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Mechanization of cleaning the area of operating belt conveyor system

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Abstract:

Cleaning the belt conveyor system components is one of the greatest challenges when it comes to operational reliability and fire safety.

Machines and equipment used abroad for cleaning the conveyor belt and removing dirt accumulating under and next to the conveyor are discussed. The importance of cleaning the conveyor's surroundings with respect to reliability of the belt operation and fire hazard, is emphasized. Design of the boom to clean the floor under and next to the conveyor belt, is presented in detail. The boom is equipped with a jaw bucket that allows for pushing, scooping, and moving (hauling away) the run-of-mine. It was installed on an adapted existing caterpillar chassis powered by an electro-hydraulic unit.

The kinematics of boom operation in a confined workspace is analysed. The 3D visualization and a description of the boom design with a preliminary FEM analysis of the boom's arm is presented.

The design and range of the boom's operation allow cleaning backfilled and hard-to-reach spaces under the working conveyor.

Keywords: small mechanization, power industry, conveyor transport, boom

1. Introduction

Belt conveyors transport thousands of tons of aggregate, what requires ongoing monitoring of their condition, service and maintenance to ensure their uninterrupted operation. Conveyor belts are widely used to convey and transport different types of materials.

Improper operation of belt conveyors poses a serious risk of exogenous fire. A number of mathematical models are being developed to enable predicting the basic physical parameters indicating for fire of conveyor belts to improve work safety in mines. Mathematical models of a belt fire, based on belt fire observations and analyzes are developed [1].

Ignition of the run-of-mine gauge on the conveyor belt and/or the run-of-mine falling on the floor through leaks along the conveyor route may be one of the fire sources [2].

Many innovations were introduced in development of new solutions of cleaning devices for belt conveyor systems to obtain optimal cleaning effectiveness depending on the type of transported material and the ambient temperature. The design of the cleaning equipment can be adopted to different types of belts: plastic, vacuum type and high temperature belts, designed for a specific purposes. Conveyor belt cleaners are designed to clean by scraping the hardened materials sticking to the surface of the conveyor belt. There are basic (e.g. scrapers) and secondary (e.g. washers, rotating brushes) belt cleaners that are designed to solve cleaning and maintenance problems where it is necessary to transport materials that are exposed to wet, dirt and corrosive environment [3]. Swinderman [4] patented the adjustable conveyor belt cleaner that is capable of gradually adjusting the blade angle to the belt, with the ability to go from negative to positive angle depending on circumstances and environmental conditions. There are several other designs of primary and secondary cleaners on the market, adapted to different factors such as the type of material being conveyed, type of a belt, and speed of the belt movement.

Scrapers or other methods of cleaning the belt surface do not eliminate completely dirt from the belt conveyor system, as during its operation unpredicted disturbances such as belt cut or belt overload may occur. This causes spill out of the load and dirt covers the space under the conveyor belt. If there is no reaction from the conveyor's operator, excessive accumulation of the flammable material becomes dangerous causing a fire hazard or blocking the conveyor or breaking the belt [5].

In the Polish coal mining industry, roadheading machines are often used to clean the space under the conveyor route. The machines are of big size, so their maneuverability in mine workings is limited. They are not suitable to be used in this type of operations. Their possibilities of cleaning are only partial and they require a significant lifting of the lower belt, and the machine itself can only be set at a slight angle to the longitudinal axis of the conveyor.

However, very often cleaning the space under the conveyor route is manual, and to a small extent as the access to the space under the lower conveyor belt is limited. This is due to the low height of installed conveyor and the large depth of this space, defined by the width of the conveyor and a distance of the service route from the side wall.

Direct involvement of people in this activity is a laborious and dangerous task. Thus, it is reasonable to mechanise this operation, where the role of man is limited only to operating the equipment (as operator).

The analysis of existing technical solutions [6,7] indicates that self-propelled machines have become more and more common. These machines have a specific functional range allowing them to be used for collecting the material located in places that are difficult to access, e.g. to clean the space under conveyor belts in mines, in underground tunnels, box culverts and drainage systems, pumping stations, irrigation systems and others.

