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SIMULATION AND LABORATORY STUDIES OF A STAIR-CLIMBING WHEELCHAIR AS AN ELEMENT OF DISABLED PEOPLE-ORIENTED MEANS OF TRANSPORT

Abstract: On the market there are only a few offers of wheelchairs combining their motor function with the function of surmounting physical obstructions and ascending or descending stairs. Their prices are comparable to those of luxury cars. There are also few research papers concerning the dynamics of wheelchairs. Definitely too few considering the social demand for vehicles of this type. The authors of this paper are convinced that it is one of the first papers in the world dealing, in a comprehensive way, with wheelchairs. It presents the design process using CAx techniques together with the prototype construction and verification/validation studies conducted on the prototype.
Keywords: wheelchair, dynamics, simulation, modelling

1. INTRODUCTION

The conditions of the contemporary civilization require a broadly-understood improvement and facilitation of citizens' everyday existence, creating thereby a new quality of life for each individual. At the same time, the present-day dynamic development generates grave dangers to the life and health of man. The advance in motor transport, civilization diseases and wars are just a few of the possible examples. They often lead to death or permanent disability, including the disability affecting human motor function. There is another essential aspect which should be mentioned here as well; namely, the general process of the ageing of societies. What has recently become a social problem is the full participation in life of the elderly, who are no longer involved in the production process, often suffering from dysfunctions of the motor system. The elderly, on the other hand, often isolate themselves from social and professional life because of obstacles that seem insignificant and unnoticeable to the healthy part of the population. These problems inspired us to tackle the issue of the construction of technically advanced, cheap vehicles intended for people with motor system impairment.

One of the most important features of the new design of a wheelchair is its ability to surmount physical obstructions that may appear in the way. The adjective “mechatronic” used in the title of this paper is connected with the fact that the wheelchair will be equipped with integrated steering systems allowing for surmounting obstructions, e.g. a threshold or stairs. The basic requirements for wheelchairs of this type are as follows:

- To enable the wheelchair to move along various kinds of surfaces (e.g. uneven surface, sand, snow, etc.)
- Small size
- To enable the wheelchair to move up and down straight stairs
- To enable to get on (while unassisted) a low-deck bus
- To raise or lower a disabled person in the wheelchair (for instance to reach something from a top shelf in a supermarket or deal with formalities at a post-office if the counter is high)
- Low price

There are only few offers on the market of wheelchairs combining such features and their prices are comparable to those of luxury cars. There are also too few research papers dealing with the dynamics of wheelchairs. Definitely too few considering the high social demand for vehicles of this type. The authors of this paper are convinced that it is one of the first papers in the world dealing, in a comprehensive way, with wheelchairs and presenting the design process (using CAx techniques), the prototype construction and verification/validation studies conducted on the prototype.

2. DESCRIPTION OF THE COPYRIGHT METHOD OF SURMOUNTING OBSTRUCTIONS AND STAIRS BY A WHEELCHAIR

This paper presents the general idea of a copyright method of surmounting physical obstructions and stairs by a wheelchair 6. Owing to the ongoing patent procedures, the chapter is limited to the presentation of most important functional characteristics of the device. Figure 1 presents the general functional model of the wheelchair called WEKTOR. Based on this concept, the main constructional and functional assumptions have been discussed. The wheelchair is capable of moving on both flat surfaces and stairs, steps or curbs. The vehicle’s drive consists of two electric engines (4) which propel its back wheels. The change of direction is possible by differentiating their speed. The wheelchair’s systems are powered by two batteries-12V, 2x12Ah. They are positioned in such a way that the gravity centre is in its optimal position. (3). Under the seat there is a seat raising system (1). It is connected with a system correcting the position of a seat if it leans sideways while surmounting an obstruction. At the back of the wheelchair there is an arm which lifts the vehicle onto the obstruction (8). It is driven by an engine module with a special gear (6) while surmounting an obstruction. Two systems of distance evaluation: front (5) and back (7), are also important as they recognize the distance between the wheelchair and the edge of an obstruction. During the ascent and descent from an obstruction a slide track is also very helpful (2).

