https://doi.org/10.7494/miag.2021.2.546.33

KRZYSZTOF ZAGÓRSKI
DANIEL STOMPOR

A manual winch project with a two way ratchet mechanism

The article describes a solution to an engineering problem concerning the development of a design of a manual winch for off-road vehicle users. The aim of the design is to provide the possibility of extracting an off-road vehicle which is not equipped with an electric winch in the event it becomes stuck in mud or sand. The concept was based on a review of available solutions on the market and an analysis of their advantages and disadvantages. The design was based on calculations performed in accordance with the literature recommendations and FEM strength analyses carried out on a model created using Autodesk Inventor Professional 2020. The developed device is able to provide a pulling force of over 50 kN with an unladen weight of 35 kg, and also provides the possibility of controlled lowering of the load.

Key words: *Manual winch, ratchet mechanism, cable, rope, pulley, off-road vehicle*

1. INTRODUCTION

In Poland, off-road vehicles have become increasingly popular in recent years [1, 2]. The growing popularity of events for owners of such vehicles, as well as the large availability of second-hand cars on the market, has led increasing numbers of people to decide to buy and use an off-roader. Vehicles capable of driving off-road are used by private persons, e.g. to get to fishing places, trips on available off-road routes, to reach properties in places where access is difficult due to the lack of paved roads, or by foresters, forest guards or employees of power plants. Regardless of the equipment of the vehicle, the terrain can surprise anyone, and with the increasing number of users of such vehicles, the number of cases of getting stuck in mud or sand increases. There is a wide range of electric winches available on the market which can be fitted to a vehicle in order to enable it to be driven out of the muddy terrain. The installation of such a winch often requires the appropriate modification of the car body by equipping it with a solid and heavy bumper or the additional attachment of the winch to the frame, which in turn is associated with an increase in fuel consumption and often with problems during technical inspections of the vehicle. Because of this, not everyone decides to install an electric winch, as it is not cost-effective for those who only use their vehicles off-road occasionally. To overcome this problem, an alternative solution was developed to replace the electric winch and safely pull out a vehicle that has become bogged down.

Reviewing the solutions available on the market and analysing their advantages and disadvantages allowed us to develop our own new device concept. Almost all manual winches used by owners of off-road vehicles allow only for lifting the weight, and in the case of the considered application – pulling the vehicle out of the muddy terrain. Based on our own experience and observations, we decided to construct a device, which, apart from providing adequate pulling power in case of winding up the rope, would enable the controlled lowering of the load. When viewed from the perspective of off-road driving, this feature is a considerable improvement. It is intended to help overcome the problem of steep slopes, from which a vehicle descending freely could tip over or lose traction.

2. OVERVIEW OF AVAILABLE SOLUTIONS

The most common alternative to an electric winch used by off-road vehicle users is a rope winch called a kifor [3], shown in Figure 1.

Fig. 1. Rope winch [4]

The greatest advantages of this device are its simple and reliable construction and high nominal hauling capacity, which for the strongest variant amounts to 30 kN. However, the construction of the standard kifor has a significant disadvantage – its weight for the variant with such a pull is 46 kg, which makes it very difficult to use it in off-road conditions, where you often have to walk through deep mud to attach the rope to the anchor point. Another disadvantage is that the long steel cable has to be reeled in on a separately attached pulley. It is also worth mentioning the high application force assumed by the manufacturer of almost 440 N. These disadvantages make the device hard to use in difficult conditions.

Another commercially available device is the crank winch [5] as shown in Figure 2.

Fig. 2. Crank winch with ratchet mechanism [5]

This device is not designed for car winching, however, it is used for such purposes probably because of its low price. Crank winches provide a maximum pulling capacity of up to 20 kN, however, due to the design for attaching the device to a restraint, it is extremely inconvenient to use such a winch to pull a car, as the device rotates around the axis of the rope on which it is suspended during the pulling process when cranking. It also gives the illusion of being able to lower the vehicle or load in a controlled manner by having a double sided ratchet mechanism, which blocks the gearbox from rotating in one direction. However, when lowered, the return of the force in the rope does not change direction, so the load falls automatically and the device can become unstable and unsafe for the user.

A solution that can also be used for the aforementioned purpose is that of the manual winch with a ratchet mechanism [6] shown in Figure 3.