The DOUGLESS 900 mini loader (Fig. 1), which is an automated device capable of moving under a running conveyor belt, is known. Its height is 560 mm, length 2254 mm, width 1050 mm and weight about 900 kg. It is driven by a 12 kW diesel engine and can move at speed 3.5 km/h on rubber tracks. Bucket capacity is 0.13 m^3. The control of the machine is wireless. What is surprising, this machine, in an iron ore mine was able to recover 300 tonnes of material from under the haulage system in 12 hours.

Fig. 1. Mini loader DUGLESS 900 made by MINPROVISE [8,9]

The HMS 200 mini-loader (Fig. 2), a remote-controlled, diesel-powered device, capable of cleaning the space under an operating belt conveyor is another solution. Its height is 650 mm, width is 1322 mm, and length is 2720 mm. The engine power is 16 kW and the bucket capacity is 200 kg.

Fig. 2. The HMS 200 mini-loader by HMS Group [10]

The devices presented above enable cleaning the space under the belt conveyor route are widely used in Australia, Canada and South Africa. Despite a tight construction, they certainly cannot be used in hard coal mine conditions due to lack of adaptation to the dust and methane hazards. Good maneuverability within the operational space such as the roadways, due to their dimensions, is an unquestionable advantage of these solutions.

However, the small dimensions have one major disadvantage, which is the low lifting height of the bucket. This does not allow in any way to return the recovered material directly to the belt of a conveyor.

2. Materials and Methods

2.1. Design of the boom

When designing the boom [11], the attention was primarily paid to the aspect of operational self-sufficiency, enabling the removal of material located under the belt conveyor. This means the boom should pick up material from the cleared space under the conveyor and put it directly on the belt.

The boom can be adapted to cooperate with a loader on wheels and on trucks (Fig. 3).

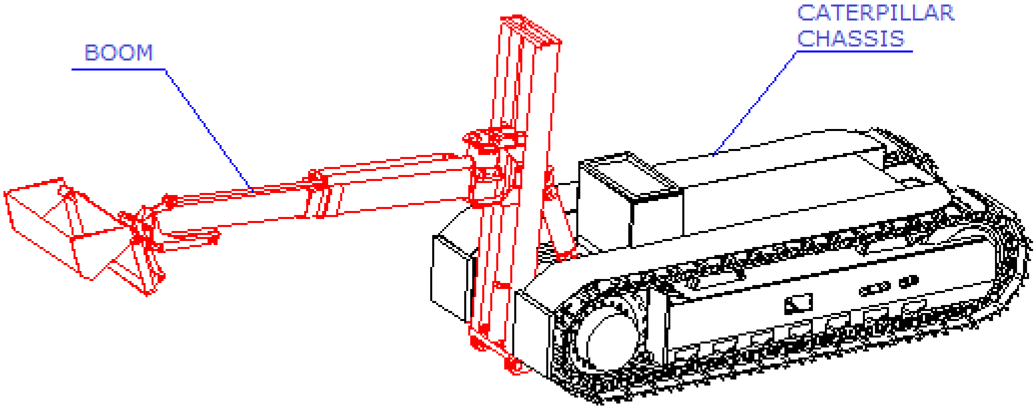

Fig. 3. The concept of a boom to be installed on a caterpillar chassis

The boom (Fig. 4) has three main components, connected to each other by sliding and articulating joints. In a result, its movement in three planes are possible. It is equipped with a multi-purpose bucket, mounted on a telescopic extending arm cooperating with the arm lifting the mast.