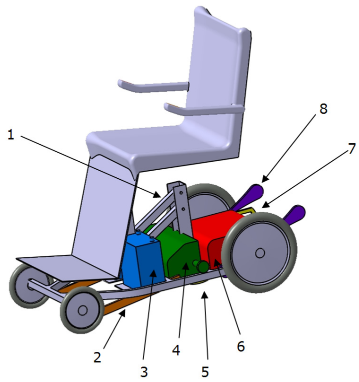

Figure 1. General model of the wheelchair construction concept

The wheelchair has two modes of ride: normal and obstruction. The normal mode is used to move along flat and slightly bumpy surfaces. There are two gears to choose: I and II. In the first gear the wheelchair achieves maximum velocity of 3 km/h and is intended for use in small spaces. Easy steering seems to be of its great advantage. Gear II is used to cover longer distances. It also requires greater precision in operating the steering lever. Additionally, the wheelchair performs the function of raising the seat to a higher position. During this operation the wheelchair's wheels are blocked and no ride is possible. We are planning to install a signal system which would remind the user of this mode of operation if it is on.

The assumptions concerning the exploitation parameters were based on the analysis of the disabled people's needs. During the preliminary stage of the project, the following exploitation parameters were assumed:

• Height of a step	0,05/0,2 m
• Depth of a step	0,27/∞ m
• Battery	12V, 2x12Ah,
• Total battery mass	16kg
• Autonomy (working time)	5 hours
• Maximum load	90kg
• Weight	70kg
• Minimum space necessary for a monoeuvre	1,1*1,1 m
• Speed at gear 1	0,8 m/s
• Speed at gear 2	2 m/s
• Average speed on stairs	0,05 m/s
• Minimum width of stairs	0,8 m
• Maximum gradient of stairs	35°
• Height to which the seat can be raised	0,50 m;

Figure 2 presents the algorithm of surmounting an obstruction which explains the workings of the design concept incorporating the idea of 'a step arm'. The name is derived from the main construction element which fulfills the requirement that a wheelchair should be capable of surmounting obstructions on its own. The presented stages of the ascent (Figure 2) are realized in the same way if more steps are involved, but after stage e) is completed, stage a) recurs over and over until all steps are mounted. The descent from stairs (Figure 2 – on the right) is realized in an identical way as a descent from a single step, with recurring stage g) after stage c).

Mounting an obstruction. In order to surmount an obstruction higher than 5 cm, it is necessary to climb it with the back of the vehicle. Approaching an obstruction like stairs or a curb backwards, the user of a wheelchair should change the mode of ride to ‘obstruction’. The velocity of main engines will be reduced and the systems of distance evaluation will start working (Figure 2, stage a). The steering system will approach the wheelchair to the edge of the obstruction at an appropriate distance and position it perpendicularly. Then stage b) will begin. The main engines will be shut off and the wheels blocked. The drive of the step arm will start functioning. During the stages c) and d), the steering system will keep the seat in a horizontal position. Stage e) begins after the step arm has rotated by 180º. Then the main engines start working and, at reduced speed, will mount the wheelchair onto the obstruction. The active distance evaluation systems will monitor if there is another step to be mounted. If so, the cycle beginning with stage a) will restart. If it is the last step, the wheelchair will continue moving backwards at reduced speed. During stage f), the edge of an obstruction slides along a slide track and then the front wheels climb onto the obstruction. In the final stage g) the user changes the mode of ride to ‘normal’.

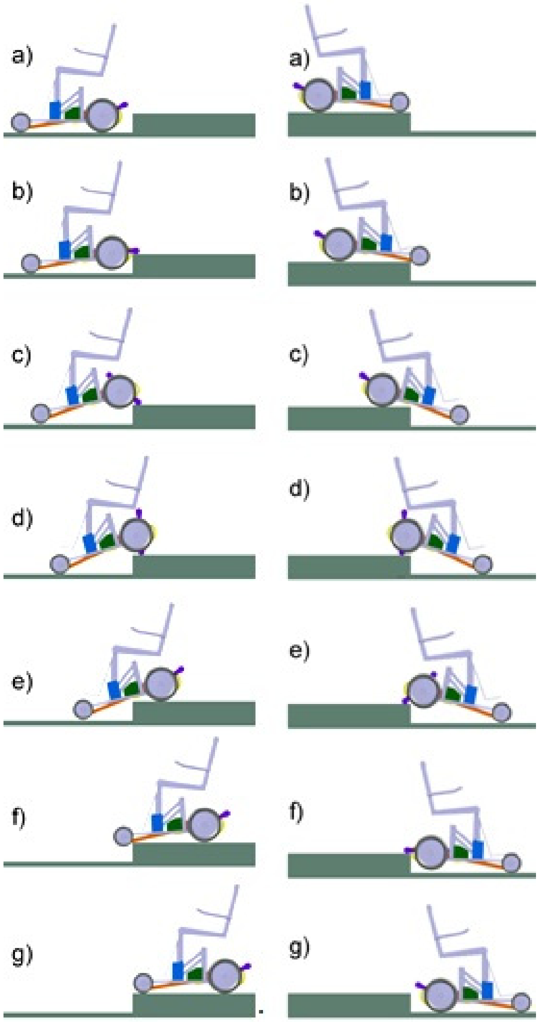

Figure 2. A sequence illustrating the algorithm of an ascend and descend from an obstruction

