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# The determination of the parameters of wheelchair driving with the use of a test bench

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The article presents the aspects related to the preparation and performance of the bio-mechanics tests on the man-wheelchair system during its manual driving. The testing methodology is discussed in detail, including the test stand structure and the measurement system outline. The selected results of the tests and measurements carried out are presented in this work. They referred to the determination of the course of movement, speed and acceleration of the wheelchair-man system driven manually by means of sequences. In addition, the system mass was determined in a continuous manner during each experiment. Such a set of results, at the final stage of works, was analysed and evaluated in terms of quality.

**Keywords:** biomechanics of movement, manual propulsion, wheelchair, tests and measurements

## Introduction

The object of the tests performed is the analysis of the bio-mechanic changes in the man-wheelchair system during its manual driving. The determination of bio-mechanic parameters for this system is crucial. It is a basis for establishing project requirements and assumptions, during works related to designing the assisting technique transport means and their wheel and steering systems. It is especially important to conduct experiments which will allow for determining the course of a movement value, speed and acceleration during the manual driving of a wheelchair. They affect lots of parameters referring to the motion of this system, such as: the response of wheelchair wheels axes, motion resistance forces or demand on an propulsion torque. The author's specialist test stand for the bio-mechanic testing of driving manual wheelchairs [8] was used. It allows for speed measurement during wheelchair driving. It also enables measurements as a result of which it will be possible in the future to determine the location of the system centre of gravity. It

is quite a significant parameter used in the bio-mechanic description of this type of anthropotechnical systems [1]. The measurement results obtained in the above manner allow, for instance, for evaluating the system stability [2]. The type of tests presented related to driving a wheelchair using ergometers and other technical measures based on a similar operating principle are the objects of research conducted by many scientific teams [3, 5, 6]. The aspects discussed in the article are the continuance of researches conducted [4, 7].

## 1. Testing methodology

The main part of the test stand discussed is a specialist test bench presented in Fig. 1. The test stand consists of a base 1 which is positioned on the ground. Four strain gauge scales 2 are fastened rigidly to the base; internal frame 3 is positioned on them. It has rollers 4 which cooperate with larger wheels of the wheelchair. The wheelchair 5 is immobilised by means of an additional positioning mechanism 6 which also ensures the possibility of setting a specific angle between the seat and the base. The wheelchair has encoders 7 coupled frictionally with the wheels driven.

Discussed test stand enables conducting the testing of the driven man-wheelchair system although it does not move in relation to the ground. It is a basis for the bio-mechanic analysis of the manual driving of a wheelchair.

The measurement system consists of the data acquisition system PMX made by HBM 1, cooperating, through a wireless network 2, with computer PC 3, equipped with dedicated software. Mass is measured by converters Z6FC6 50kg 4, also manufactured by HBM. Rotational speed is measured through the use of incremental encoders 5, series 30 manufactured by Hohner Automaticos S. L. Data acquisition frequency during experiments amounted to 100 Hz. The outline of the measurement system is presented in Fig. 2.

The objective of the tests performed was to determine characteristics enabling the analysis of changes in the bio-mechanics of the man-wheelchair system. For this purpose, a range of experiments was carried out. One male person, aged 30, was the subject of testing. His task was to speed up the wheelchair located in the

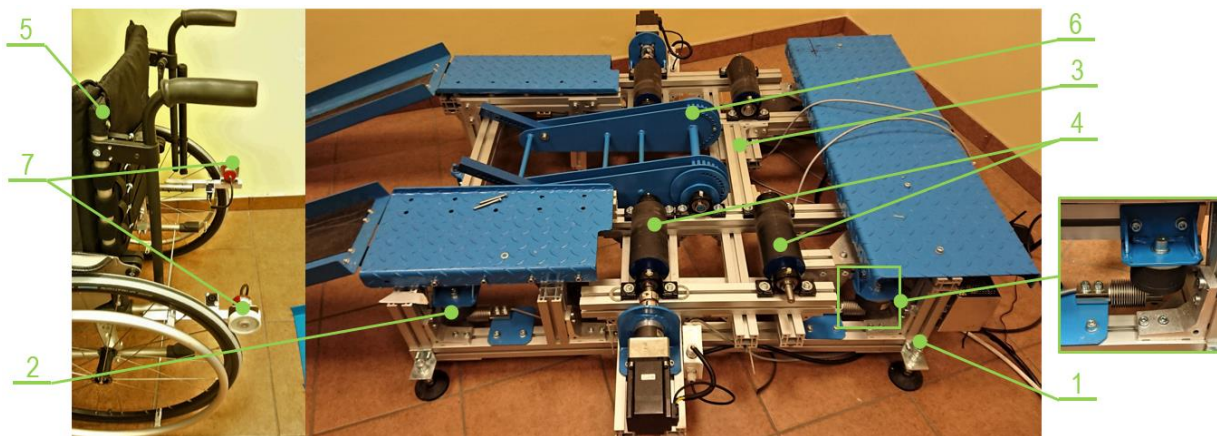
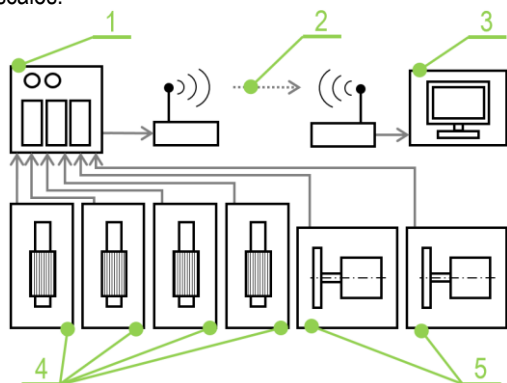