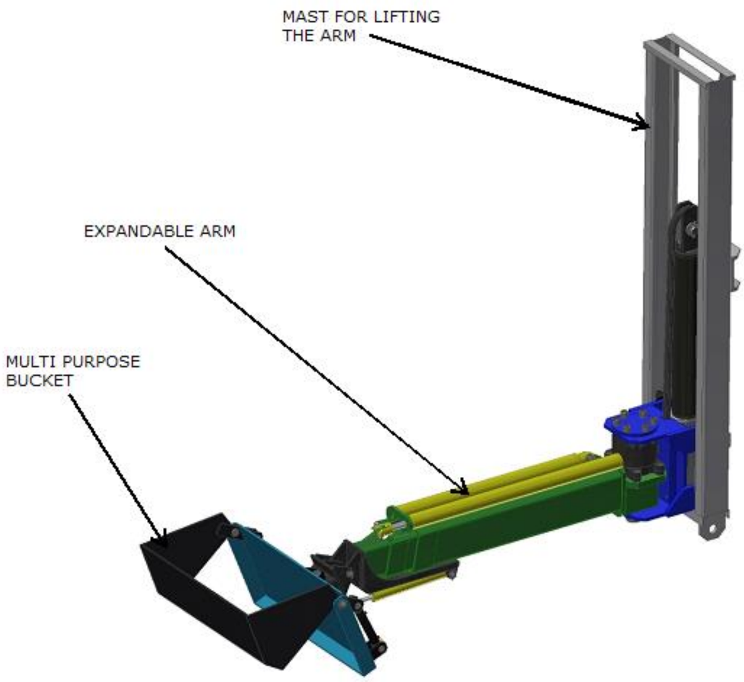

Fig. 4. 3D visualization of the boom

The multi-purpose bucket can rotate and twist in two planes (XY and YZ). The boom extension has the ability to move and swivel also in two planes (XZ and XZ). The boom lifting mast can also move and turn in two planes (YZ and XY).

The boom lifting mast (Fig. 5) is a welded frame. The side components of the frame are made of steel profiles open on one side. Their internal surfaces are the driving routes for a carriage with rollers. At the bottom of the carriage there is a chain lock that moves the carriage. On the opposite side there are holes to which a hydraulic turntable is bolted. At the bottom, in the turntable axis, there is a sliding bearing for the pin. The upper and lower parts of the mast frame are connected by transverse profiles. In addition, the lower part has mounting eyes, connected with the frame of the caterpillar chassis with bolts. In the central part of the frame there is a transverse profile, which is as an attachment point for the chain, and a single cylinder eye of articulated mast is welded to it. The base of the cylinder, on which the lifting cylinder rests, is welded to the frame bottom. The cylinder lifts the carriage, to which the boom with the multi-purpose bucket is attached. Chain mechanism was used to convert the sliding movement of the cylinder piston rod into the carriage lifting movement. Its double gear ratio allows the carriage to advance along the entire length of the mast. The gear ratio is achieved by immobilising one end of the chain attached to the mast frame while the other end was attached to the bottom of the carriage. The chain runs through a sprocket attached to the piston rod of the lifting cylinder. Extending the piston by a given stroke, the cylinder shortens the chain length twice, causing the carriage to move by twice the cylinder stroke. The stroke of the carriage is 1200 mm.

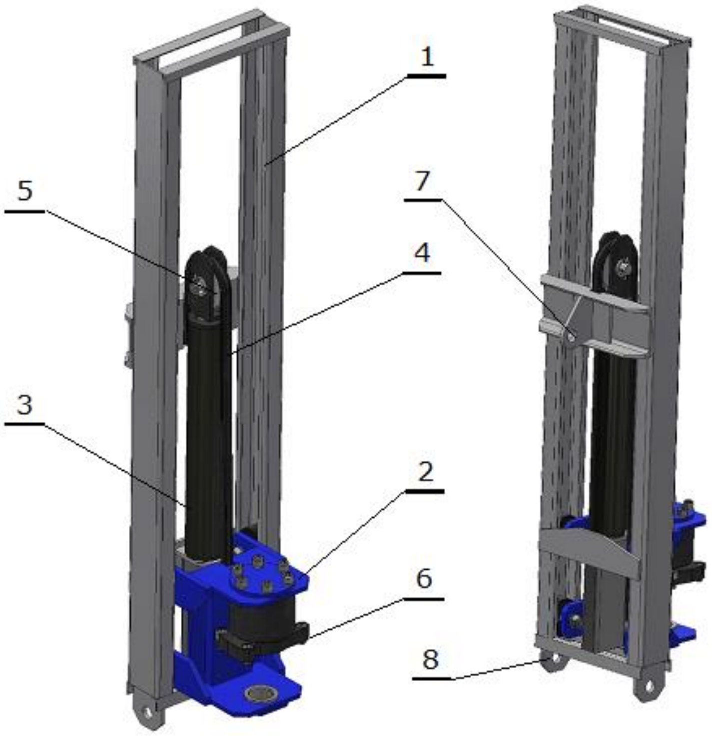

Fig. 5. Mast for lifting the arm
(1 – mast frame, 2 – carriage, 3 – lifting cylinder, 4 – chain, 5 – chain wheel, 6 – hydraulic swivel, 7 – eye of mast articulation cylinder, 8 – mast assembling eyes)

