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Individual rail transport and the conception of a means of transport using a suspended railway track

Distances to cover are still growing in Polish coal mines. It is not a real issue in terms of material and staff transport, which commonly uses suspended monorails with a friction wheel drive. The problem is how to transfer single people and small loads behind the scheduled times and routes of monorails.
The goal of this work was to design and construct an individual mean of transport with its own drive using a monorail track which would meet the requirements of law, safety, mobility and can be used behind the scheduled times of monorails.

Key words: *suspended bike, individual mean of underground transport*

1. INTRODUCTION

This article about individual means of transport which could be used in underground workings, as well as works on its construction, started with considerations on the history of bicycles and rail transport.

The beginning of bicycle history is dated to 12 June 1817 in Mannheim, when Karl Drais demonstrated his balance bike, called "Draisine", which in a short period of time revolutionized individual transport (Fig. 1). The invention was a subject of numerous modifications, thanks to which todays bicycle received its current shape. Because of the rising popularity, simplicity and reliability of bicycles, in 1892 after bike's redesign, it was adapted for suspended rail rides and was used as an individual means of municipal transport [1, 2].

Figure 2 presents a suspended monorail bicycle on a purpose-built line connecting Mount Holly with Smithville in New Jersey, USA. It was invented by Arthur E. Hotchkiss and it was built in 1892.

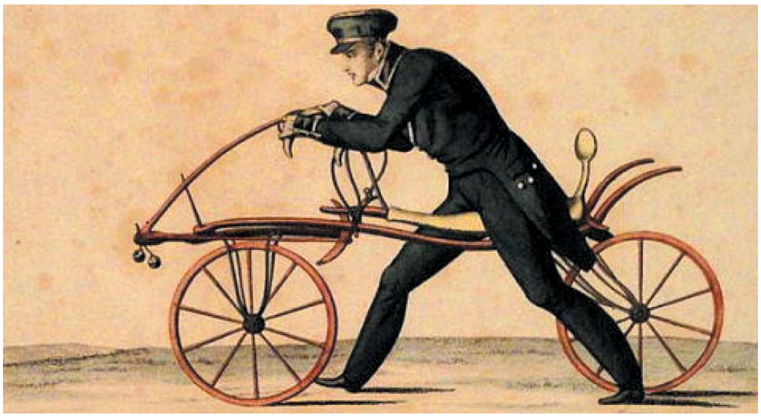

Fig. 1. "Draisine", Karl Drais' balance bike [3]

Fig. 2. Suspended monorail bike [4]

This special line was dedicated for workers who had to commute to the factory in Smithville. Workers who wanted to commute were supposed to borrow a bike which was available in storage situated along the rail route. The main disadvantages of the project mentioned above were lack of possibilities to overtake other riders and the need to use one line for riding in both directions, because the second line was never built. In the case of heavy traffic, it significantly slows the transport down [4, 5].

Monorail transport

A relatively new means of transport are monorail systems. Their origins are dated on the beginning of 19th century. They can be divided in two groups: suspended systems (Fig. 2) and systems in which a means of transport is situated on the rail (Fig. 3). The origin of monorail transport usage dates back to 1820, when the inventor Iwan Elmanow developed an elevated single-track railway line. Horses pulled trolleys on wooden rails (the horses moved along the rail). Because of the simplicity of this idea, it gained in popularity and the invention was adapted as a means of transport for miners in Crimean salt mines [7, 8].

Another Russian inventor, Belozersky, proposed a railway system in 1836 with two rows of wheels which was built on column structure. In 1872 the Łuszczski monorail railway was developed and it was presented at a polytechnical exhibition in Moscow and in 1874 the construction of Aleksji Chludow's monorail railway, dedicated to timber transport, began.

Monorail systems developed dynamically not only in Russia but also in other parts of the world. One of the most famous pioneers of monorail technology was the engineer Henry Robinson Palmer, who patented the concept of the monorail in 1821 (GB nr 4618). A line was constructed in Deptford Quays in London in 1824, and in June 1825 a monorail was launched in Cheshunt intended for brick transport. Wooden carriages hung under the rail and were pulled by horses. Friedrich Harkort worked on the development of rail transport in Germany, and his aim was to build a demonstrative route between Elberfeld and Barmen, districts of the German industrial town of Elberfeld. In 1827 Harkort improved Palmer's railway – instead of horses he used steam engines. In subsequent years, the concept developed further and the effects of improvement can be observed in example of Wuppertaler Schwebebahn railway, which was installed in Wuppertal and is still functioning as the longest suspended railway line in the world, connecting the Oberbarmen and Vohwinkel districts (Fig. 4) [1].

