A Unit for Inflating and Maintaining a Constant Pressure in the Tires During the Movement of a Slow-Moving Vehicle

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Abstract. In land transport, low-speed and special vehicles move over various terrain. From paved surfaces, through gravel and forest roads to boggy and muddy terrain, and the ability to overcome road obstacles depends, among others, on tire pressure. The obtained traffic parameters also depend on the environmental conditions, the condition and type of surface, the load, and the tire-surface cooperation area. The pressure in the tires of a moving vehicle has a significant impact on steering, driving stability, fuel consumption (ecology) and safety. Therefore, these vehicles are equipped with tire pressure systems. The article presents the conceptual design of the pumping unit and the constant pressure maintenance in the wheels of a slow-moving vehicle while driving. The presented unit is based on a hose pump located inside the wheel rim and a control system. For the designed structure, the values of forces and the time of inflating the tire to the given pressure were determined and subjected to FEM analysis.

Introduction
The environmental protection directives established by the Community have introduced standards for the emission of harmful compounds in the exhaust gases of motor vehicles. The European exhaust emission standard applies to new vehicles sold within the European Union [1]. The standards and norms were described in a series of directives that gradually increased their restrictiveness from the first standard called Euro 1, which came into force in 1993, to Euro 6 in 2014 [2-8] and the planned Euro 7 standard (currently in the social pre-consultation phase). The air resistance, the vehicle load [9-11] and the friction forces between the tires and the road surface have a significant impact on the increase in fuel consumption by vehicles [12-14]. Depending on the load of the vehicle, manufacturers recommend the appropriate pressure in the tires, which reduces the tire wear and affects the fuel combustion process. Maintaining the recommended pressure has an impact on the economy and ecology of the vehicle's movement. On November 1, 2014, the EU directive came into force, stating that all new vehicles must be factory-fitted with a pressure control system called TPMS (Tire Pressure Monitoring System).

The TPMS systems have been divided into two basic types: the indirect system and the direct system. The indirect system allows the tire pressure to be controlled via the ABS system. The sensors monitor the rotational speed of individual wheels, and the system calculates the rotation of a given wheel. The pressure drop in the tire reduces the rolling radius of the wheel, which causes the wheel to rotate more. The on-board computer compares the received data with the reference values and sends information to the dashboard when the set amount of air is lost. The system does not require additional
equipment and special service procedures when replacing the tires. The direct TPMS system is equipped with pressure sensors, and the on-board computer displays the measured values in real time, or informs about too low pressure depending on the vehicle model and the installed equipment. The movement of vehicles, apart from the driver's abilities, depends on the transferred forces and moments acting in the area of tire-road interaction [15-18]. The vehicle motion parameters also depend on the adhesion coefficient, which is determined by the features of the road surface [19-21], the tires [22-24], the structure of the vehicle's drive and suspension [25, 26] and the features of the environment [27, 28]. Apart from external factors, it is also the vehicle design changes that have an impact [29-31].

Moving on marshy and soft terrain, the possibility of transferring forces and moments at the contact of the tire with the ground is used at reduced tire pressure. Lowering the pressure increases the contact surface area and reduces the unit pressures [31]. Suitable tires are used in off-road, agricultural, slow-moving and special vehicles to more effectively overcome unfavorable terrain. Driving such a vehicle on an uneven terrain, overcoming various obstacles, often has a negative effect on the tires and the suspension [29, 32, 33]. By controlling the tire pressure, we influence the traffic safety, the traction, the vehicle steerability, the rolling resistance and the fuel consumption.

The tire pressure is easily adjustable and controllable and plays an important role in reducing skid on unpaved roads. This aspect greatly affects the fuel consumption. Damanauskas et al. in 2015 show that reducing tire pressure reduces drive wheel slip and fuel consumption, while increasing work efficiency, and the occurrence of skid in the range of 7 to 15% can be considered normal during field work [34]. In the case of wheel slip control in conjunction with changes in the tire pressure, Janulevičius and Damanauskas in 2015 predict the possibility of minimizing the fuel consumption [35].

Correctly selected pressure enables better contact with the surface, limiting the slip phenomenon. This translates into more effective use of the available power of the machine. Less energy is wasted on movement, thus saving fuel and time for work (ecology + economy). However, reduced tire pressure increases the radial deflection and negatively affects the heat balance of the tire composite layers during motion. Similarly, too low tire pressure and reduced tension value of composite drive belts cause their premature wear [36-41].