The extendable arm (Fig. 6) consists of three segments that slide into each other. The segments are made of bent sheets with a closed cross-section. The arms are reinforced with a metal sheet at their ends. The extension cylinders are attached to the middle arm. Attachment lugs of the multi-purpose bucket and the bucket tilt cylinder are at the end of the extendable arm. On the other side the arm has a socket for mounting in a turntable with a pin.

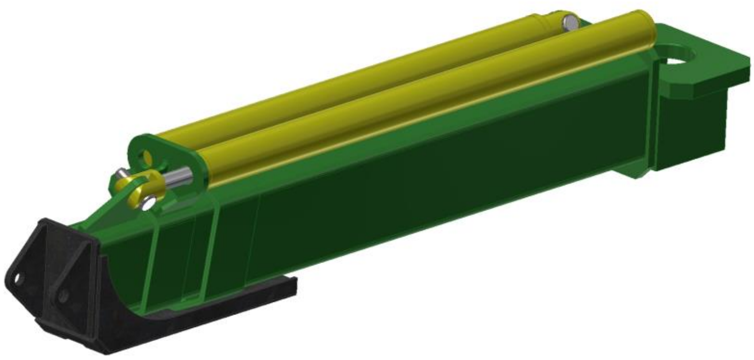

Fig. 6. Extendable arm

Multi-purpose bucket (Fig. 7) consists of the following two subassemblies:

- a bucket with a possibility of opening – for scrapping with the bottom edge,
- articulating joint – which enables movement in two planes: horizontal with inclination ±30° and vertical with inclination from -45° to +35°.

Hydraulic cylinders are used to open and control the bucket movement in horizontal and vertical planes.

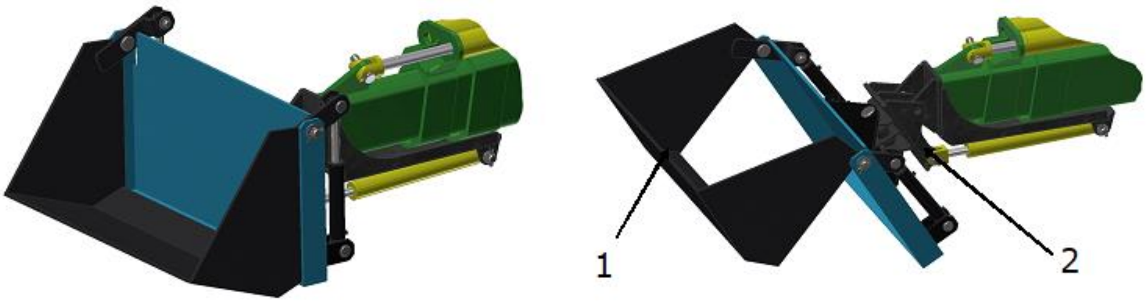

Fig.7. Multi-purpose bucket – general view
1 – bucket, 2 – articulating joint

2.2. Strength analysis of the arm

The boom has to work in a confined space, therefore it should be as small as possible. In addition, the boom should have flexible manoeuvrability allowing easy access to the required area to be cleaned, and its structure should carry the expected range of loads. Autodesk Inventor was used for the initial static analysis.

The arm was subjected to action of force 19.5 kN, causing the arm to bend. It is equal to half the nominal force of the cylinder tensioning the chain lifting the arm. Since one end of the chain is fixed the other end causes the trolley to move with the arm, the speed of the carriage is twice as high as the speed of the cylinder extension. Additionally, the arm was loaded with M1 and M2 torques. The torque M1 results from the articulating mechanism of the trolley guides, while the torque M2 comes from the operation of a hydraulic swivel powered by a working fluid under a pressure of 10 MPa.

