A SIMULATION STUDY OF THE NEW CONCEPT OF A STAIR-CLIMBING WHEELCHAIR

Concept of Construction

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Abstract: The authors present an idea of construction, modelling and simulation studies of a new generation, mechatronical wheelchair. The wheelchair is meant to drive on various surfaces. Its important feature is the possibility to overcome obstacles, such as a doorstep of max. 220 mm. The construction model and simulation studies were carried out in the environment of MBS ADAMS package. An algorithm of controlling the process of overcoming the doorstep was proposed and an analysis of parametrical sensitivity of the construction was performed.

1 INTRODUCTION

Modern transport systems should be created with appropriate observance of the needs of the disabled. At the design stage, special attention should be paid to the needs of people with mobility problems. For these people, important elements of the transport system include: architectural features, specially adapted public means of communication, and individual means of transport (Axelson, 1995), (Blachowski, 1993). A wheelchair with special transport features is an important element in the whole system. The development of the motor industry led to a dramatic increase of accidents, which in turn increased the number of people suffering from permanent disability or impairment of their movement capabilities. The feedback received from the disabled clearly suggests that there are still many barriers that make it difficult for these people to function individually in society. Irrespective of the laws in force, the number of buildings that are not adapted for the disabled is large. And the adaptation process is long and expensive. What could help the disabled to overcome architectural obstacles is a new wheelchair with special functions, such as moving up and down the stairs or lifting the disabled person to such a height that is achievable by a healthy individual.

This paper presents assumptions and preliminary simulation tests of a new concept of a wheelchair for people with motion disabilities. The goal of the simulation model is first of all to optimize the wheelchair's parameters in order to achieve the most desirable safety and ergonomic conditions. The main advantage of the wheelchair will be its ability to overcome terrain obstacles, such as thresholds, stairs or curbs, or lifting the user to heights that are achievable by healthy people. The wheelchair will be able to drive into a low-deck bus or tram on its own. Furthermore, its construction will be simple and spatially limited.

2 THE CONCEPT OF A STAIR-CLIMBING WHEELCHAIR

The concept is presented in the form of a 3D picture (Fig. 1). The wheelchair can move over flat surfaces, as well as thresholds, stairs and curbs. The drive system of the wheelchair consists of two electric motors (4). The vehicle changes its direction by means of differentiating the speed between the two motors. The wheelchair systems are powered by two service-free gel batteries, 12 V, 2 x 40 Ah. The batteries are located relatively low to achieve the most advantageous location of the centre of gravity. Beneath the seat, there is a seat lifting mechanism (1). The seat lifting mechanism is connected with the system to correct the inclination of the seat while driving through an obstacle. The rear part of the wheelchair features an arm that can lift the

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wheelchair over an obstacle (8). It is driven by a motor module with a gear (6). Distance measuring systems play an important role when the wheelchair is moving over an obstacle. There are two such systems: a front one (5) and a rear one (7). The slide skid (2) also proves useful in negotiating obstacles.

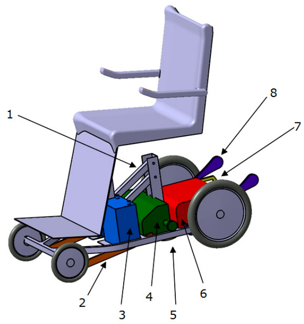

Figure 1: Wheelchair contraction model – own concept.

The wheelchair features two drive modes: "normal" and "obstacle". The normal mode is used to drive on flat or slightly uneven surfaces. The user has two gears to choose from: I and II. The first gear (I) allows the wheelchair to drive with the maximum speed of 3 km/h. It is meant to be used in small compartments or rooms. One of the benefits of using the first gear is that it makes steering the wheelchair much easier. Gear II is to be used for greater distances. It also requires a greater precision in handing the steering lever.

The wheelchair also features a lift function. It lifts the seat to a higher level, which is important for disabled people.When the lift function is activated, the wheels of the wheelchair are blocked and driving is not possible. An audible signal will be introduced to remind the user that the lift function has been activated.