**The influence of tire pressure on skidding**

Tire manufacturers usually list the permissible pressure of the tires they sell. This value is not optimal for the work to be performed. For example, at the permissible pressure, e.g. 0.20 MPa, works can be most effective at the pressure of 0.12 MPa. This is due to the increased contact area and greater use of the tread pattern. Tests carried out by Michelin show a strong correlation between the slip of the wheels and the tire pressure. It has been shown that lower pressure causes lower wheel slip value during field works. It was noticed that for the field works performed at the speed of 10 km / h, the pressure of 0.25 MPa caused a slip of 38%, while the pressure of 0.10 MPa was 17%. It can be seen that the difference of 0.15 MPa allows for reducing the wheel slip value by as much as 21%.

The currently used central pressure regulation systems in wheels are characterized by high complexity of the structure. The key element is the use of a central pumping unit, which requires the use of pneumatic lines and connecting them to a moving valve located on the rim. Today there are two constructional solutions enabling the air supply to the wheels. In structures equipped with portal bridges, the possibility of making a "through" axis is used. The medium is supplied by feeding the cable through the central axis of the hub and connecting the cable to a dedicated adapter. Forming a sliding pair with the lead-out, the end of the tubing connects the end of the tubing to the rim valve. This prevents the pneumatic hoses from twisting. In other cases, the medium is supplied through a connection mounted above the wheel and, similarly to portal bridges, an adapter is used to connect the pipes to the valve on the wheel rim.

There are also methods for delivering air to the tires through the special construction of the rim. It then has a hollow frame through which the medium is delivered to the inside of the tire. In this case, it is also necessary to use a special adapter in the centre of the wheel.
Table 1. Comparison of the features of compressed air supply to the inside of the tire

| Disadvantages | Advantages |
|---------------|------------|
| power cord routed through the reduction gear pinion | - necessity to use a rotating head | - low cost of production |
| the power cord routed outside the vehicle | - frequent mechanical damage to the cord | - possibility of using a larger diameter hose (shorter pumping time) |
| power cord routed through the wheel drive shaft | - system leakage problems | - avoiding the breakage of the guide cord |
| supplying of the compressed air through the hollow rim shoulder | - significant cost of a specialized reinforced rim with a hollow shoulder | - avoiding the breakage of the guide cord |
| (increased costs) | - complicated adaptation of the drive system | - easy sealing of the system by minimizing the number of pipe connections |
| (increased costs) | - weakening of the drive system | - |
| (increased costs) | - necessity to use a rotating head | - |
| (increased costs) | - weakening of the drive system | - |
| (increased costs) | - necessity to use a rotating head | - |

Another example is the solution proposed by Mercedes-Benz. The system is equipped with a central compressor and a pneumatic installation system. The difference to other solutions is the use of pressure tanks as compressed air accumulators. These elements are embedded in the wheel arches of the vehicle. In the system, the compressor is responsible for maintaining high pressure in the tanks. This solution allows for raising the pressure in the tires from 0.05 MPa to 0.18 MPa in about 20 seconds.

Most modern constructions are based on a common concept of equipping the vehicle with a central pumping unit and supplying the air to the wheels while the vehicle is moving. This affects the complexity of these solutions, which directly translates into the system costs and difficulties in adapting to the already existing vehicles. These systems are prone to a number of failures, and a failure of the central pumping unit practically means the loss of the possibility of pressure adjustment. The mentioned wheel pumping systems have a number of drawbacks, such as [own elaboration]:

- the complicated system of pneumatic connections,
- the need to use adapters to obtain a rotary pneumatic connection,
- problems with the occurrence of mechanical damage,
- a large number of connections favours the formation of leaks,
- the weakening of the drive system (in the case of using solutions consisting in supplying the medium through the drive shaft),
- a failure of the central unit paralyzes the operation of the system,
- low adaptation possibilities,
- high system costs.

