

Determining the rolling resistance coefficient of wheelchairs

JEL: L62 DOI: 10.24136/atest.2019.067

Data zgłoszenia: 15.12.2018 Data akceptacji: 08.02.2019

People moving on wheelchairs overcome the forces of resistance such as: air resistance, resistance of the ascent, inertia force and rolling resistance force. Under certain conditions of use of the wheelchair, the only resistance that must overcome the driving force during the movement is the rolling resistance force. This situation occurs during uniformly rectilinear movement, on a flat level surface at speeds of up to 20 km/h, because at this speed the air resistance is negligible. Rolling resistance is mainly influenced by the mass of the rolling object and the rolling resistance coefficient of the running gear. The value of the rolling resistance coefficient can be influenced, among others, by the surface, type and level of pressure in the tire, and the measurement method. There are test methods that in the resistance of rolling beyond the resistance resulting from the contact of the tire with the surface take into account the resistance to connection of the wheel with the driven object. One of them is the innovative method of measuring the rolling resistance coefficient of objects equipped only with the running gear according to the patent application P.424484 and the developed device for these tests in accordance with the patent application P.424483. The article presents the results of wheelchair rolling resistance test with a classic drive system and wheel attachment. These results show differences in the aspect of rolling resistance of classic wheelchairs with wheelchairs equipped with innovative propulsion solutions, such as a lever drive system or a hybrid drive. The study was financed from the means of the National Centre for Research and Development under LIDER VII programme, research project no. LIDER/7/0025/L-7/15/NCBR/2016.

Słowa kluczowe: wheelchair, rolling resistance coefficient, non-road vehicles, pneumatic and non-pneumatic wheels.

Introduction

Rolling resistance coefficient is one of the basics parameter that characterizes vehicles. It enables to determine the rolling resistance force that is counter-party to the propulsion force. The rolling resistance force depends mainly on the surface, wheels and vehicle's suspension. There are available publications on the research on the rolling resistance coefficient but the applied research method concern mainly car tires [1-2, 4, 6-10, 12-13, 15-16, 23] and road surfaces [1, 3-9, 11, 13, 23]. The article discusses the issue of research on the rolling resistance coefficient of non-road vehicles the example of which are wheelchairs. In case of wheelchairs the rolling resistance coefficient is influenced by:

- elastic strain of pneumatic tire;
- ground strain (only on soft surface);
- rolling resistance in wheel mounting;
- wheel alignment.

Modern construction of wheelchairs are characterized by developer drive systems. The examples of such solutions are wheelchairs equipped with i.e. lever drive system[21], multishift transmission [22] or hybrid electro-manual drive [18]. Such solutions are characterized by a higher resistance of internal drive mechanisms. In literature there are available research results on rolling resistance of rear

pneumatic wheels [14] and front non-pneumatic of wheelchairs with classic drive system. A lack of comprehensive research results on wheelchairs can be observed. Such results would allow to assess the influence of modernization resulting from the application of innovative drive systems in wheelchairs. The article presents research results of wheelchairs with classic drive system with variable pressure in pneumatic wheels.

1. Research object and methodology

The research objects were two wheelchairs with classic manual drive system. The first one had a steel frame, pneumatic rear wheels and non-pneumatic self adjustable front wheels (fig.1). The second wheelchair had a different frame made of aluminum (fig.2). Both wheels were loaded with a weight of 100 kg that reflects real working conditions. The weight of wheelchairs and the attached measurement system is presented in table 1. The tests were carried out on a hard surface.



Fig. 1. Wheelchair with steel frame



Fig. 2. Wheelchair with aluminum frame

Tab. 1. Weight of research objects

Research objects:	Weight:
Weights	100kg
Research equipment	3kg
Steel frame wheelchair	25kg
Aluminium frame wheelchair	27kg

The method and research equipment were in accordance with the description of way of measurement in patent application P.424484 [19] and the developed device for these tests in accordance with the patent application P.424483 [20]. The innovative method allowing to determine the rolling resistance coefficient of objects equipped with a drive system is also described in Warguła's and team scientific article [17]. The measurement of

force of a pulled vehicle under specified measurement conditions allows to determine the rolling resistance coefficient of research vehicles (fig. 3).

2. Research results

The results of force measurement tests using the described research methodology are shown in Figure 4, indicating the characteristics of the force measurement from the start of the movement to the stopping of the tested object. The characteristics of the force values during the constant speed movement are shown in Figure 5. The research results of average value of the force necessary for the object to move at a constant speed with a constant load and variable pressure in pneumatic rear wheels are shown in table 2.