The metal plate, to which the hydraulic swivel was attached, was loaded with the arm bending force of F1 = 19.5 kN, the same place was also loaded with the M1 and M2 torques. Fixation of the arm was simulated rigidly by fixing the distinguished nodes and removing the axial displacement of the pivot nodes in axial direction. (Fig. 8 and 9).

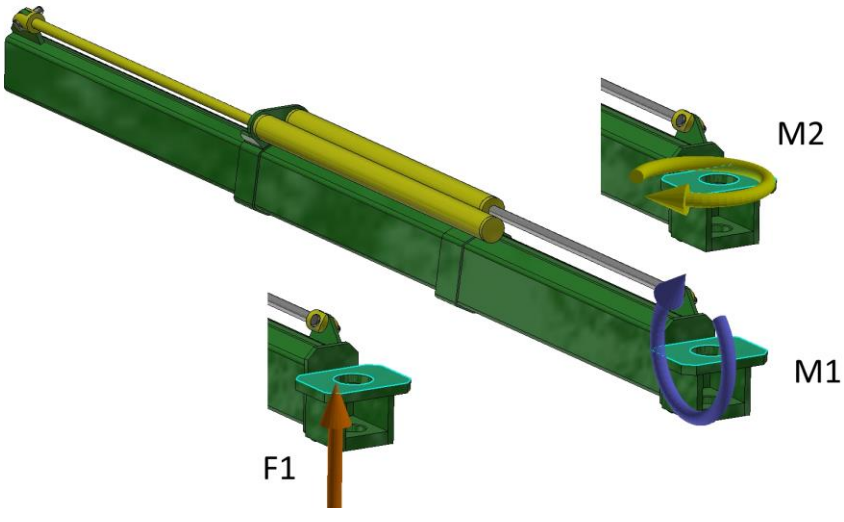

Fig. 8. Scheme of load to the arm model
(Assumed: concentrated force F1 = 19.5 kN, torque M1 = 11.5 kNm, torque M2 = 300 Nm)

The removed model degrees of freedom are presented in Fig. 9.

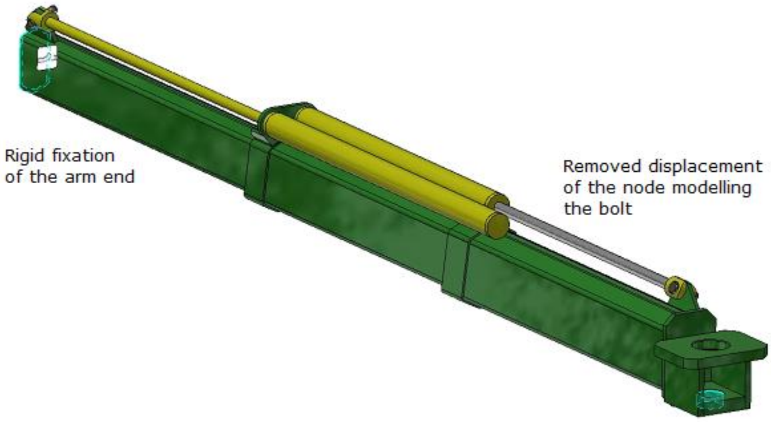

Fig. 9. Assumed boundary conditions

In Fig. 10 the arm model, created by the Finite Elements Method consisting of 4022 tetra finite elements is presented.

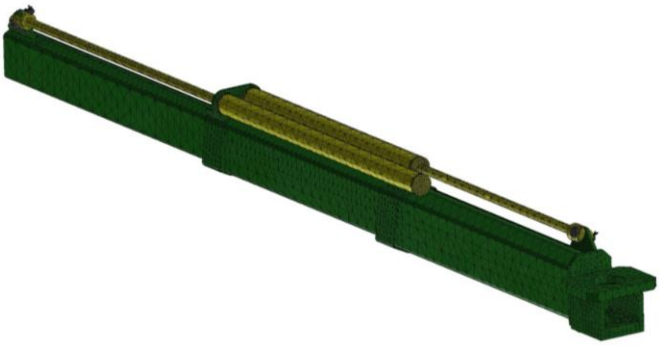

Fig. 10. Model FEM of the arm

Adequate material parameters were assigned to each metal sheet. S690Q steel was assumed.

The results of the arm calculations are presented in the form of contour maps. Fig. 11 shows displacement maps with a maximum displacement of 26.03 mm.