The ability to remotely adjust the pressure in the tires due to the tire-surface cooperation determines the need to design a new construction of the tire inflation system for the slow-moving vehicle while driving. The ability to quickly and smoothly adjust the pressure for such machines is a desirable feature that can affect the comfort, cost and culture of operation of such machines. The paper presents a conceptual design of a pumping unit and a constant pressure of pneumatic wheels during the movement of a slow-moving vehicle

**Conceptual design of the inflating unit**

The use of portal bridges in vehicles enables them to overcome higher obstacles and reduces the probability of damage. More and more often, portal bridges are also used to make it easier to equip a vehicle with a central tire inflation system. An alternative solution may be to use a peristaltic pump.
The main feature of peristaltic pumps is their tightness. The pumped medium does not come into direct contact with the mechanical parts of the pump. This results in a significant reduction in the possibility of contaminants getting inside the tire. This pump is also characterized by a simple structure limiting the elements present in it. The pumping of substances is possible using one pipe, the ends of which are connectors, and the pipe itself is the working section of the pump. The drawback of the presented concept is the impossibility of using the structure for steering axles, as well as the need to supervise and plan the replacement of working cables due to their wear and degradation. Changing of the orientation of the wheel in relation to the driving axle may result in the damage and destruction of the inflating unit.

The construction and design assumptions
The assumption of the structure is to maintain its full functionality, to inflate the wheels while the vehicle is in motion, and to minimize the modifications to the existing machine structure. The conceptual design assumes interference only with the vehicle wheels. This involves the necessity to make an additional hole in the rim and to equip it with an additional ring with an elastic element. In order to implement the design assumptions, it was decided to install a mechanism based on the construction of peristaltic pumps inside the wheels of the vehicle. A view of the pneumatic wheel inflating unit while driving and maintaining a constant pressure is shown in Figure 1.

The device carries out the process of inflating the wheels without an additional pump that would require an external drive. The pneumatic wheel inflating unit while driving and maintaining a constant pressure is intended for installation in non-driven and non-steered wheels. In such a solution, the wheel is made of a pneumatic tire, mounted on a rim adapted for mounting the axle, a flexible pneumatic channel and pneumatic valves: a suction valve, a pumping valve and a pressure control valve. A cross is mounted on the stationary axis. A flexible pneumatic duct is permanently attached to the rim from the inside. Flexible pneumatic duct is equipped with a suction valve and a pumping valve fixedly attached to the rim. The pressure for inflating the wheel is generated by the rolling of the rollers on the flexible pneumatic duct. The air in the flexible pneumatic duct is forced only while the vehicle is moving. The continuous supply of air to the pneumatic tire could contribute to its damage, therefore a pressure control valve was used.

This approach eliminates the drawback of the central unit by equipping each wheel with a separate air delivery unit. The independence of the inflating units in the event of failure of one of the systems enables further pressure adjustment of the other wheels and the maintenance of the overall efficiency of the vehicle. The encapsulation of the pressed elements inside the rim reduces the possibility of damage to the elements responsible for transmitting the air to the inside of the tire, e.g. by their accidental breaking. To simulate a system, it is necessary to perform preliminary calculations and determine the forces acting on the structure. The calculations assumed that air is a perfect gas and its parameters correspond to the characteristics of the isentropic transformation.

Figure 1. Conceptual design of the pneumatic wheel inflating unit while driving and maintaining a constant pressure (own study): 1 pneumatic tire, 2 rim, 3 rollers, 4 flexible pneumatic duct, 5 cross, 6 assembly axis, 7 key connection, 8 spring snap ring, 9 bearing, 10 internal snap ring, 11 external snap ring, 12 snap ring, 13 slide bearing, 14 suction valve, 15 pumping valve, 16 pressure control valve.
The requirement for the proper functioning of the unit is the minimum pressure difference necessary to open the one-way inflating valve 15. For the calculations, it was assumed that the required pressure difference was 0.001 MPa. The force acting on the shoulder of the cross will be equal to the pressure acting on the surfaces of the elastic element. The assumed cross-section of the elastic element is:

\[
S = \frac{\pi d^2}{8} + h(l - d) = \frac{\pi 60^2}{8} + 30(110 - 60) = 2913.72 \text{ mm}^2
\]

Assuming that air is the ideal gas and the assumed pressure to open the valve is, e.g. 0.201 MPa, the force of impact on the arm will be:

\[
F = P \cdot S = 0.201 \cdot 2913.72 = 585.66 \text{ N}
\]

where:
- \(F\) - force of impact on the arm,
- \(P\) - pressure to be achieved on the pressed side,
- \(S\) - area affected by the pressure.