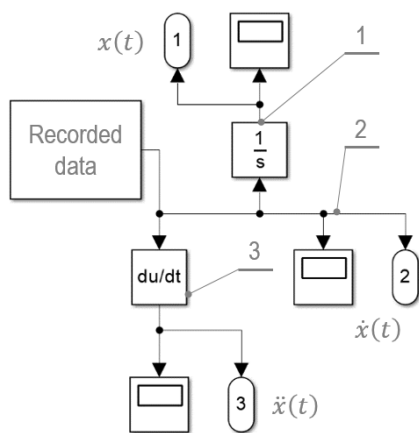
Fig. 1. View of the constructed measuring stand and specially adapted wheelchair; 1 – base, 2 – strain gauge scales, 3 – internal frame, 4 – rollers, 5 – wheelchair, 6 – positioning mechanism, 7 – encoders

test bench to a specific speed and then to maintain this speed. The measurements were repeated for four various speed values. A single experiment involved 10 driving cycles. On this basis, the rotational speed of the wheelchair larger wheel was registered. At the same time, measurement was carried out with the use of strain gauge scales.

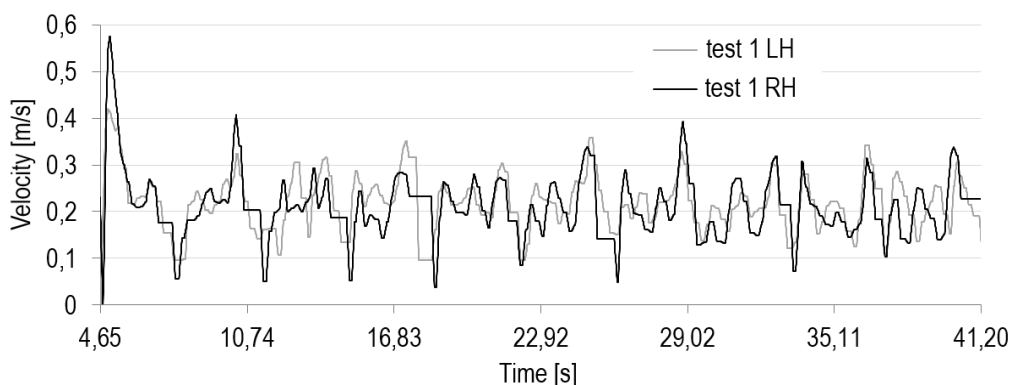


**Fig. 2.** The measurement system outline; 1 – data acquisition system, 2 – wireless communication, 3 – personal computer, 4 – strain gauge scales, 5 – incremental encoders

The data on the diameters of encoders measurement wheels and wheelchair wheels allowed for the determination of linear speed which would correspond to its real motion on the flat surface. Whereas, the data on the wheelchair speed for each moment enabled the numerical determination of acceleration and the distance made. For this purpose, MatLab Simulink environment for numerical computations was used. The outline of the system created there is presented in Fig. 3.