Fig. 3. A winch with a ratchet mechanism [6]

This device provides comfort while pulling a car at the same time with a high pulling force declared by the manufacturer, equal to 40 kN. The design seemingly meets the need under consideration, however, according to the users the declared pulling capacity of the winch does not reflect the real pulling capacity of the device. Amateur tests [7] have shown that the device is not able to provide the pulling capacity needed to pull a vehicle that is stuck in sand.

3. DESCRIPTION OF THE SOLUTION

The design assumptions are as follows: to ensure pulling capacity to pull a vehicle in muddy terrain, to enable controlled unwinding of the tightened rope, resistance to unfavourable working conditions (mud, moisture, dirt) while limiting the weight and dimensions of the device. Due to the fact that during operation the device will be stretched between two ties in a horizontal position, the most convenient form of drive for the user was considered to be a lever performing a swinging movement. This type of drive eliminates the tendency for the device to rotate around the rope axis during operation, which occurs when using a crank winch because the force applied by the user will act in the rope axis. The lever through a ratchet mechanism will transmit the torque to the gears. The main problem was to realise the possibility of a controlled lowering of the load when using such a mechanism. This was solved by using a block brake, which during the unwinding of the tensioned rope will provide resistance to prevent the load from running away, as shown in Figure 4.

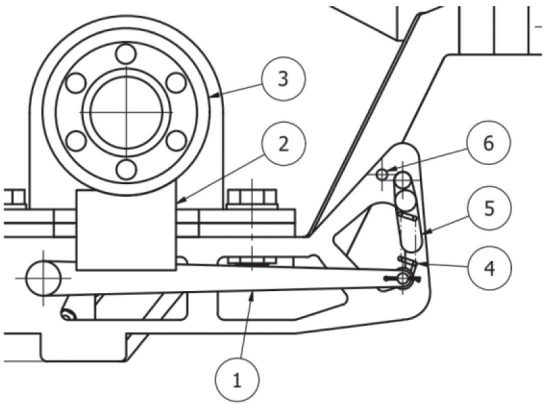

Fig. 4. Mechanism which allows for lowering the weight

The lever (1) pushes the brake pad (2) against the brake drum (3). The spring (4) provides the force needed to apply the required torque to the brake drum. The spring tensioning device (5) locks onto the pin (6).

The device is equipped with a crank on the cable drum shaft for fast winding or unrolling of the cable as shown in Figure 5.

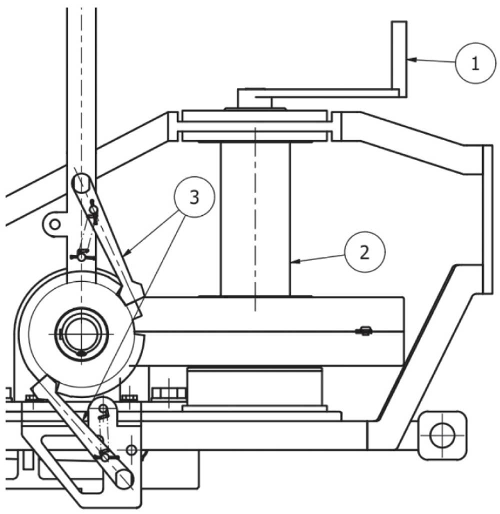

Fig. 5. Crank for rapid winding or uncoiling of the rope

The crank (1) allows the user to quickly wind or uncoil the rope from the drum (2). In order to use it, the ratchets (3) should be set in a position allowing the drum to rotate in the desired direction.

The rope is attached to the drum using a dedicated rope attachment tape for winch drums as shown in Figure 6. The rope, properly interwoven through the tape, is secured against slipping from the drum when fully unwound.

Fig. 6. Rope attachment tape [8]