Fig. 3. Research on the rolling resistance coefficient in accordance with P.424484, where: 1 – monitoring-recording device, 2 – force measurement sensor, 3 – research object, 4 - rope tension adjusting system, 5 – drive system

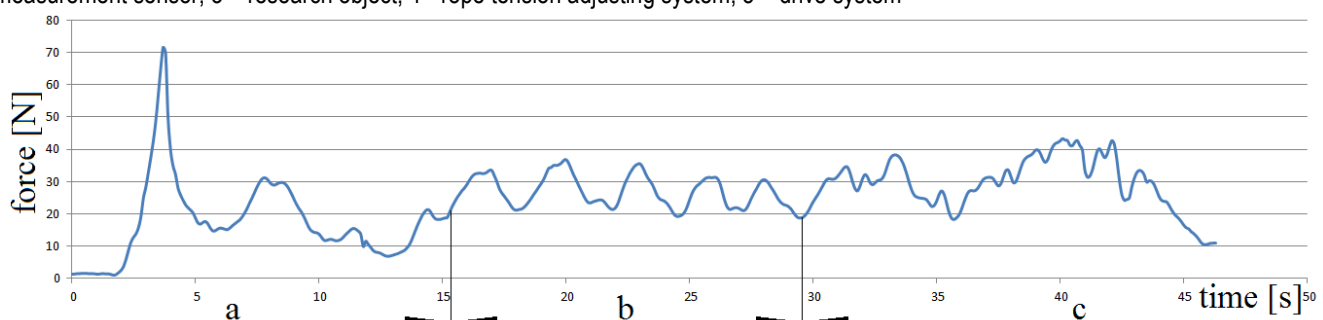


Fig. 4. Characteristics of change of force as a function of time while towing a wheelchair, where: a – acceleration, b – stabilization of movement, c – delay of movement

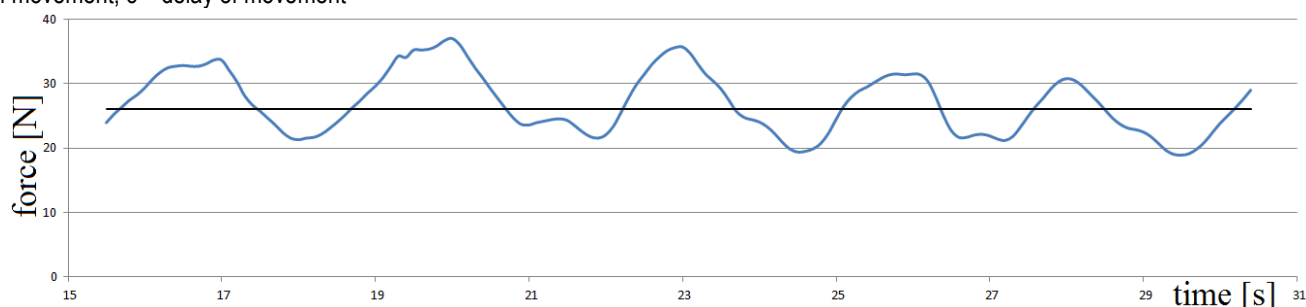


Fig. 5. The characteristics of changes in force as a function of time while towing a wheelchair within a range of stable movement where: blue line - force characteristic as a function of time, black line – average value of rolling resistance force

3. Results analysis

The developer method and research stand allowed to determine the rolling resistance coefficient for the tested wheelchairs on a hard surface of ceramic tiles at variable pressure of rear axle wheels. The determined values are presented in table 3. Wheelchair with steel frame was characterized by lower values of the rolling resistance coefficient than the wheelchair with aluminum frame. The change of wheel pressure from nominal value of 6 bar to 1,5 bar did not influence significantly on the value of the rolling resistance coefficient (about 0,001). Tests were carried out in utmost pressure ranges of pneumatic tires, 6 bar is the maximum pressure declared by producer, whereas 1,5 bar is the minimal tire pressure assumed by the authors allowing the wheel to move without putting the rim at risk of damage

Conclusions

The values of the rolling resistance coefficients are in accordance with the data available in literature on pneumatic tires. It implies that this method can be applied to continue research to determine the value of the rolling resistance coefficient of wheeled systems. Subsequent research will be carried out in order to determine the rolling resistance coefficient resulting from resistances of internal drive mechanisms of wheelchairs equipped with innovative drive systems i.e. lever drive system [21], multishift transmission [22] or hybrid electro-manual driver [18].