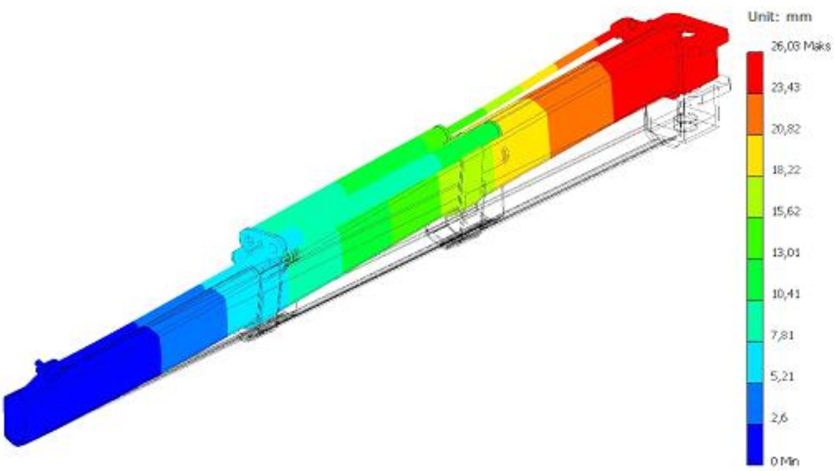

Fig. 11. Displacement maps

Fig. 12 shows the results of the numerical simulation of the arm model in the form of reduced stresses maps. The maximum stress was found in the place of mounting the cylinders and was 708 MPa, while the greatest reduced stress in the remaining arm modelling elements was not greater than 400 MPa.

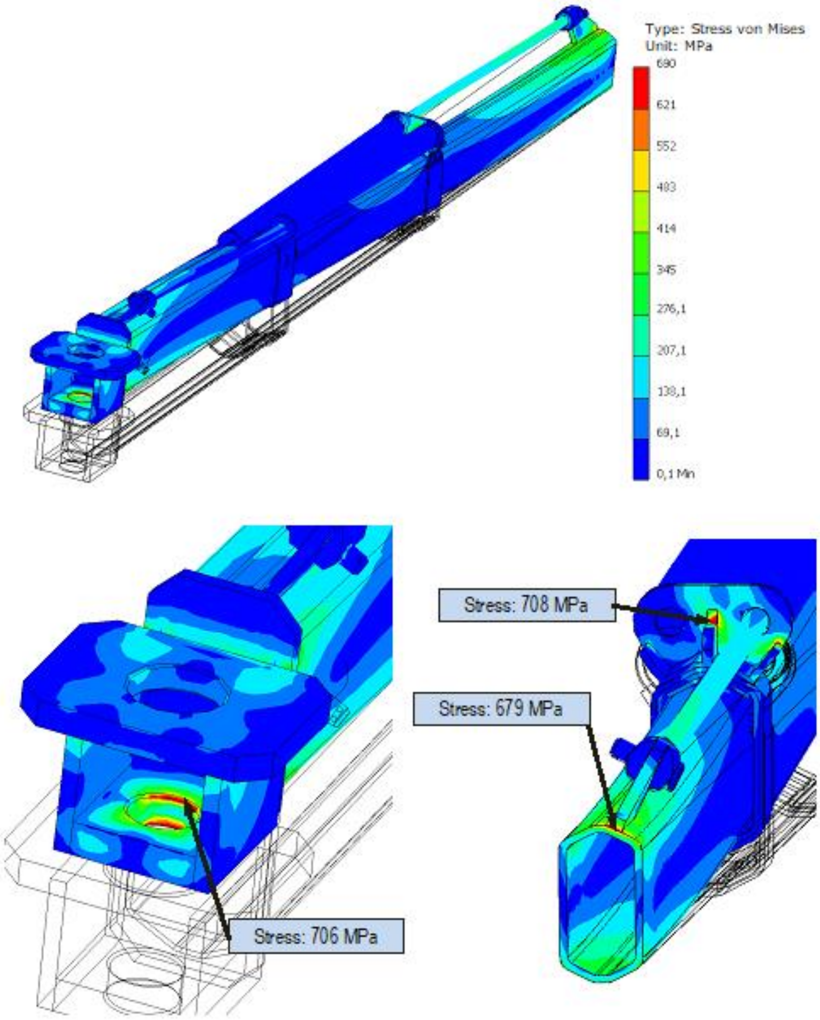

Fig. 12. Maps of reduced stresses

To summarize the strength analysis, it should be stated that the reduced stress in the arm components reaches the value of about 400 MPa, thus lower than the yield point for the adopted arm material (Re = 690 MPa). In the bolt opening and in the place where the boom extension cylinders are installed, the reduced stress locally amounts to more than 700 MPa (see Fig. 12).