The division of monorails into external and own drive devices was caused by differences in their construction. A historical example of a monorail is the *Bicycle Railroad*, constructed by Arthur Hotchkiss from New Haven, New England (Fig. 5). His invention was patented in December 1892 (US 488.201) [5].

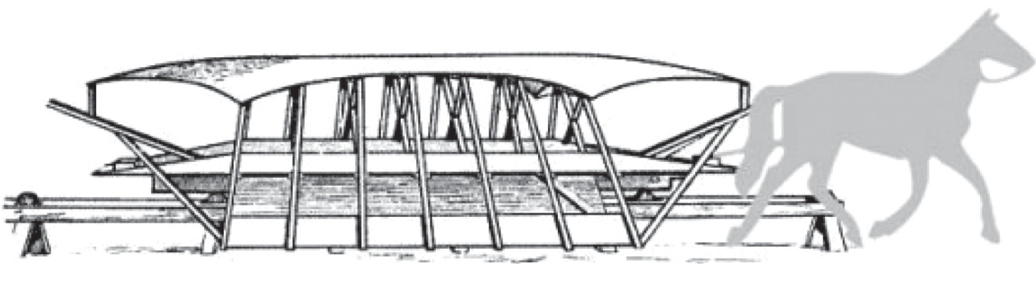

Fig. 3. Iwan Elmanow's monorail single-track railway solution [8]

Fig. 4. Wuppertaler Schwebebahn railway [3]

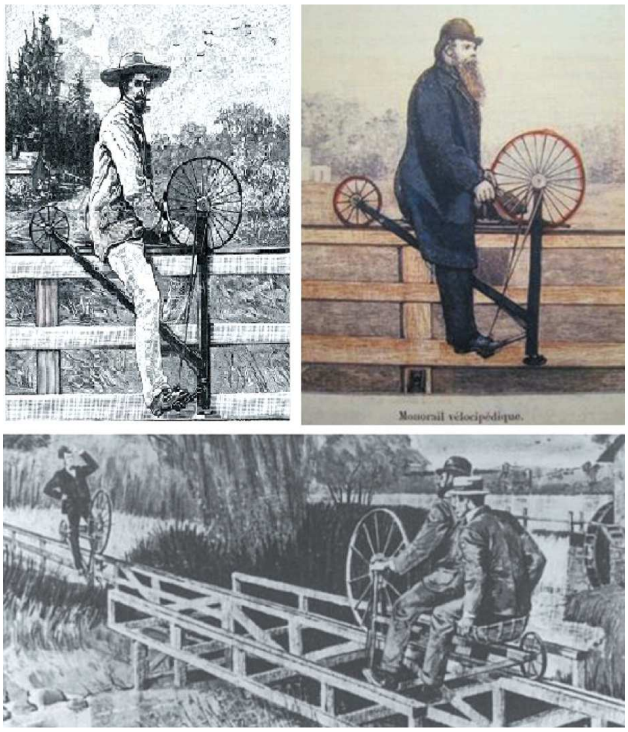

Fig. 5. Bicycle railroad [4]

1.1. Historical application of bicycles as individual means of transport in underground mining

The dynamic growth of industry at the turn of 19th and early 20th century caused a rise in demand for hard coal as a basic energy resource. Rising coal production was a reason for collieries development, which in turn entailed the elongation of the distance between the main shaft and working place of miners. A result of this situation was the rapid development of improvised means of underground transport. Mines management adapted means of transport to underground application which were typically used on the surface. One of the most popular and commonly used underground individual transport devices was the bike (widely in use in German and Dutch mines). In the beginning, the miner's bike was produced in short series by the mines themselves, because of no existing bike producer. In 1954, the first serial miner's bike *Grubenflitzer*, was introduced by Scharf GmbH from Hamm, Germany. Brochure and logo of this product is shown in Figure 6 [9–11].