The value of the force acting on the arm depends on the set tire pressure. For the selected range of pressures, the values of the forces necessary to overcome the resistance of the rollers movement along the flexible pneumatic channel were presented (Table 2).

| Target pressure [MPa] | Minimum compression pressure [MPa] | Calculated force acting on the frame [N] |
|-----------------------|------------------------------------|----------------------------------------|
| 0.150                 | 151                                | 439.97                                 |
| 0.175                 | 0.176                              | 512.81                                 |
| 0.200                 | 0.201                              | 585.66                                 |
| 0.225                 | 0.226                              | 658.49                                 |
| 0.250                 | 0.251                              | 731.34                                 |

The second important parameter is the pumping time, which depends on the size of the tire used and the speed of the vehicle. For example, for a tire of the size R26 480/80, the projected necessary vehicle speed to inflate the wheel from 0.15 MPa to 0.25 MPa to 1 minute is approximately 17 km / h. This speed is the value achievable by a slow-moving vehicles, since the limit speed is 25 km / h.

**Numerical analysis - FEM**

The designed structure of the pneumatic wheel inflating unit while driving and maintaining a constant pressure is shown in Figure 2. While the vehicle is moving, the wheels rotate causing the apparent movement of the cross with rollers on the elastic element. The structure must be characterized by strictly defined geometrical relations to enable the inflating process.

The location of the structure in the vehicle and the function it performs are strictly determined by the strength criterion. The cross with the rollers is the most heavily loaded. Under normal conditions, when working in the setting that maintains the pressure of 0.25 MPa in the tires, the maximum value of the force acting on the rollers of the cross is the 730N wheel. The structure is equipped with four rollers and each of them is subjected to variable loads during movement. During the analysis, for safety reasons, the same force value of 1000 N was assumed for each of the rolls. The areas of higher stress values are the support frame and the roller seats. The results show negligible stresses in the main plate of the cross. In order to investigate specific important points in the structure in more detail, a probe was used to read the stress values. The system of forces and the grid structure for numerical calculations are shown in Figure 3.
For the adopted boundary conditions, the maximum stress values were 219.1 MPa. The maximum stress values occur on the support and do not exceed the yield point of the material accepted. The greatest displacements are 2.41 mm and occur at the ends of the arms of the cross. The displacement analysis performed shows that the entire structure retains the required stiffness, as shown in Figure 4. The values of safety factors were determined for the entire structure. The designed cantilever has a factor above 1.5, and the main structure plate from 7 to 15.

In addition to the mechanical structure, it is necessary to introduce a tire pressure control system. By changing the settings on the control panel, the pressure adjustement valve is controlled. The operation of the control system should be divided into the transmitting and receiving part. The transmitting system should be based on a microcontroller that allowing for controlling the settings of the pressure adjustement valve and collecting the information about the current pressure in the tires. The receiving system is present in all wheels on which the inflating unit is mounted. It consists of the receiver signal, and executive part of the control relay is a solenoid valve.
Conclusions

The wheel inflating systems are playing an increasingly important role in vehicles. A number of benefits result in great interest in adapting such systems to military and civilian applications. The developed structure of the system is an innovative solution, not present before in wheel inflating systems. The possibility of easy adaptation and the lack of integration in the basic structure of cooperating machines makes the developed system unprecedentedly versatile. Equipping the machine with the additional feature of tire pressure adjustment could therefore take place in a very short time, and the process itself would resemble wheel replacement. Other features, such as the lack of a central inflating unit or the lack of elements protruding beyond the outline of the vehicle, translate into a reduced failure rate of the system.

The designed system has great opportunities for further development of the construction. Equipping the cross with appropriate gears and drive will result in the possibility of its operation while the vehicle is not in motion. Such a functionality and development of the control program may result in active monitoring of the pressure in the wheels.

In order to thoroughly analyze the system, it would be necessary to make a prototype and subject it to a series of tests. Such tests would show the actual parameters achieved by the system and would provide data on the existence of possible risks related to the strength of individual components. Such collected complete data would allow for the improvement of the construction and for its adaptation to proper functioning in real conditions.