References:

1. Dębicki M., Car theory. Drive theory (original title in Polish: Teoria samochodu. Teoria napędu) WNT, Warszawa 1969.
2. Grishkevich A.I., Automobiles, Theory (original title in Russian: Автомобили, Теория,) Издательство Высшей Школа 1986.
3. Merksiz J., Pielecha J., Stojek A., Jasiński R., The influence of terrain topography on vehicle energy intensity and engine operating conditions, Combustion Engines, 162(3) p.341-349, 2015. ISSN 2300-9896
4. Minchejmer A., The theory of a moving car (original title in Polish: Teoria ruchu samochodu) Państwowe Wydawnictwo Naukowe, Warszawa 1960.
5. Mitschke M., Dynamika samochodu. Wydawnictwa Komunikacji i Łączności, Warszawa 1977.
6. Mitschke M., Car Dynamics. T. 1. Drive and braking (original title in Polish: Dynamika Samochodu. T. 1. Napęd i hamowanie) WKŁ, Warszawa 1987.
7. Orzełowski S., Construction of chassis and car bodies (original title in Polish: Budowa podwozi i nadwozi samochodowych), WSiP, Warszawa 1996. ISBN 83-02-08785-8
8. Prochowski L., Car vehicles. Movement mechanics (original title in Polish: Pojazdy samochodowe. Mechanika ruchu), WKŁ, Warszawa 2008. ISBN 978-83-206-1701-6
9. Prochowski L., Unarski J., Wach W., Wicher J., Car vehicles. Basics of reconstruction of road accidents (original title in Polish: Pojazdy samochodowe. Podstawy rekonstrukcji wypadków drogowych) WKŁ, Warszawa 2008. ISBN 978-83-206-1688-0
10. Reimpell J., Sponagel P. Chassis technology: tires and wheels (original title in German: Fahrwerktechnik: Reifen und Räder) Vogel Buchverlag, Würzburg 1988.
11. Sawicki P., Waluś K.J., Warguła Ł., The comparative analysis of the rolling resistance coefficients depending on the type of surface – experimental research. Transport Means 2018 : Proceedings of the 22nd International Scientific Conference, October 03-05, 2018, Trakai, Lithuania. Part 1, p. 434 – 441
12. Silka W., Theory of car motion, part II. Energy consumption of traffic and fuel consumption (original title in Polish: Teoria ruchu samochodu, cz. II. Energochłonność ruchu i zużycia paliwa) WSi, Opole 1994.
13. Silka W. The theory of a moving car (original title in Polish: Teoria ruchu samochodu), Wydawnictwo Naukowo-Techniczne, Warszawa 2002. ISBN 83-204-2748-7
14. Sydor M., Choosing and operating a wheelchair (original title in Polish: Wybór i eksploatacja wózka inwalidzkiego) Wydawnictwo Akademii Rolniczej im. Augusta Cieszkowskiego w Poznaniu, Poznań 2003. ISBN 83-7160-315-0
15. Taryma S., Opór toczenia opon samochodowych. Wydawnictwo Politechniki Gdańskiej, Gdańsk 2007.
16. Taryma S., Woźniak R., Passenger car tyres/road rolling resistance measurements on different surfaces. Archiwum Motory-

Tab. 2. The average value of the force while towing a wheelchair within a range of a stable movement in dependence of the wheel pressure and kind of wheelchair frame

No	Wheelchair with aluminum frame				Wheelchair with steel frame			
	6 bar		1,5 bar		6 bar		1,5 bar	
	F [N]	SD*	F [N]	SD*	F [N]	SD*	F [N]	SD*
1	26,0	3,4	25,7	2,9	21,8	3,8	19,9	3,1
2	29,8	2,8	27,9	2,6	21,2	2,1	20,8	2,3
3	27,2	2,4	26,5	2,7	20,3	2,5	18,6	2,0
4	29,0	2,4	27,0	2,0	20,3	2,9	20,5	2,0
5	28,7	2,2	26,6	1,9	21,5	3,1	20,0	2,6
6	27,9	2,5	25,8	2,5	20,4	2,2	19,5	2,9
7	28,2	3,0	26,5	2,3	20,5	2,8	20,7	2,1
8	28,9	2,4	27,8	2,7	21,6	2,4	20,4	2,2
9	26,3	2,2	25,7	2,5	21,2	3,2	19,6	2,3
10	29,4	2,7	27,5	2,1	20,4	3,3	19,3	2,1
	F [N]	SD**	F [N]	SD**	F [N]	SD**	F [N]	SD**
	28,1	1,22	26,7	0,79	20,9	0,57	19,9	0,66

F – average force,
SD* – standard deviation for the mean,
SD** – standard deviation for a single measurement.