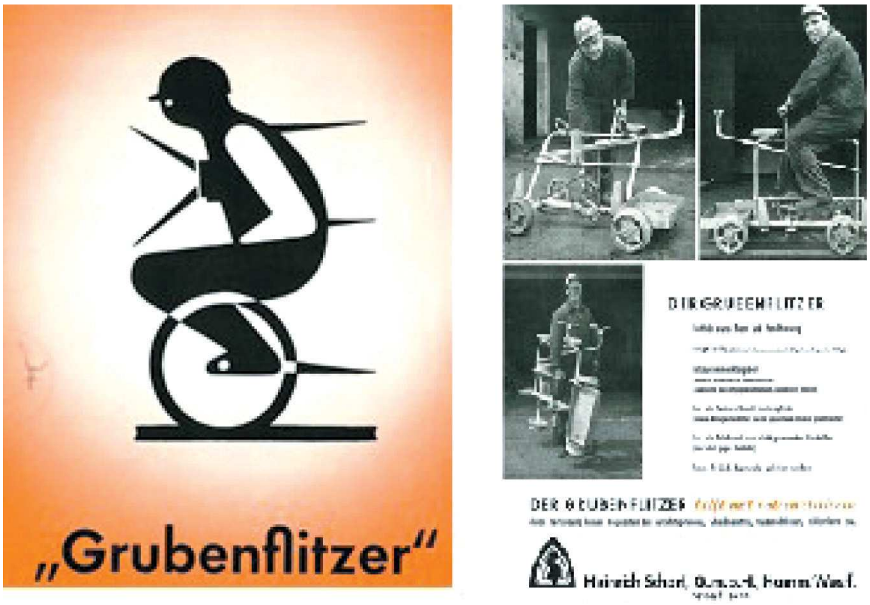

Fig. 6. Logo and brochure of Grubenflitzer, first miner's bike [11]

Grubenflitzer's target were mine workers whose job characteristics caused a need for frequent communication between different underground workings, e.g. mine supervisors, carpenters, electricians etc. The prototype was a simple, small construction with a cargo box placed in the back. The vehicle was noticed by West Germany's federal Minister of Economy, Erhard, at a mining fair in Essen in 1954. In the following years, sales of the miner's bike varied between 30 and 40 vehicles per month. It was also developed to fit the different needs of buyers, e.g. variants of a bike were introduced – made to fit various working dimensions, equipped with toolboxes or made of a AlMgSi alloy, which is corrosion resistant and lighter than steel, the result of which was a weight reduction to only 30 kg.

Numerous types of miner's bike were introduced in accordance with miners' needs. Their features varied depending on the workings parameters, daily distances to cover or the bike's capacity. Some of these types are presented below.

The basic model produced by Scharf GmbH was the Zg-Nr. 35003-00.00 miner's bike (Fig. 7) made of aluminum with a folding frame, in versions with two saddles and one toolbox, one saddle and one toolbox or one saddle and two toolboxes, while bike model S-35017 was equipped with two toolboxes and two saddles. Basic technical data are presented in Table 1 and Figure 7 [6].

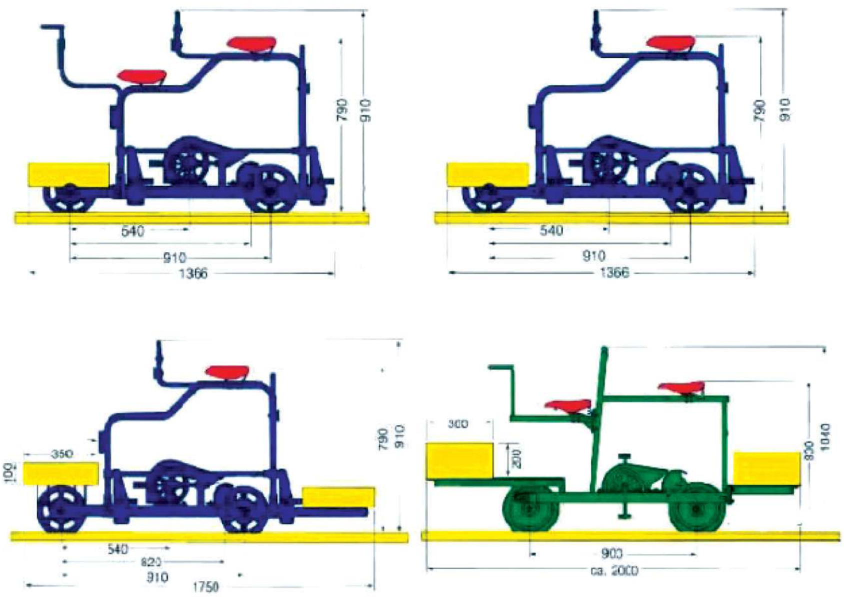

Fig. 7. Basic model of miner's bike in different versions [6]

Table 1

Basic technical data of the Zg-Nr. 35005-00.00 and Zg-Nr. S-35017 bike models (Fig. 7) [6]

Model	Zg-Nr. 35003-00.00	Zg.-Nr. S-35017
Total length [mm]	1366	2000
Height [mm]	910	1040
Curbweight [kg]	50	100
Payload [kg]	200	250

The next model was equipped with a toolbox in front of the bike and carriage with three-pointed bearing to avoid derailing of the vehicle even in bad trackway conditions. In case of tight spaces in the workings, the bike could be easily folded. Furthermore, to create some pieces of the bike, producers used corrosion resistant alloy 6060 (EN AW-AlMgSi), which resulted in decreasing the prototype's mass.