References

[1] Waluś K J Warguła Ł Krawiec P and Adamiec J M 2018 Legal regulations of restrictions of air pollution made by non-road mobile machinery – the case study for Europe: A review Environmental Science and Pollution Research 25 3243-59 https://doi.org/101007/s11356-017-0847-8

[2] Council Directive 93/12/EEC of 23 March 1993 relating to the sulphur content of certain liquid fuels

[3] DIRECTIVE 94/12/EC OF THE EUROPEAN PARLIAMENT AND THE COUNCIL of 23 March 1994 relating to measures to be taken against air pollution by emissions from motor vehicles and amending Directive 70/220/EEC

[4] European Parliament and Council Directive 94/63/EC of 20 December 1994 on the control of volatile organic compound (VOC) emissions resulting from the storage of petrol and its distribution from terminals to service stations

[5] Directive 98/70/EC of the European Parliament and of the Council of 13 October 1998 relating to the quality of petrol and diesel fuels and amending Council Directive 93/12/EEC

[6] COMMISSION REGULATION (EC) No 692/2008 of 18 July 2008 implementing and amending Regulation (EC) No 715/2007 of the European Parliament and of the Council on type-approval of motor vehicles with respect to emissions from light passenger and commercial vehicles (Euro 5 and Euro 6) and on access to vehicle repair and maintenance information

[7] REGULATION (EC) No 661/2009 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 July 2009 concerning type-approval requirements for the general safety of motor vehicles their trailers and systems components and separate technical units intended therefor

[8] COMMISSION REGULATION (EU) No 214/2014 of 25 February 2014 amending Annexes II IV XI XII and XVIII to Directive 2007/46/EC of the European Parliament and of the Council establishing a framework for the approval of motor vehicles and their trailers and of systems components and separate technical units intended for such vehicles

[9] Kukla M Wieczorek B Warguła Ł and Berdychowski M 2019 An analytical model of the demand for propulsion torque during manual wheelchair propelling Disability and Rehabilitation Assistive Technology 1-8
[10] Wieczorek B and Kukla M 2019 Effects of the performance parameters of a wheelchair on the changes in the position of the centre of gravity of the human body in dynamic condition PloS one 14(12) e0226013

[11] Wieczorek B and Kukla M 2020 Biomechanical Relationships Between Manual Wheelchair Steering and the Position of the Human Body’s Center of Gravity Journal of Biomechanical Engineering 142(8)

[12] Wieczorek B and Wargula Ł 2019 Problems of dynamometer construction for wheelchairs and simulation of push motion MATEC Web of Conferences 254 01006 https://doi.org/101051/matecconf/201925401006

[13] Pałasz B Waluś K J and Wargula Ł 2019 The determination of the rolling resistance coefficient of a passenger vehicle with the use of selected road tests methods MATEC Web of Conferences 254 04006 https://doi.org/101051/matecconf/201925404006

[14] Pałasz B Waluś K J and Wargula Ł 2019 The determination of the rolling resistance coefficient of a passenger vehicle with the use of roller test bench method MATEC Web of Conferences 254 04007 https://doi.org/101051/matecconf/201925404007

[15] Olszewski Z and Waluś K J 2012 Effects of Atmospheric Conditions on The Mechanical Properties of Tires Applied Mechanics and Materials 232 14-18

[16] Waluś K J and Olszewski Z 2011 Analysis of Tire-road contact under Winter conditions Lecture Notes in Engineering and Computer Science 2192 World Congress on Engineering 3 2381-4

[17] Waluś K J 2017 Driver's Strategy and Braking Distance in Winter Transport Means Proceedings of the 21st International Scientific Conference 505-9

[18] Farhadi P Golmohammadi A Sharifi A and Shahgholi G 2019 The CIGRE e-journal Prediction of the tractor tire contact area contact volume and rolling resistance using regression model and artificial neural network Agricultural Engineering International 21(3) 26-38

[19] Sawicki P Waluś K J and Wargula Ł 2018 The comparative analysis of the rolling resistance coefficients depending on the type of surface — experimental research Transport Means Proceedings of the 22nd International Scientific Conference 434-41

[20] Kędziora K and Waluś K J 2013 Experimental and simulation research on car acceleration and braking on snow-covered roads Activities of Transport Telematics 13th International Conference on Transport Systems Telematics TST 2013: selected papers ed Jerzy Mikulski: Springer Berlin Heidelberg Communications in Computer and Information Science 395 433-40

[21] Waluś K J Polasik J Mielenzczuk J and Wargula Ł 2019 Experimental tests of vehicle body acceleration at selected railway crossing MATEC Web of Conferences 254 04002 https://doi.org/101051/matecconf/201925404002