4. CALCULATION PART

According to the recommendations for the design of electric winches as specified in EN 14492-1, the basic parameters for drum size and rope strength were selected. Initially it was assumed that the winch should provide a force of 60 kN, which corresponds to double the weight of a large off-road vehicle. For further calculations it was necessary to know the force available to an average person. The literature on biomechanics [9] was used to estimate the force of 150 N, which was used for further calculations. The knowledge of the torque required on the winch drum as well as the torque that the user is able to produce at the assumed lever length allowed for the estimation of the required transmission ratio, which was 42.5. The worm gear was considered to be the best for its implementation, as it is possible to provide such a transmission value in one gear stage. Considering the use of a crank for fast rope winding, which is located on the output shaft of the gearbox, its parameters were selected so that it would not be self-locking. The phenomenon of gearbox self-locking could not be used in this case, as it not only depends on the geometrical parameters of the worm and worm wheel, but also on friction coefficient, which would be variable under assumed operating conditions, which would make the device unsafe. The lack of a self-locking gearbox also carries the advantage of increased efficiency. In order to carry out the strength calculations of the gearbox according to the procedure presented in the literature [10], it was necessary to estimate the speed of the gearbox. For this purpose, an experiment was carried out, consisting in making cycles of movements with a provisional lever, imitating movement between extreme positions of the lever. The length of the makeshift lever corresponded to the assumed length of the device lever. Assuming that one movement would rotate the worm by 120°, the time (60 seconds) and the number of cycles performed were counted. The experiment was performed by two people three times and the average number of cycles performed per minute was 70. This made it possible to estimate the speed of the worm, which was approximately 23 rpm. The lever on which the experiment was carried out was not loaded and therefore does not reflect real-life conditions where human condition would play a significant role, but it was advantageous to use a slightly higher speed value for strength calculations. It was also important to determine the value of the torque on the drum on which the rope is wound. The device was assumed to provide the original pull value when the force acts on the outer layer of rope coils – i.e. when the rope is not fully unwound, so that the pull does not decrease with each additional layer of rope wound on the drum. The following steps were taken to determine the gearbox dimensions:

Calculation of the pre-assessed slip speed:

$$v_s = 4.5 \cdot 10^{-4} \cdot n_1 \cdot \sqrt[3]{T_2} = \\ = 4.5 \cdot 10^{-4} \cdot 23 \cdot \sqrt[3]{5160} = 0.18 \text{ m/s} \tag{1}$$

where:

n_1 – worm speed [1/min],
T_2 – output torque value [Nm].

Determination of allowable contact stresses of the worm gear:

$$\delta_{HP} = 175 - 35 v_s \tag{2}$$

Calculation of the gearbox centre distance:

$$a'_w = \left(\frac{z_2}{q'} + 1\right) \cdot \sqrt[3]{\left[\frac{170}{\delta_{HP} \frac{z_2}{q'}}\right]^2 \cdot T_2 \cdot k_h \cdot 10^3} = \\ = \left(\frac{43}{10} + 1\right) \cdot \sqrt[3]{\left[\frac{170}{168.7 \frac{43}{10}}\right] \cdot 5160 \cdot 1.1 \cdot 10^3} = \\ = 359.4 \text{ mm} \tag{3}$$

where:

k_h – design load factor,
q' – presumed value of the diameter index,
z_2 – number of worm gear teeth.

Calculation of axial modulus:

$$m' = \frac{2 a_w{}'}{q' + z_2} = \frac{2 \cdot 359.4}{10 + 43} = 13.56 \tag{4}$$

Then, a standardised axis distance of 355 mm and a modulus value of 12.5 were selected from the PN-93/M-88527 standard to determine the gearbox dimensions shown in Figure 7.

Worm pitch diameter:

$$d_1 = m \cdot q = 12.5 \cdot 10 = 125 \text{ mm} \tag{5}$$

Worm gear pitch diameter:

$$d_2 = m \cdot z_2 = 12.5 \cdot 43 = 537.3 \text{ mm} \tag{6}$$

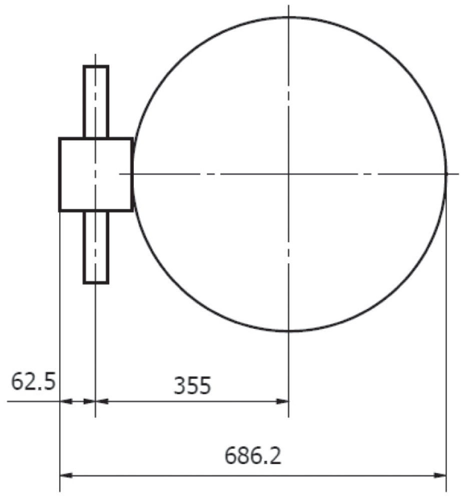

Fig. 7. Initially determined dimensions of the gearbox

It would not have been possible to handle a device of such considerable dimensions with ease. This fact necessitated a change to a smaller towing capacity. Numerous calculations in search of an optimum solution, the results of which are shown in Table 1, made it possible to change the concept to the following: the nominal pull will be reduced to 30 kN and it will be possible to double it by using a pulley. At this point, a further development of this concept emerged, namely the reduction of the dimensions of the winch, which can be achieved by reducing the torque on the drum while multiplying the force using a pulley. However, it should be remembered that the device will be used in unfavourable conditions, e.g. in mud or bushes, and also that it will be transported in the boot of a car. The use of a multi-pulley with a rope interwoven several times could result in the rope falling from the pulleys in such conditions, tangling and making free use impossible. Figure 8 shows a diagram of the use of the device.