Bike model Zg-Nr S-135016 was designed as an emergency vehicle. This type of vehicle was used in rides with distances longer than 5000 m. It was equipped with two drives, a coaster brake and a bench on which three people could sit. The basic specification is presented in Table 2 and in Figure 8 [6, 12].

Table 2

Basic technical information about the Zg-Nr S-135016 five-person emergency bike (Fig. 8) [6]

Model	Zg-Nr. S-135016
Total length [mm]	1790
Height [mm]	130
Curb weight [kg]	130
Payload [kg]	600

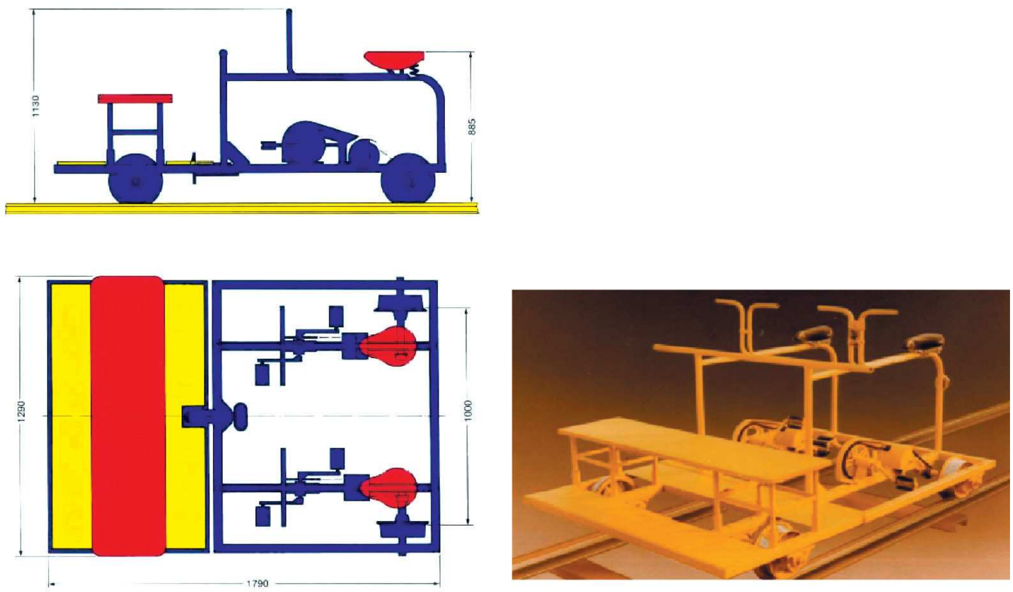

Fig. 8. Five-person emergency bike Zg-Nr-S-135016 [6]

This vehicle was produced especially for short--distance rides. It was equipped with two bucket seats placed next to each other, two drives and tool-box placed in front of the bike. The highest part of the bike was the top edge of the bucket seat. There was also the option of attaching a trailer to the bike, the trailer was 680mm high and weighed 42 kg. The basic technical information of the bike and the trailer is shown in Figure 9, Table 3 and Table 4.

There is no doubt that during a period which saw a low level of mechanization in mining, the miner's bike had a great impact on the development of the whole industry by extending effective worktime. It was possible by shortening the time of transport between distant workings. In subsequent years, the growing number of vehicles and other machines operating in mine workings made bike usage hazardous for miners. It is also important to note that in the first years of their operation, there were no legal restrictions on bikes but that this changed in the following years. For example, the application of aluminum in underground machines was forbidden and the need for bikes to be equipped with lights became a legally requirement, which in turn led to an increase in weight [6].

