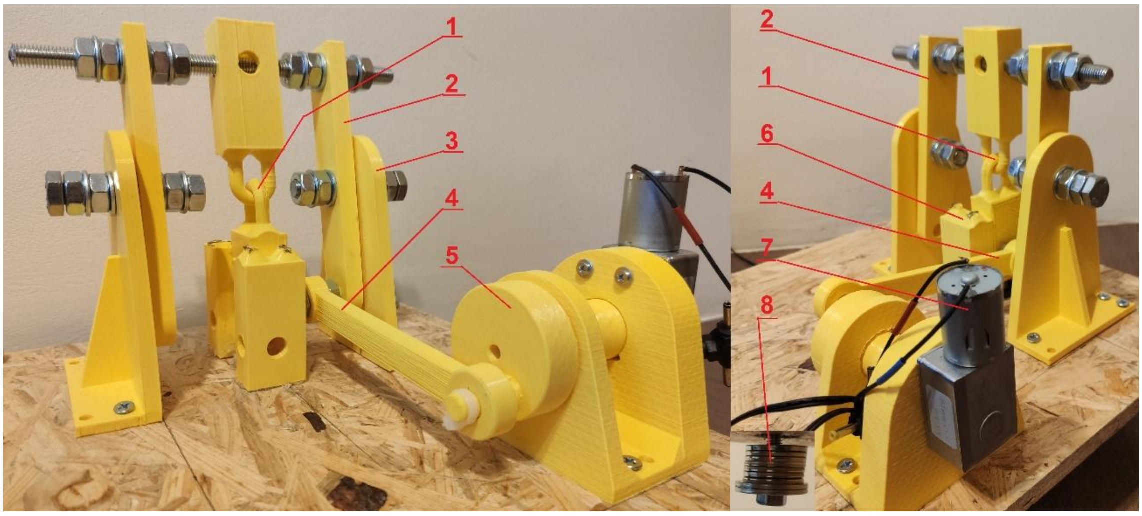

Fig. 9. Mechanism of the stand (3D printout)
(1-cooperating links, 2-rocker, 3-stand, 4-connector, 5-eccentricity (crank), 6-guides, 7-DC gear motor, 8-load suspended from the bottom)

4. Conclusions

The described test stand allow to tests and identify multi-factor wear providing significant knowledge on wear of materials used in link chains, mainly in scraper conveyors. This knowledge is necessary for the design and engineering staff in the development of innovative and state-of-the-art solutions for machines equipped with chains of increased service life. This, in turn, will allow for development of the machine design solutions optimized for the actual environmental conditions and dedicated to various industries.

The analysis and the designing work showed that the construction of the test stand for testing the wear of chain links, considering the synergy of impact of many destructive factors, is justified and possible to be implemented with the use of a simple mechanical system. The proposed stand is marked by small overall dimensions.

It is expected that the results of future research work will be useful in engineering works in the design of new solutions for cable transport machines. Moreover, the authors hope to be able to relate the research work results to other mechanical nodes with tribo-corrosive processes, exposed to many aggressive agents.

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