The presented contour maps show that the stress zone greater than 700 MPa covers a small area lying on the model surface. Probably a more detailed analysis of the FEM model would show that the extreme values of the reduced stress are the result of extrapolation of the stress fields in the finite elements modelling the boom plate. Therefore, it can be assumed that for the assumed boundary conditions, the structure of the arm and the thickness of the metal sheets are appropriate.

3. Results - technical parameters of the boom

Fig. 13 shows the range of operation of the boom installed on a sample caterpillar chassis.

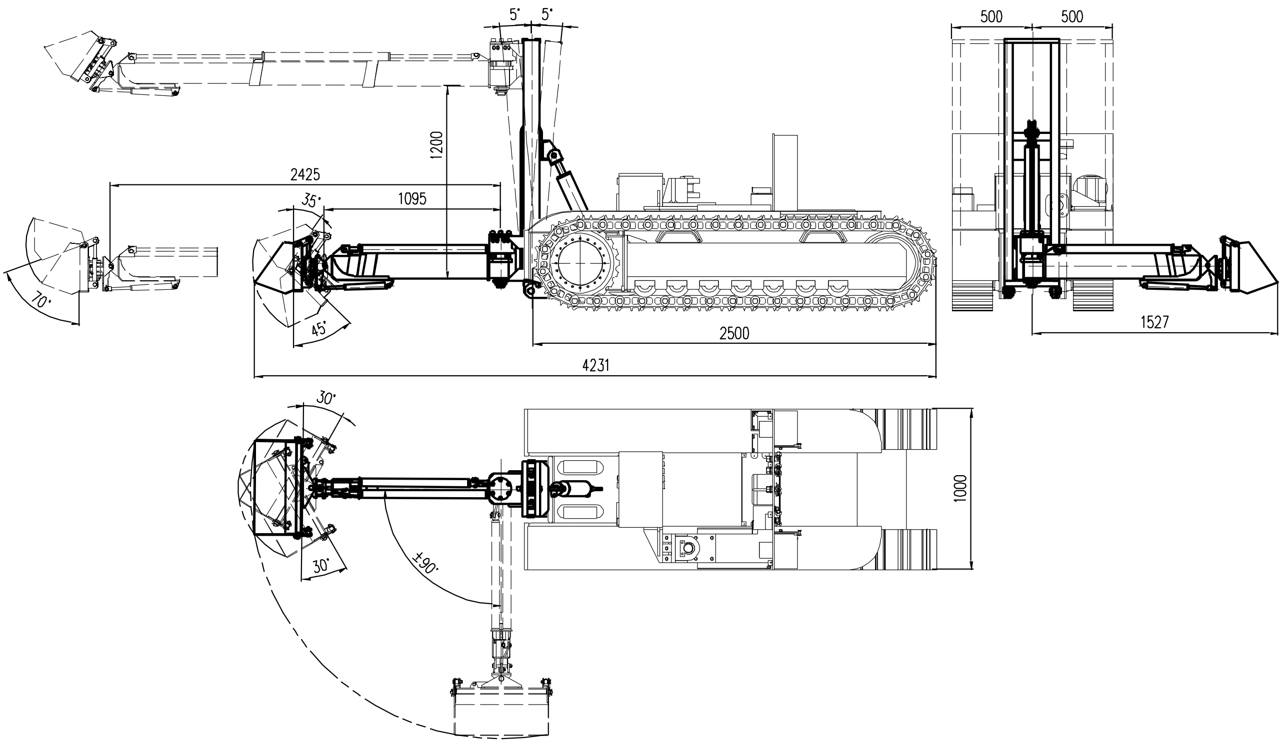

Fig. 13. Range of the boom operation

Technical parameters of the boom are given in Table 1.