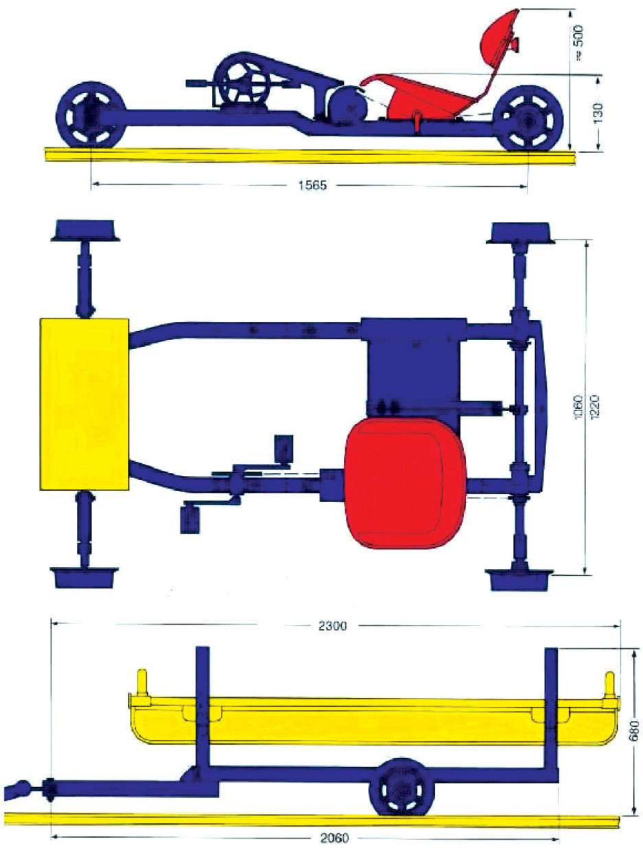

Fig. 9. Special model [6]

Table 3

Basic technical information about the Zg-Nr. S35011 bike (Fig. 9) [6] Fig. 9. Special model [6]

Model	Zg-Nr. S35011
Total length [mm]	1900
Height [mm]	500
Curbweight [kg]	90
Payload [kg]	300

Table 4

Basic information about the S-3501 trailer [6]

Model	Trailer S-3501
Total length [mm]	2060
Height [mm]	680
Curbweight [kg]	42
Payload [kg]	150

The advantages of using miner's bikes were: fast transport between remote working with less tiredness of employees, extending effective worktime, cheap and easy transport of small loads, possibility of rapid evacuation of injured workers. There were also disadvantages, which made them disappear from underground mines, including: complicated construction, which made assembling (and disassembling) them long and difficult, the fact that passing them was almost impossible, high sensitivity to track conditions (which often happened to be bad in effect of bottom deformation), relatively high mass and failure to comply with the law (construction made of aluminum, no lights). Moreover, the growing popularity of suspended rails (which made floor railway look old fashioned) also had an impact.

2. AN IDEA FOR A NEW INDIVIDUAL MEANS OF TRANSPORT IN AN UNDERGROUND MINE USING A SUSPENDED RAIL TRACK (PATENT)

Following an analysis of historical patents in light of modern technology, the idea of a new underground means of transport was born. The resulting brand-new miner's bike is a vehicle which connects the advantages of this historical individual means of transport with the utilization of a typical modern mine's equipment in accordance with legal regulations.

Suspended railways with friction wheel drives are clearly the most common means of transporting employees and materials in underground mines. They are usually equipped with a friction wheel drive, which works together with the rail. Pressure put on the rail by the drive wheel regulates the tractive force of the railway, in accordance with the track inclination or direction of transport.

In the Polish mining industry distances between main shafts and longwall headings are constantly growing. While this is not a problem in terms of staff and material transport, it can cause inconvenience in transferring small loads or single people behind scheduled time and route of monorails. Solving this problem is a real economic and practical issue.

This idea led to the construction of a vehicle for individual underground transport with its own drive, utilizing a monorail track while providing an appropriate level of mobility and safety. The projected construction of a new miner's bike consists of a carrier situated in the bottom part of a basic beam suspended on a rail. On the top part of the basic beam, the drive roller assembly is located. The drive rollers' rotation axes are horizontal and the drive wheel is connected to the drive which is located on the carrier. The essence of the solution is its mounting method on the rail. In the upper part of the basic beam there are horizontal stiff beams with other bars, vertically oriented, at their ends. Those bars are equipped with clamps with actual rollers. Those rollers are mount on the lower part of the rail. Details of the construction are presented in the patent [13].

The greatest advantage of the proposed means of transport is that it can be mounted on, as well as dismantled from, a rail in default place of the track. The presented construction is designed to be used as a means of transport for staff (especially overlong distances), carriage for tools, small loads and devices or for maintaining the routes of the monorail, so its purpose is similar to that of the historical miner's bike. However, its simpler construction and lower mass makes it easier to use and more versatile. No previous training, permissions or licenses are needed. Another option to consider is whether to use an electric drive with a battery.