Table 1

Summary of device parameters for different initial assumptions

Gear ratio	Torque of winch drum [Nm]	Pull value [kN]	Overall dimensions of the gear [mm]	Comments
45.0	5160.0	60.0	686.2	–
30.0	2250.0	40.0	547.5	–
22.5	1687.5	60.0	470.0	pulley ratio $i_w = 2$
12.0	1125.0	40.0	432.0	pulley ratio $i_w = 2$

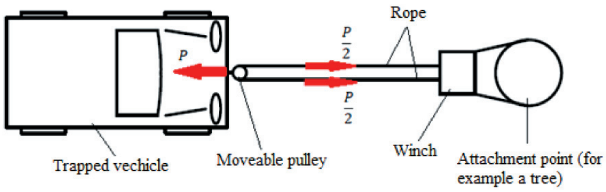

Fig. 8. Scheme of use of the device

There are inconsistencies in the values presented in Table 1 that need to be corrected. Reducing the gear ratio by a half did not result in a corresponding reduction in the drum torque. This is due to the fact that, after reducing the nominal pull, a rope of smaller strength and diameter was used, which changed the arm on which the force acts on the drum.

In order to check the strength of the remaining elements of the gearbox, FEM analysis was carried out using Autodesk Inventor Professional 2020. The analysis was carried out for the complete model of the device with all the elements, taking into account all the forces with which it is loaded. Figure 9 presents the loads that were given in the analysis.

Figure 10 shows the model with the finite element mesh, specified loads and assumed restraint method. It was assumed that the device would be restrained by two pin ties at the point of attachment of the device to the restraint and at the point of attachment of the cable to the device if a multistrand was used. The connections between the components have been imposed automatically and consequently all components are considered to be bonded together. When selecting the material parameters, simplifiying assumption was that all components are made of the same material – steel with Young's modulus E = 210 GPa, Kirchhoff modulus G = 80 GPa and Poisson's ratio ν = 0.3.

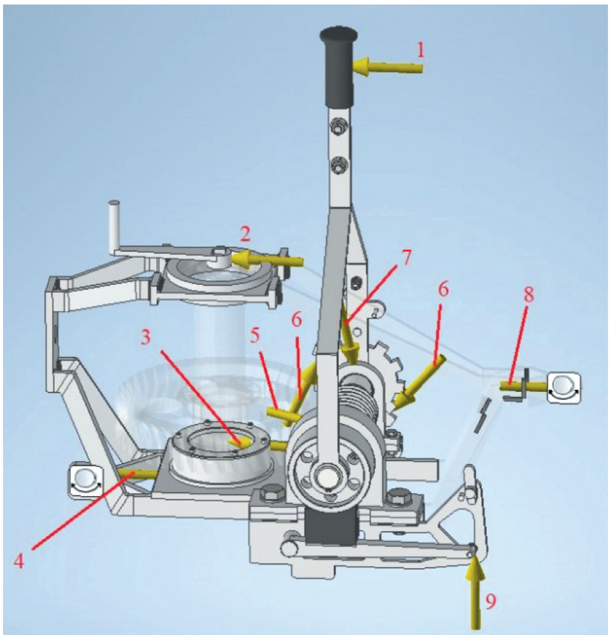

Fig. 9. Loads assumed in FEM analysis:
1 – lever driving force – 150 N;
2, 3 – bearing load, depending on the position of the rope on the drum – in the most un favourable case it amounted respectively to 28,000 and 30,500 N;
4 – force coming from the rope threaded through the pulley – 30,000 N; 5 – bearing load – 12,500 N;
6 – forces in the ratchet mechanism – 1250 N;
7 – bearing load – 970 N; 8 – force acting on the fastening of the winch to the restraint – 60,000 N;
9 – force acting on the brake lever – 290 N