Descending an obstruction. To prepare the wheelchair for a descent from various kinds of obstructions it is necessary to position the front of the wheelchair as perpendicularly to the edge of the obstruction as possible. In order to surmount steps higher than 5 cm, the ‘obstruction’ mode is used. The user decides whether to switch it on or not. The moment the ‘obstruction’ mode is on (Figure 2 stage a), the main engines reduce their speed and distance evaluation systems, which are located between the front and back axles of the wheelchair, start working. The steering system will correct the direction of motion by observing the position of the wheelchair’s slides on the edge (stage b). During the descent the distance evaluation system will stop the engines at the right time (stage c). Then stage d) will begin. The wheels will be blocked and the arm’s drive will start operating. Continuing through stages e) and f), the steering system will keep the seat in a horizontal position. Stage g) will begin after the 180° rotation of the arm has been performed. Then the main engines will start and, at reduced speed, will take the wheelchair off an obstruction. At the same time distance evaluation systems will decide if there is another step ahead or not. If so, the cycle will start again beginning with stage d). If it is the last step of an obstruction the wheelchair will continue moving forward at reduced speed. When stage g) is completed, the user changes the mode of ride to ‘normal’.

3. SIMULATION STUDIES

In the era of intense computerization, before an actual model (prototype) is constructed, there are more and more computer simulations carried out. These simulations allow – even at an early stage of design – to discover possible faults, solve various construction problems, which, not long ago, necessitated high financial means, and involved many people and much time to build a real model and, additionally, a research centre. In this paper a virtual model has been analysed. The research was conducted by combining the construction of a CAD model with an MBS system. Since certain simplifications have been assumed, the model of the human body has been reduced to one solid with the mass and inertial parameters of a human body 2. To simplify this process Catia programme has been used.

Based on the data available in literature 1, 3, 4, 5, a multi-body system has been generated representing a seated man. Then the mass, the gravity centre and moments of inertia of this system have been obtained. A detailed description of the simulation model man-wheelchair-stairs has been presented in the paper 6. Figure 3 presents a view of a simulation model.

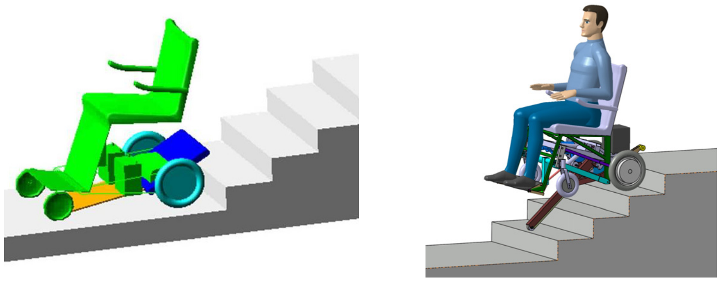

Figure 3. Simulation model of a wheelchair in ADAMS system and Catia v5

The above model has undergone simulation studies. Below there is a diagram presenting the changeability of forces in contact areas while a wheelchair climbs four steps (Figures 4). It can be assumed that it is the recurring multiple algorithm illustrated in Figure 2.

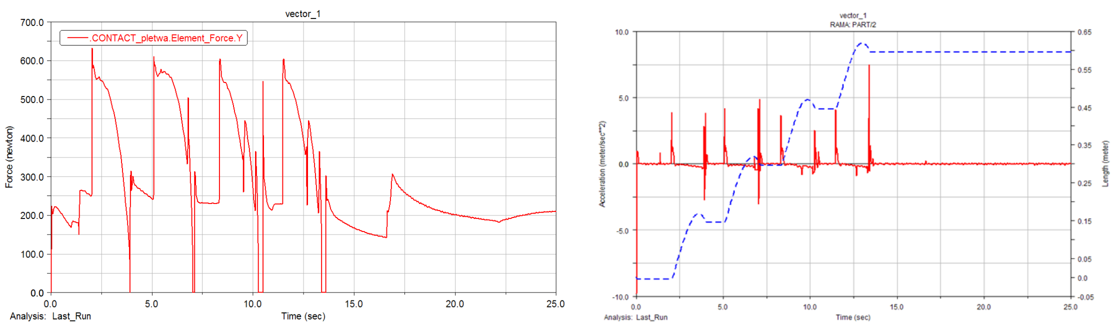

Figure 4. Resultant forces occurring during the contact of an arm with the surface and process of acceleration changes, affecting a user of the wheelchair vertically

Figure 4 presents the process of acceleration changes which affect the user of the wheelchair. The results allow to assess the kind and the parameters of damping elements between the seat and the wheelchair's frame which were used in the model.