Table 1. Technical parameters of the boom

Parameter	Unit	Amount
Height of the bucket lifting	mm	1200
Arm load-bearing capacity	kg	1500
Arm stroke	mm	1330
Bucket capacity	dm^3	20
Horizontal tilt of the bucket	-	±30°
Vertical tilt of the bucket	-	-45°÷+35°
Bucket opening angle	-	70°
Working pressure	MPa	10

Fig. 14. shows the machine equipped with the boom operating in a roadway with ŁP-10 support.

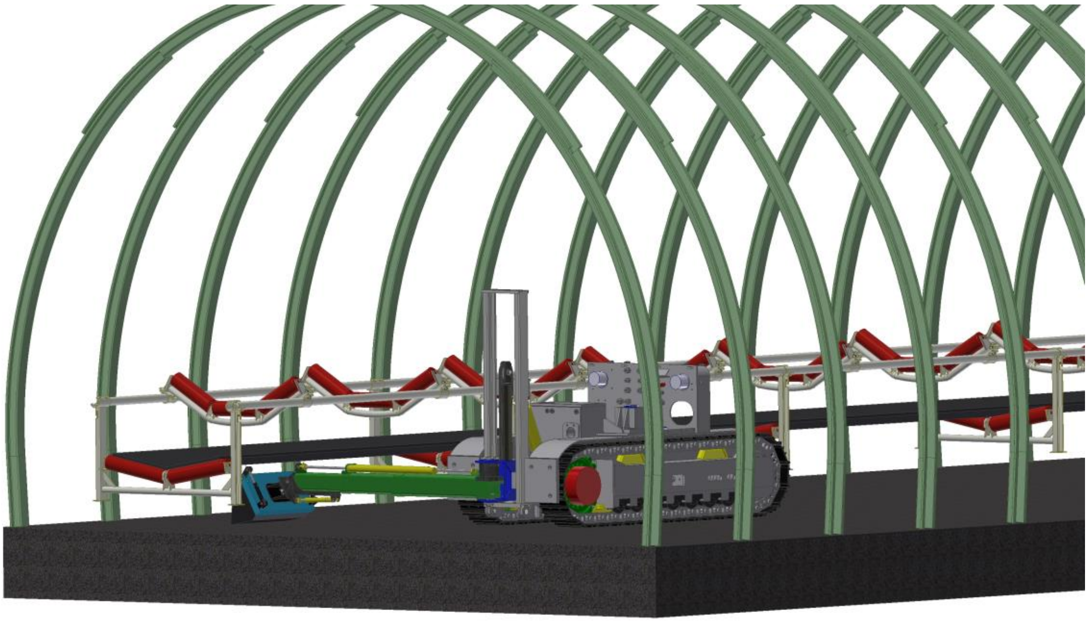

Fig. 14. 3D visualization of cleaning the floor under the belt conveyor system

4. Conclusions

The concept of a machine equipped with a multifunctional boom, which limits human presence in a high-risk work environment, such as confined spaces and hard-to-reach areas, and allows working at a safe distance with a drastic reduction in working time in this space was the research project main objective. The boom allows cleaning almost the entire floor under the conveyor, access to which is dangerous as well as loading the scraped material directly onto the conveyor.

It has been assumed that the minimum clearance under the conveyor belt should be 500 mm.

The benefits of using a machine equipped with a boom for cleaning the space under the belt conveyor are as follows:

- easy access to the conveyor of low clearance,
- does not require stopping the conveyor while it operates,
- eliminates physical effort of the personnel responsible for cleaning the dirty surfaces,
- increases safety of the personnel working in dangerous and confined spaces or in areas of high risk,
- reduces rate of incidents as well as fire hazard,
- increases effectiveness of cleaning the dirty surfaces under the conveyor,
- reduces the failure rate of the belt conveyor operation.

The above-mentioned advantages of the presented solution justify the necessity of further tests to implement the discussed boom on an industrial scale.

The scope of application of the discussed boom goes far beyond the hard coal mining industry, because use of any belt conveyor requires removal of the transported material that pollutes its surroundings.

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