3 OPERATIONAL PARAMETERS AND ALGORITHM FOR OVERCOMING OBSTACLES

The following operational parameters were assumed for the initial phase of the project:

- Threshold height (max) 0.22 m
- Threshold depth (min) 0.25 m
- Battery 12V, 2 x 40 Ah,
- Battery weight 24 kg
- Autonomy (working time) 5 hours
- Load bearing capacity 100 kg
- Weight 80 kg
- Min. space required for manoeuvring 1.1x1.1m
- Gear I speed 1 m/s
- Gear II speed 2 m/s
- Mean speed while overcoming stairs 0.1 m/s
- Minimum width of staircase 0.8 m
- Maximum surface inclination 35°
- Seat lift height 0.45 m

The above-mentioned values result from an analysis of specific features of the wheelchairs currently available on the market. These values are subject to minor modifications (Kowara, 2005), (Milanowska, 1997).

The algorithm used to overcome obstacles that is presented here explains the principles of operation of the construction described in the above paragraph. The ascending phases (Fig. 2.) will be carried out in the same manner if the wheelchair has several stairs to overcome: when Phase e) is completed, the system will carry on to Phase a) again. It will operate through all the phases in a closed loop until all stairs have been overcome. Descending the stairs (Fig. 2) will look exactly the same as descending a singular threshold. It will be carried out in a closed loop: when Phase g) is completed, the system will start from Phase c) again.

Ascending an Obstacle. To overcome an obstacle higher than 5 cm, the obstacle should be approached backwards, i.e. with the back of the wheelchair. When the user approaches an obstacle, such as a curb or stairs, he or she switches the driving mode to "obstacle". The speed of the main motors is reduced and the systems detecting distances are activated (Fig. 2, Phase a). The steering system brings the wheelchair to the appropriate distance from the edge of the obstacle and positions the wheelchair perpendicularly to it. Then, Phase b) starts. Main drive motors are de-activated and the drive wheels are blocked. The lift arm starts operating. Moving to subsequent Phases c) and d), the steering system controls the seat and keeps it horizontally. Phase e) starts when the lift arm makes a 180°- turn. The main drive motors are activated again and, at a reduced speed, bring the wheelchair onto the obstacle. The distance measuring systems keep checking if there is another obstacle for the wheelchair to overcome (such as another stair). In case there is another stair, the whole cycle starts form Phase a). When the last stair has been overcome, the wheelchair moves backwards at a reduced speed. During Phase f), the edge of the obstacle moves over the slide skid and the front wheels are mounted onto the obstacle. At the end of Phase g), the user switches the driving mode back to "normal".

Descending an Obstacle. Preparing to descend an obstacle, the wheelchair should be driven up to the obstacle with the wheelchair front positioned perpendicularly to the edge of the obstacle. The "obstacle" mode should be used when the height of the obstacle (stair or threshold) is higher than 5 cm. It is the user who decides to switch to this mode of driving.

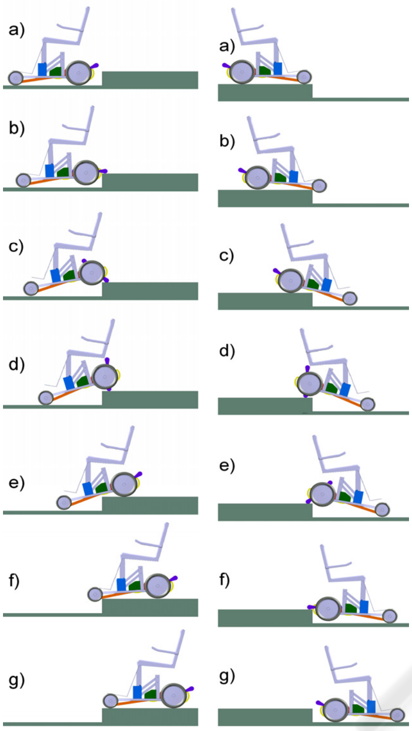

Figure 2: Ascending and descending an obstacle– algorithms of operation.