[22] Wargula Ł Wieczorek B and Kukla M 2019 The determination of the rolling resistance coefficient of objects equipped with the wheels and suspension system—results of preliminary tests MATEC Web of Conferences 254 01005

[23] Wargula Ł Kukla M Wieczorek B 2020 IOP The impact of wheelchairs driving support systems on the rolling resistance coefficient Conf Series: Materials Science and Engineering 776 012076 https://doi.org/101088/1757-899X/776/1/012076

[24] Kulikowski K and Szpica D 2014 Eksploatacja Determination of directional stiffnesses of vehicles’ tires under a static load operation Niezawodnosc – Maintenance and Reliability 16 (1) 66–72

[25] Wieczorek B Wargula Ł and Rybarczyk D 2020 Impact of a Hybrid Assisted Wheelchair Propulsion System on Motion Kinematics during Climbing up a Slope Applied Sciences 10 1025

[26] Waluś K J Polasik J Krawiec P and Wargula Ł 2017 The research on the intensity of sports car acceleration with the use of launch control system Transport Means Proceedings of the 21st International Scientific Conference 564-8
[27] Martin D P and Schaefer G F 1996 Tire-Road Friction in Winter Conditions for Accident Reconstruction SAE Technical Paper Series 960657

[28] Navin F Macnabb M and Nicolletti C 1996 Vehicle Traction Experiments on Snow and Ice SAE Technical Paper Series 960652

[29] Đičo J Blatnický M Sága M Harašinec J Gerlici J and Legutko S 2020 Development of a New System for Attaching the Wheels of the Front Axle in the Cross-Country Vehicle Symmetry 12 1156

[30] Waluś K J Warguła Ł Krawiec P and Adamiec J M 2017 The impact of the modernization of the injection-ignition system on the parameters of motion of the motorcycle Procedia Engineering 177 347-51 https://doi.org/10.1016/j.proeng.2017.02.203

[31] Polasik J Waluś K J and Warguła Ł 2017 Experimental studies of the size contact area of a summer tire as a function of pressure and the load Procedia Engineering 177 347-51 https://doi.org/10.1016/j.proeng.2017.02.203

[32] Polasik J and Waluś K J 2016 Analysis of the force during overcoming the roadblock – the preliminary experimental test Transport Problems 11(1) 113-20 https://doi.org/10.20858/tp201611111 ISSN 1896-0596

[33] Waluś K J Polasik J Mielniczuk J and Warguła Ł 2019 Experimental tests of vehicle body accelerations at selected road and rail crossings MATEC Web of Conferences 254 04002-7 https://doi.org/10.1051/matecconf/201925404002

[34] Damanauskas V Janulevičius A and Pupinis G 2015 Influence of extra weight and tire pressure on fuel consumption at normal tractor slippage Journal of Agricultural Science 7(2) 55-67

[35] Janulevičius A and Damanauskas V 2015 How to select air pressures in the tires of MFWD (mechanical front-wheel drive) tractor to minimize fuel consumption for the case of reasonable wheel slip Energy 90 691-700

[36] Czarnecka-Komorowska D and Tomczyk T 2008 Influence of montmorillonite (MMT) on the mechanical properties in recycled rubber Arch Mech Technol Autom 28(1) 145-52

[37] Czarnecka-Komorowska D and Wiszumirska K 2020 Sustainability design of plastic packaging for the Circular Economy Polimery 65 8-17

[38] Czarnecka-Komorowska D Wiszumirska K and Garbacz T 2018 Films LDPE/LLDPE made from post-consumer plastic: processing structure mechanical properties Adv Sci Technol Res J 12 134-42

[39] Krawiec P Waluś K J Warguła Ł and Adamiec J 2018 Wear evaluation of elements of V-belt transmission with the application of optical microscope MATEC Web of Conferences 157 01009-1-8 https://doi.org/10.1051/matecconf/201815701009

[40] Krawiec P Waluś K J Warguła Ł and Adamiec J 2019 Wear evaluation study of the multiple grooved pulleys with optical method MATEC Web of Conferences 254 01004-1-8 https://doi.org/10.1051/matecconf/201925401004

[41] Krawiec P Warguła Ł Małozięć D Kaczmarzyk P Dziechciarz A and Czarnecka-Komorowska D 2020 The Toxicological Testing and Thermal Decomposition of Drive and Transport Belts Made of Thermoplastic Multilayer Polymer Materials Polymers 12 2232