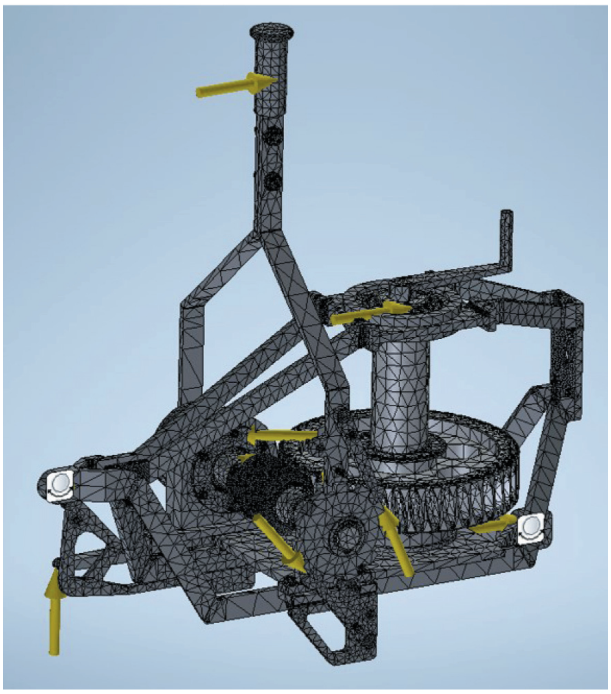

Fig. 10. Device model with FEM mesh and specified loads

Figure 11 shows the graphs of the convergence of the mesh. The number of grid elements was 579166 while the number of nodes was 976125.

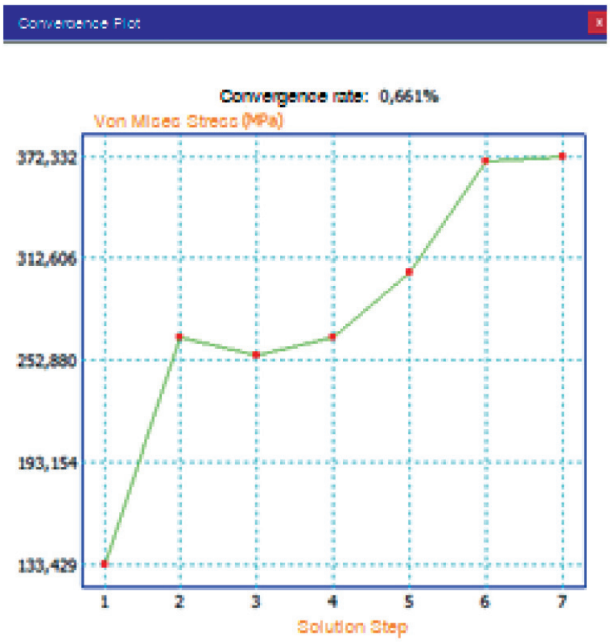

Fig. 11. Grid convergence diagram

The results of the analysis made it possible to optimise the shape of the body and eliminate stress concentration points by removing parts of the surface of unloaded elements to reduce mass and using rounding radii. Figure 12 shows the results of the analysis. The tools for constructing bolted connections and shafts available in Autodesk Inventor Professional 2020 were also used in the design.

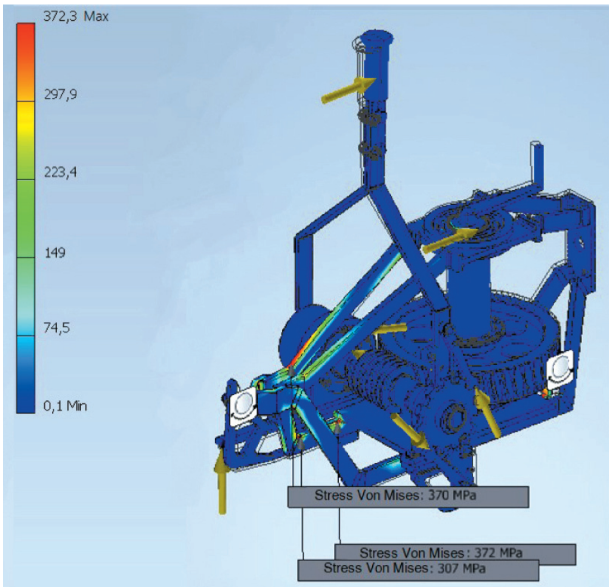

Fig. 12. Results of FEM analysis

Figure 13 shows the results of the analysis with a narrowed stress scale to show the stress distribution.