2.1. Construction

The main part of the bike's construction is a basic beam with a carrier, with a rider's seat on the beam's bottom and a drive roller assembly on its top. The drive assembly is installed on a bar which can be tilted in the horizontal plane of the basic beam. The drive wheel's axis is horizontal and the drive roller is connected with the hydrostatic transmission and drive in the front part of carriage. Two drive wheels are located symmetrically to the rail. Clamps used to stabilize the vehicle on the rail are wider than the rail, an advantage when it comes to mounting the bike on the track. Clamps are equipped with guiding wheels. Technical details are presented in patent [13]. Schemes of the new miner's bike are shown in Figures 10. and 11.

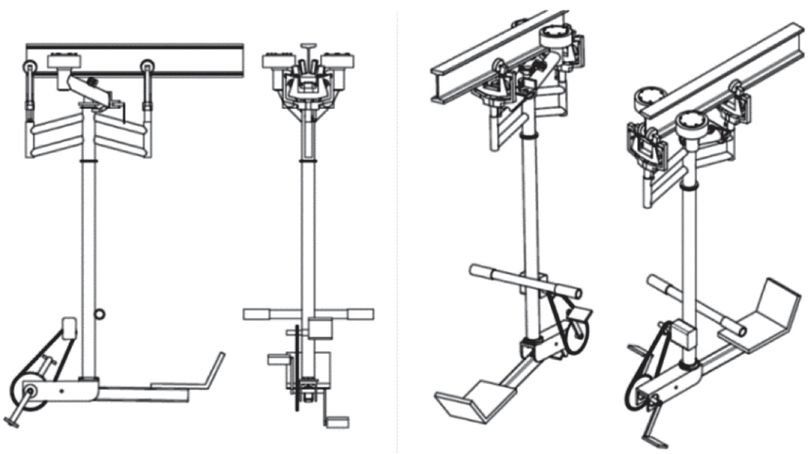

Fig. 10. Mean of individual underground transport with own drive

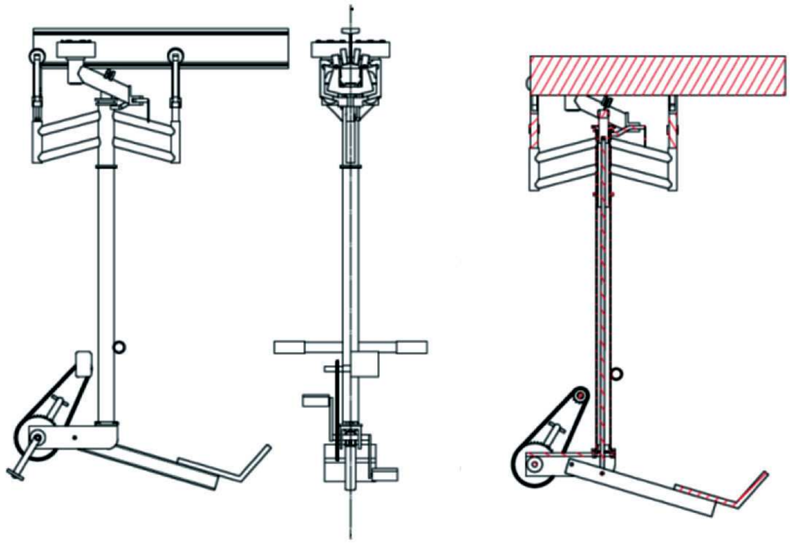

Fig. 11. Drive of the new miner's bike

3. A PROTOTYPE OF THE MEANS OF TRANSPORT USING A SUSPENDED MONORAIL TRACK

After analysis of the characteristics desired of means of individual underground transport, employees of the Shaft Sinking Company (PBSz S.A.) constructed a prototype and tested to check if the designed assumptions and solutions proposed in the patent had been met.

The prototype construction process was divided into two stages. The first consisted of a computer simulation, the other was a real-life underground test.

In the first phase, a virtual model of the bike was made which was then used in simulations with a "working model" software. The aim of the simulations was to specify the technical characteristics of the vehicle. The bike was tested to determine its maximum possible velocity, maximum inclination of ride and average pressure put on the pedals to set the bike in motion. The prototype model is presented in Figure 12.

Observation of traditional bike's showed that pressure put on the pedals to make the bike move is greater than when the bike is already in motion. Based on this observation, a relationship was assigned between pressure on the pedals at the momentt_0 and its later reduction to 50% of its initial value (Fig. 13 and Fig. 14).

Several simulations of different bike versions were made in which different parameters were changed, such as track inclination, pressure on pedals, additional load on bike construction. The weight of the bike assessed in simulation was equal 40 kg and the mass of the bike's user was 80 kg. Additionally, simulations included the use of the different type of wheels used: wheels made of steel and steel wheels covered with rubber. Example of the simulations are presented in the Figures 15 and 16.