Tab. 3. The value of the rolling resistance coefficients of wheelchairs

The average value of the rolling resistance coefficient determined on the basis of rolling resistance force			
Wheelchair with aluminum frame		Wheelchair with steel frame	
6 bar	1,5 bar	6 bar	1,5 bar
0,022	0,021	0,017	0,016

- zacji 2, p.1-10, 2006
17. Warguła Ł., Wieczorek B., Kukla M., The determination of the rolling resistance coefficient of objects equipped with the wheels and suspension system - results of pilot tests. MATEC Web of Conferences (2019), MMS 2018, (in print)
 18. Warguła Ł., Wieczorek B., Kukla M., patent application number P.427855, Zestaw modyfikacyjny układu napędu do hybrydowego elektryczno-ręcznego do wózka inwalidzkiego (2018.11.21)
 19. Wieczorek B., Warguła Ł., Waluś K.J., Krawiec P., patent application number P.424484, The method of determining the rolling resistance coefficient of objects equipped with the wheels and suspension system. (original title in Polish: Sposób wyznaczania współczynnika oporów toczenia obiektów wyposażonych w układ jezdny) (2018.02.02)
 20. Wieczorek B., Warguła Ł., Waluś K.J., Kukla M., patent application number P.424483, A device for measuring the rolling resistance of objects equipped with the wheels and suspension system. (original title in Polish: Urządzenie do pomiaru siły oporów toczenia obiektów wyposażonych w układ jezdny) (2018.02.02)
 21. Wieczorek B., Zabłocki M., Dźwigniowy system napędowy wózka inwalidzkiego, patent number PL223141B1, date of patent application (07.07.2014)
 22. Wieczorek B., Zabłocki M., Piasta przekładniowa wielobiegowa do ręcznych wózków inwalidzkich. patent number PL223142B1, date of patent application (07.07.2014)
 23. Wierciński J., Reza A., Road accidents. Vademecum of the court expert (original title in Polish: Wypadki drogowe. Vademecum biegłego sądowego. Wydawnictwo Instytutu Ekspertyz Sądowych, Kraków 2002. ISBN 83-87425-65-6

Wyznaczenie współczynnika oporu toczenia wózków inwalidzkich

Osoby poruszające się na wózki inwalidzkich pokonują siły oporów ruchu takie jak: siła oporów powietrza, siła oporów wzniesienia, siła bezwładności oraz siła oporów toczenia. W określonych warunkach użytkowania wózka inwalidzkiego jedynym oporem, który musi pokonać siła napędowa podczas realizacji ruchu jest siła oporów

toczenia. Sytuacja taka występuje podczas ruchu jednostajnie prostoliniowego, na płaskiej poziomej nawierzchni przy prędkości do 20 km/h, ponieważ przy tej prędkości opór powietrza jest pomijalnie mały. Na siłę oporów toczenia główny wpływ ma masa toczącego obiektu oraz współczynnik oporów toczenia układu jezdny. Na wartość współczynnika oporów toczenia może wpływać między innymi nawierzchnia, rodzaj i poziom ciśnienia w oponie, oraz metoda pomiarowa. Istnieją metody badawcze, które w skład oporów toczenia poza oporami wynikającymi z kontaktu opony z nawierzchnią uwzględniają opory połączenia koła z napędzanym obiektem. Jedną z nich jest wykorzystana w badaniach innowacyjna metoda pomiaru współczynnika oporów toczenia obiektów wyposażonych tylko w układ jezdny zgodna ze zgłoszeniem patentowym P.424484 oraz opracowanym urządzeniem do tych badań zgodnym ze zgłoszeniem patentowym P.424483. W artykule przedstawiono wyniki badań oporów toczenia wózków inwalidzkich z klasycznym układem napędowym i mocowaniem koła. Wyniki te pozwalają wykazać różnice w aspekcie siły oporów toczenia klasycznych wózków inwalidzkich z wózkami inwalidzkimi wyposażonymi w innowacyjne rozwiązania napędowe takimi jak np. dźwigniowy system napędowy lub napęd hybrydowy. Badanie zostało sfinansowane ze środków Narodowego Centrum Badań i Rozwoju w ramach programu LIDER VII, projekt badawczy nr. LIDER / 7/0025 / L-7/15 / NCBR / 2016.

Keywords: wózek inwalidzki, współczynnik oporów toczenia, pojazdy niedrogowe, pneumatyczne i nie pneumatyczne koła.

Autorzy:

dr inż. **Łukasz Warguła** – Poznań University of Technology, Faculty of Transport Engineering, Chair of Basic of Machine Design, Piotrowo street 3, 60-965 Poznań, Poland, lukasz.wargula@put.poznan.pl

dr inż. **Bartosz Wieczorek** – Poznań University of Technology, Faculty of Transport Engineering, Chair of Basic of Machine Design, Piotrowo street 3, 60-965 Poznań, Poland, bartosz.wieczorek@put.poznan.pl

dr inż. **Mateusz Kukla** – Poznań University of Technology, Faculty of Transport Engineering, Chair of Basic of Machine Design, Piotrowo street 3, 60-965 Poznań, Poland, Mateusz.kukla@put.poznan.pl