**Fig. 3.** The system outline for the numerical determination of motion parameters; 1 – movement, 2 – speed, 3 – acceleration



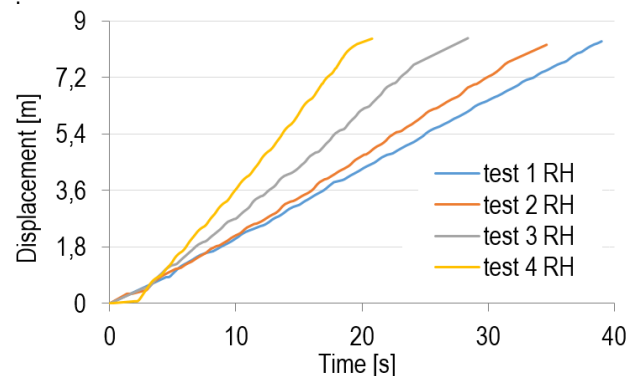
**Figs. 4.** Selected characteristics of the wheelchair linear speed determined for individual wheels

## 2. Test results

Fig. 4 presents the selected characteristics of the wheelchair linear speed determined as a result of the measurements performed. The characteristics obtained for given wheels are presented separately, namely for: the wheel driven with a left hand (LH) and driven with a right hand (RH).

The analysis of the diagram presented allows for noticing the cyclic nature of the courses presented. This is accurate since the manual driving of the wheelchair by means of sequences does not take place on a continuous basis. The initial parts of the characteristic increases of the set speed value mean the commencement of a driving phase. The minimal values of the courses presented, occurring with certain periodicity, are related to a motion phase in which a tested person changed its current limb position into an initial position in order to start another driving phase. The presented speed diagrams are different in terms of maximum values and conformities in a phase. Probably it results from a human factor and is the effect of functional asymmetry. Higher values of one of the courses determined allow for indicating a dominant upper limb. It is also worth noticing that drive transmission is not uniform. Within one driving phase, speed is not changed constantly, what may be explained by the impact of a human factor.

Fig. 5 presents the selected courses of movement in time for various speeds of the wheelchair motion. They were determined according to the previously presented testing methodology. During experiments, the wheelchair would pass in every subsequent trial a different route since the number of driving cycles was the same but their frequency was changed. In consequence, the various speeds of the wheelchair were obtained.



**Fig. 5.** The selected courses of movement in time for various speeds of the wheelchair motion

The diagram analysis allows for stating that the initial and final fragments of the determined courses are characteristic for significant non-linearity. In their central part there are some oscillations. Despite this fact, it is possible to approximate this diagram section

with a straight line with very high accuracy. On this basis it may be stated that despite the previously determined drive transmission non-uniformity, average speed in the determined motion phase is approximately constant.

Fig. 6 presents the selected course of acceleration in time, for one of experiments. Acceleration values depend on the wheelchair speed changes resulting from its driving method. Acceleration increases with the commencement of a driving phase during which mechanical energy is transmitted onto sequences connected rigidly with a larger wheel. An acceleration value decreases after completing the driving phase. It is related to the loss of speed by the wheelchair as a result of resistance forces. Rolling resistance has considerable impact on the behaviour of the system. The determined acceleration sign allows for indicating acceleration and braking phases. The data on the acceleration course are exceptionally important because they allow for indicating, with high accuracy, the quantity and duration of the respective driving phases of the wheelchair.

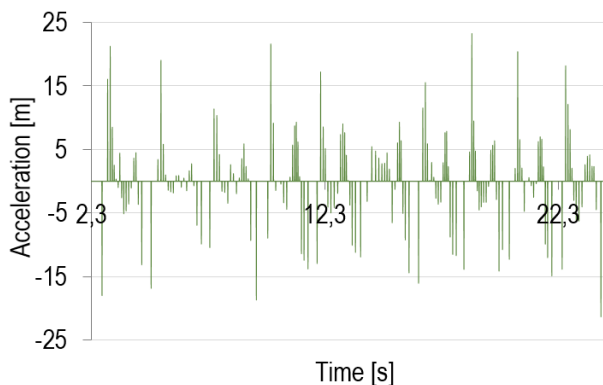


Fig. 6. The selected course of acceleration in time for one of the experiments

The determination of acceleration values is also important because it allows for determining the values of forces acting in the system. For instance, these include the values of the loading of given wheelchair wheel axes. The above data are required for the determination of a demand on torque. This is a particularly important value during works connected with wheelchairs designing and building.

Fig. 7 presents the selected measurement results of strain gauge scales. They concern this pair of sensors which is located on one side (right) of the tested patient – in the front and in the back.