4. LABORATORY STUDIES

During laboratory studies we attempted to calculate the co-efficient determining the energy of vibration which affects the user of the wheelchair. Two designs have been used in trials:

- EXPLORER – a caterpillar wheelchair made by TGR - Italy
- WEKTOR – a laboratory prototype developed by the Department of the Theory of Transport Means Construction, Faculty of Transport, Warsaw University of Technology.

Figure 5 presents the wheelchair ‘Explorer’, which enables a disabled person to move on flat surfaces by means of three wheels. This wheelchair has been purchased by Faculty of Transport and thoroughly researched in the Laboratory of Experimental and Simulation Studies in the Man – Means of Transport – Environment system. The results of these studies will be presented in the subsequent part of this paper.

This vehicle has two drive systems. If it moves along an even surface, it uses three wheels, where two back ones are powered and the front one is responsible for choosing the desired direction. On the stairs, however, it moves by means of caterpillars, each with its independent drive, which allows for mounting any type of stairs.

Since we will refer to this design later in the paper, its most important operational features must be presented. The wheelchair can be used by a person who has the psychomotor capability of using vehicles by him/herself, independently of others. It has two ride modes: on the wheels and on the caterpillars. It is designed and constructed as a device ensuring the possibility of ascending and descending stairs freely and of moving along flat surfaces. It is suggested the vehicle is used in low moisture air and temperature between -10^{o}C and +40 ^{o}C.

In order to register vibrations three-axel accelerometers were used which were connected with a registration system. A three-axel sensor was placed in the middle of the seat, in a place assumed to be the location of the resultant seat reaction on the passenger. The position of the accelerometer and the directions of forces are illustrated in Figure 5.

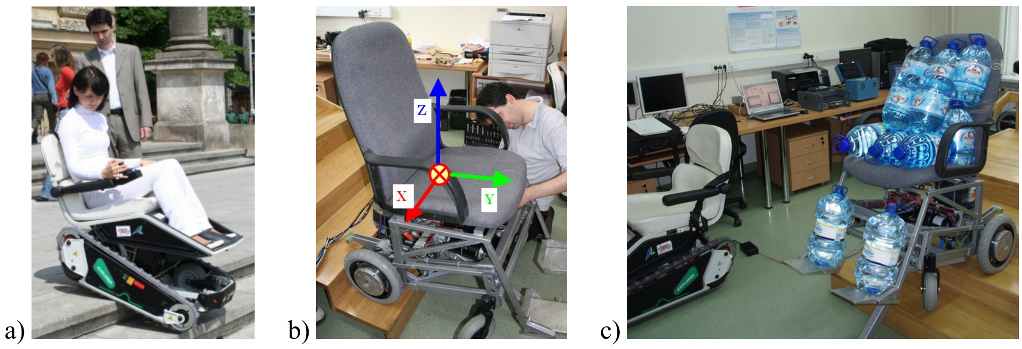

Figure 5. a) wheelchair EXPLORER with the wheel and caterpillar system, b) the Wheelchair WEKTOR, position and directions of a three-axel acceleration sensor, c) model of weights on wheelchairs

Taking into account the character of motion, further analysis used signals registered from directions **Y** and **Z**, where the highest values of vibration energy appear. After the sensor had been placed in the described place, the wheelchairs were weighted with 76kg mass. The position of weights allowed (a close approximation) to replace a model of man.

For each of the wheelchairs the stages of ascent and descent were registered separately. The studied wheelchairs have different methods of climbing stairs and the time in which they accomplish this task depends on various factors. For the needs of this paper, the research was based on the assumption that the task itself (accomplishing the climb of four steps) is most important, as illustrated in the figures above.

The measured signal was registered from the moment the wheelchairs switched to the 'climb' mode until they reached the landing and switched to the 'normal' mode, which is used for moving along flat surfaces.