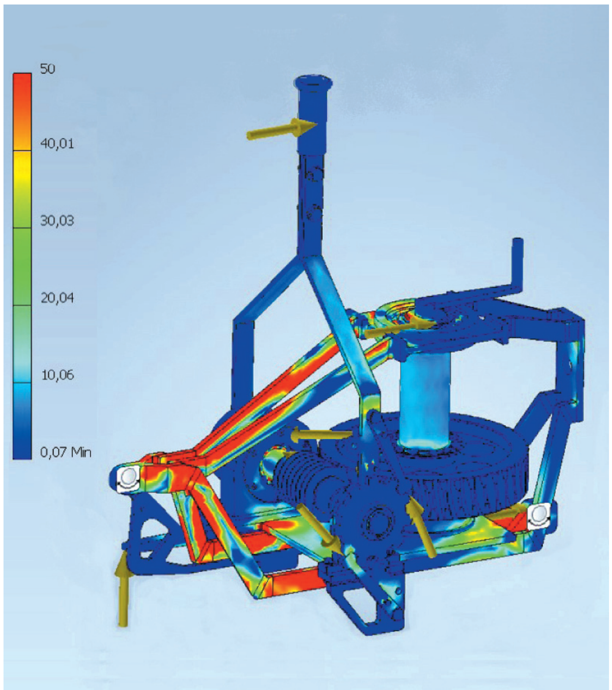

Fig. 13. Stress distribution with narrowed scale

The analysis presented above was intended to determine the stresses occurring in the body of the device. Separate analyses were carried out to check the strength of individual components such as the pawls of the ratchet mechanism.

5. SUMMARY

The end result is a device providing a real pulling force (taking into account the efficiency of the gearbox) of over 50 kN at a device weight of 35 kg. A commonly available solution with the most similar parameters guarantees a pulling force of 30 kN at a weight of 46 kg. The worm gearbox is completely protected against dirt. The ratchet mechanism and the block brake have not been protected with additional covers in order to limit dimensions and weight, as these are mechanisms that are easy to keep clean. Due to the unusual solution for lowering the weight, this design may serve as the inspiration for similar devices. A complete 3D model of the device without the rope attached is shown in Figure 14.

Fig. 14. Winch model

References

[1] Trusz F.: *Już ponad 40 proc. nowych samochodów w Polsce to SUV-y. Będzie ich jeszcze więcej.* https://moto.pl/MotoPL/7,88389,26712558,juz-ponad-40-proc-nowych-samochodow-w-polsce-to-suv-y-bedzie.html [28.11.2021].

[2] Łobodziński M.: *Zainteresowanie off-roadem rośnie i ceny terenówek także. Nie tylko przez pandemię*. https://autokult.pl/41203,zainteresowanie-off-roadem-rosnie-i-ceny-terenowek-takze-nie-tylko-przez-pandemie [28.11.2021].

[3] *Wyciągarka ręczna kifor*. https://kadimex.pl/produkt/wyciagarka-reczna-kifor/ [11.12.2021].

[4] *Wyciągarka linowa ręczna – kifor 3,2 t*. http://tynaxtools.pl/289-wyciagarka-linowa-reczna-kifor-32t-20m-liny.html [5.01.2021]

[5] *Ręczna manualna wyciągarka korbowa z zapadką*. https://www.hurtowniaprzemyslowa.pl/reczna-manualna-wyciagarka-korbowa-z-zapadka-10-m-do-1200-kg-msw-p-8109.html [5.01.2020].

[6] *Wciągarka linowa 4t*. https://www.mojenarzedzia.pl/wciagarka-linowa-4t-2-tryby-p-247.html [8.12.2021].

[7] *Patenty na zakopane auto. Testy Terenwizji*. https://www.youtube.com/watch?v=cHoNWmzWzrY [14.04.2021].

[8] *Taśma do mocowania liny do bębna wyciągarki*. https://dirtyoffroad.pl/pl/p/Tasma-do-mocowania-liny-do-bebna-wyciagarki/30 [7.01.2021].

[9] Bober T., Zawadzki J.: *Biomechanika układu ruchu człowieka*. BK, Wrocław 2003.

[10] Kurmaz L.: *Podstawy konstrukcji maszyn. Projektowanie*. Wydawnictwo Politechniki Świętokrzyskiej, Kielce 2011.

KRZYSZTOF ZAGÓRSKI, Ph.D., Eng.
Department of Manufacturing Systems
Faculty of Mechanical Engineering and Robotics
AGH University of Science and Technology
al. A. Mickiewicza 30, 30-059 Krakow, Poland
zagkrzys@agh.edu.pl

DANIEL STOMPOR
Faculty of Mechanical Engineering and Robotics
AGH University of Science and Technology
al. A. Mickiewicza 30, 30-059 Krakow, Poland
stompor@student.agh.edu.pl