Fig. 12. Computer model of miner's bike

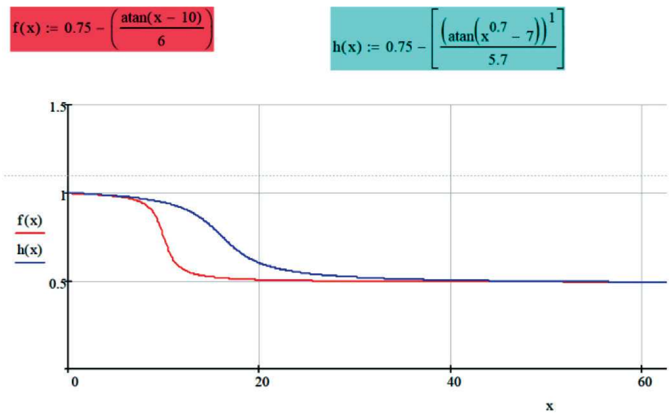

Fig. 13. Graph of relationship between load on pedals and time

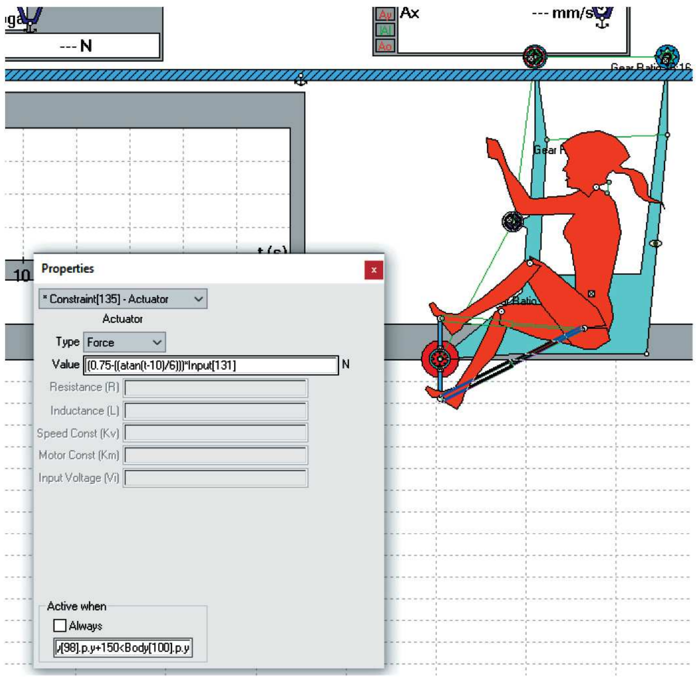

Fig. 14. Use of the function in "Working Model" programme

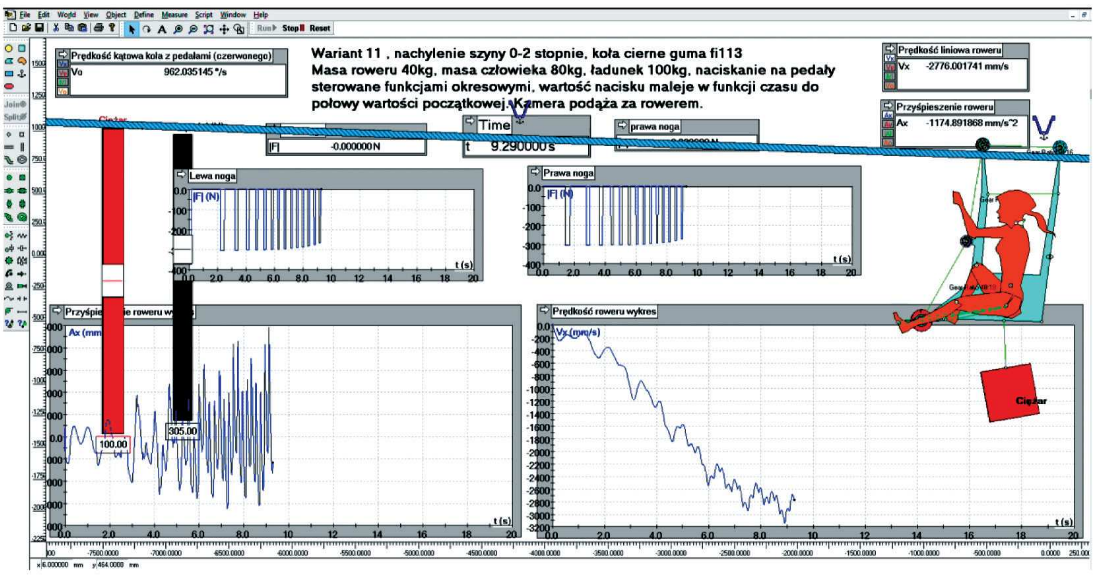

Fig. 15. Simulation of the bike with additional load

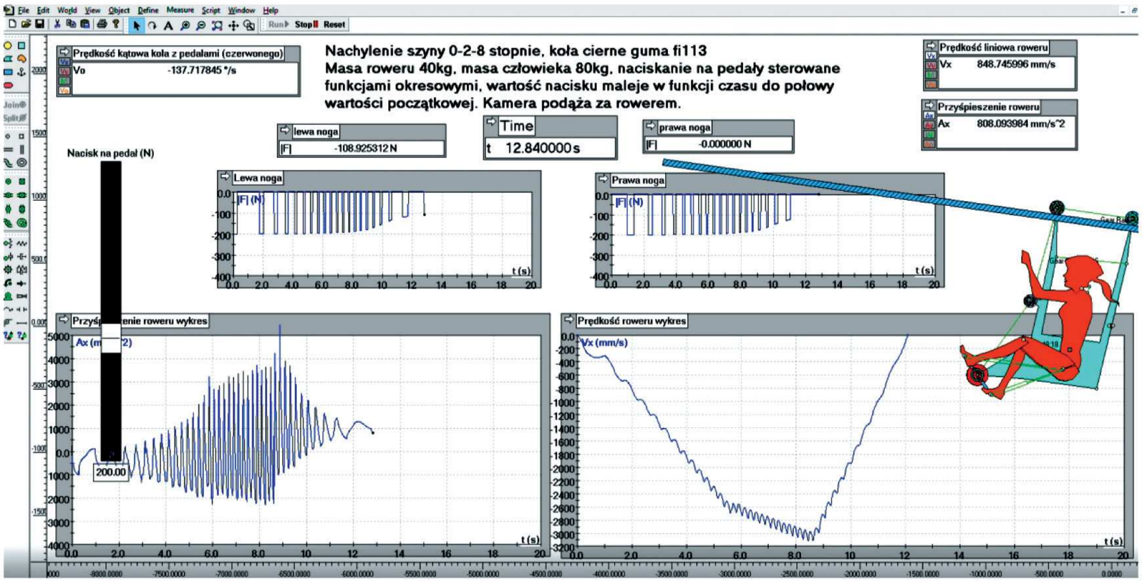

Fig. 16. Example of "Working Model" simulation

Simulations pointed out that rubber covered steel wheels work better because of the lower friction between rubber and steel rail than between wheels and rail that are both steel, meaning less force is needed to set the bike in motion. Maximum rail inclination for a bike equipped in steel wheels covered with rubber is equal to 10°.

The first real-life underground tests were conducted in Jastrzębie-Bzie[1] colliery. Based on the observations, the following conclusions were made:

- The prototype weight (36 kg) is too high to mount the bike on the rail by one person (two are needed.
- The assembly of the bike can be done by one person only, but it is easier and faster when two persons work together. It is also convenient to use wingnuts instead of regular ones to make installation possible without tools.
- The stability of the bike is sufficient because of its low center of gravity. Pedaling does not cause the lateral movement of the vehicle.
- One-wheel drive is sufficient.
- Steel wheels tend to slide on the metal rail.
- Experiments were carried out for two different transmission ratios, with sprocket wheels 46/16 and 22/16 teeth. The first configuration could require considerable effort to climb uphill, however the second one does not allow one to travel at the desired speed. It is recommended to use a sprocket wheel with an intermediate number of teeth – 34 or 36.

[1] https://www.youtube.com/watch?v=2IniLx2nJU8

Photographs from underground tests are presented below (Fig. 17 and 18)

On the basis of another underground experiment carried out in the LW Bogdanka mine, similar conclusions were drawn. Additionally, it was suggested that side guiding wheels should be eliminated from the bike's construction.

Fig. 17. New miner's bike prototype in an underground working

Fig. 18. Underground tests of a new miner's bike

4. SUMMARY

The presented vehicle is designed for mine workers whose work requires moving frequently between distant underground mine workings. The application of the bike could help reduce tiredness among staff and increase work efficiency by reducing time spent locomoting.

A bike prototype should be developed in accordance with legal requirements, as well as the demands of potential stakeholders and clients to make the final product safe and usable. The application of an electric or hydraulic drive should be considered.

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