Figure 6 below presents time processes of wheelchair vibration during the stair climb. The wheelchair EXPLORER required 42 seconds and the wheelchair WEKTOR – 54 seconds to accomplish this task. The lower value of seat vibration energy for WEKTOR is apparent from just a rough estimate of the graphs.

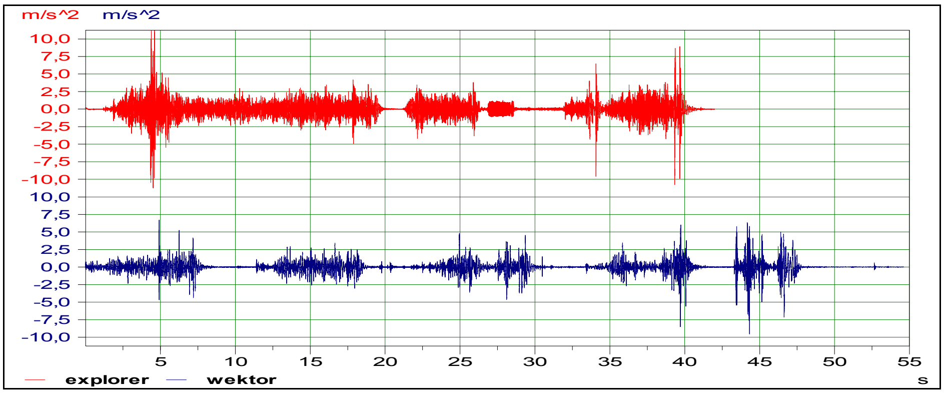

Figure 6. Time processes of vibration for wheelchairs during a stair climb

In order to compare better the results of many trails, an algorithm has been developed setting a parameter (1) determining the numerical value of vibration energy (**P**$_{stage}$). The signal (**Y**$_{(t)}$, **Z**$_{(t)}$) has been squared and integrated. Then it was divided by the value of signal duration time (**T**).

$$P_{stage} = \frac{1}{T}\int_0^T \left(Y_{(t)}^{\ 2} + Z_{(t)}^{\ 2}\right) dt \qquad (1)$$

A block graph in Figure 7 below illustrates P_{stage} values.

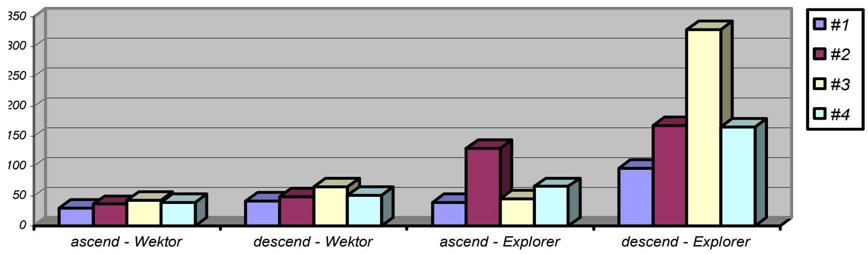

Figure 7. Parameters of vibration energy

5. CONCLUSIONS

The presented results of laboratory studies point to the fact that the original assumptions are correct as far as the method of climbing stairs by the wheelchair WEKTOR is concerned. This copyright method produces better effects than the well-known and commercially available version: EXPLORER. The article documents the process of design using CAx techniques, prototype construction and verification/validation studies conducted on the prototype.

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BADANIA SYMULACYJNE I EKSPERYMENTALNE WÓZKA INWALIDZKIEGO Z OPCJĄ JAZDY PO SCHODACH JAKO ELEMENTU SYSTEMU TRANSPORTU OSÓB NIEPEŁNOSPRAWNYCH

Streszczenie: Wózków inwalidzkich łączących cechy użytkowe z funkcją pokonywania przeszkód i poruszania się po schodach jest na świecie tylko kilka ofert rynkowych a ich cena zbliżona jest do ceny luksusowego samochodu osobowego. Prac naukowych dotyczących zagadnień dynamiki wózków inwalidzkich jest bardzo mało. Niewspółmiernie mało, w stosunku do zapotrzebowania społecznego na tego typu pojazdy. Zdaniem autorów praca jest jedną z pierwszych tego typu prac na świecie pokazujących w sposób kompleksowy badania wózków inwalidzkich. Zaprezentowano proces projektowania z wykorzystaniem technik CAx, budowy prototypu oraz badań weryfikacyjnych i walidacyjnych na prototypie.

Słowa kluczowe: wózek inwalidzki, dynamika, symulacja, modelowanie