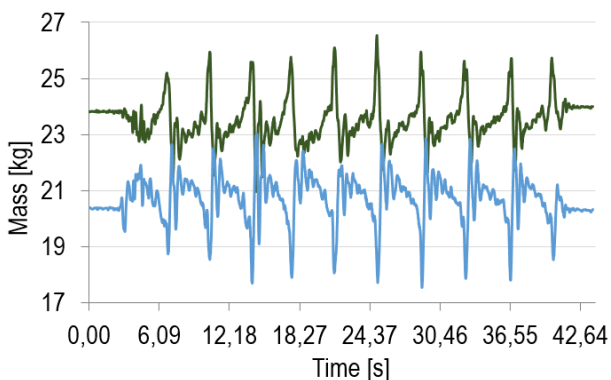


Fig. 7. The selected courses of mass measurements performed on strain gauge scales

The analysis of the courses presented allows for determining their different values. This is caused by the lack of geometric symmetry and mass symmetry of the internal frame in relation to the

mounting of strain gauge scales. The mass measurements oscillations correspond to the oscillations of the previously presented values and their cause is the same.

Fig. 8 presents the course obtained after summing up the measurement results from all the strain gauge scales. It is characteristic for certain cyclicity. The average parameters allow for obtaining one value of the determined course which is  $m_{av} = 86.22$  kg. Standard deviation of arithmetic mean, in this case, is  $\sigma = 0.62$  kg. The highest determined mass value is  $m_{max} = 88.82$  kg, the lowest is  $m_{min} = 82.19$  kg. The determined values were converted according to dependence (1) in order to evaluate the quality of measurements.

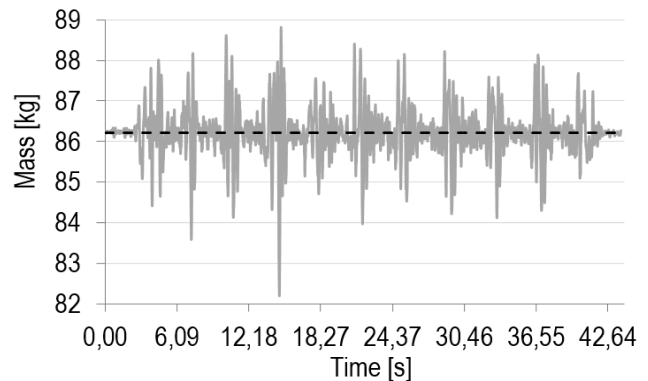


Fig. 8. The selected course of total mass determined based on the measurements performed by means of strain gauge scales

$$\Delta m_{\max/\min} = \left| \frac{m_{av} - m_{\max/\min}}{m_{av}} \right| \cdot 100\% \quad (1)$$

Calculated values  $\Delta m_{\max} = 3.02\%$  and  $\Delta m_{\min} = 4.67\%$ . As the data presented show, the highest deviances of extreme determined values differ insignificantly from the mean value. The value of standard deviation is also negligible. On this basis, it is possible to confirm the good quality of methodology and data collected as a result of data measurements.

### Summary

As part of the works performed, the methodology was devised for determining the parameters of wheelchair driving with the use of a specialist test stand. The measurement system was designed and performed. A lot of experiments and calculations were carried out and on this basis the courses of movement, speed and acceleration in time were obtained. Furthermore, the distribution of the mass of the tested person was also determined for given strain gauge scales. The results obtained will allow in the future for determining a range of parameters related to the bio-mechanics of wheelchair manual driving. These, among others, include: driving moment, wheelchair motion resistance and the centre of gravity. The values specified are particularly important in works related to the designing of wheelchairs and also to ergonomics. At the final stage of works, the data collected and determined were subject to the quality evaluation.

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### Wyznaczanie parametrów napędzania wózka inwalidzkiego z wykorzystaniem hamowni

W artykule przedstawiono zagadnienia związane z opracowaniem i wykonaniem badań biomechaniki układu człowiek-wózek inwalidzki podczas jego ręcznego napędzania. Szczegółowo omówiono metodykę badań z uwzględnieniem konstrukcji stanowiska oraz schematem układu pomiarowego. Przedstawiono również wybrane wyniki przeprowadzonych badań oraz obliczeń. Dotyczyły one wyznaczenia przebiegu przemieszczenia, prędkości oraz przyśpieszenia układu wózek inwalidzki-człowiek napędzanego ręcznie za pomocą ciągów. Dodatkowo wyznaczano również masę układu, w sposób ciągły, podczas trwania każdego eksperymentu. Tak otrzymany zbiór wyników, w końcowym etapie prac, poddano analizie oraz ocenie jakościowej.

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**Słowa kluczowe:** biomechanika ruchu, napęd ręczny, wózek inwalidzki, badania i pomiary

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