When the "obstacle" mode is activated (Phase a), the speed of the main drive motors are reduced and the distance measuring systems, located between the front and the rear axes of the wheelchair, start to operate. Watching the position of the wheelchair skids, the steering system corrects the direction of the wheelchair movement (Phase b). Continuing the descending movement, the distance measuring system stops the main drive motors at an appropriate moment (Phase c). Then, Phase d) begins. The drive wheels are blocked. The lift arm starts to operate. Moving to subsequent Phases e) and f), the steering system controls the seat and keeps it horizontally. Phase g) starts when the lift arm makes a 180°- turn. The main drive motors are activated again and, at a reduced speed, bring the wheelchair down the obstacle. The distance measuring systems keep checking if there is another obstacle for the wheelchair to overcome (another stair). In case there is another stair, the whole cycle starts form Phase d). When the last stair has been overcome, the wheelchair moves on at a reduced speed. At the end of Phase g), the user switches the driving mode back to "normal".

4 ASSUMPTIONS FOR BUILDING A SIMULATION MODEL

There is a huge variety of wheelchairs available on the market. Designers strive to achieve the most functional prototype, maintaining the most crucial features, such as low weight, simple and comfortable operation, and first of all: low price. The last aspect is very important in making the wheelchair available to a wide spectrum of the disabled who, very frequently, do not belong to the wealthiest groups of the society. To meet all these requirements, one must look for new methods of wheelchair designing and modelling. The literature available suggests that most research carried out in this field concentrates on determination the strength and resistance of the wheelchair construction, so that relevant safety standards and technical requirements are complied with. The majority of solutions focus on improving the form of additional equipment to be installed in the wheelchairs to overcome surface obstacles. They are developed without the use of computer simulation or dynamic tests.

The overview of the literature on wheelchairs able to overcome such obstacles as stairs or thresholds (Zabłocki, 2002), as well as simulation studies of simple constructions carried out in 2D-Working Model environment, shows the capabilities and limitations of this kind of vehicles. Due to the fact that one of the priorities of the model this study refers to is a simple and compact construction with due observance of the other requirements, an analysis of various systems used for overcoming obstacles of the threshold type led to the development of the structural concept presented in Chapter 3. An initial analysis of the systems lets the authors believe that the construction secures safe overcoming of obstacles and at the same time is simple and compact. For the purpose of the simulation tests, certain simplifications were made:

- The human model is represented by a number of permanently fixed solids with certain weight parameters.
- The human model is fixed to the seat.
- The surface on which the wheelchair moves is flat and horizontal.
- There is no friction between the front wheels and the front frame on the one hand, and the ground surface and the obstacle edges on the other hand.

- Ascending an obstacle, the wheelchair is positioned backwards to it.

The position of a human body's centre of gravity in the sitting position is an important variable in a simulation model of the construction. A real human body, as well as its individual elements, is a complex system with a continuous distribution of mechanical properties. Therefore, human body modelling as such is a vast area of science and the subject of a number of research projects. In this project, the approximate mass parameters of a human body model were chosen on the basis of data used in the research on car seats, and the model developed with the use of statistical data (Seireg & Arvikar, 1989), applied to analyze and simulate human walking. Using the above mentioned data, together with the recommendations made in PN ISO 7176-11 Standard, "Test dummies", the authors developed a body model of an average man of 78.5 kg in the sitting position. Catia system was used for this purpose.
Geometrical parameters of the wheelchair under this project were based on the measurements of an Explorer wheelchair carried out by the authors, as well as data found in the literature available.
When the wheelchair is in operation, certain parameters may change. It can be assumed that this has an impact on the performance of the wheelchair-user configuration while the wheelchair is in motion. To verify such a hypothesis, these variables need to be identified and their impact on the configuration performance needs to be assessed. Due to a vast number of various factors having an impact on the performance of the wheelchair-user configuration, only certain parameters were selected for further tests (i.e. those parameters that can significantly influence the performance of the vehicle while overcoming an obstacle):

- Friction between the wheels and the surface
- Obstacle height
- Distance of the user's centre of mass from the back support
- Obstacle approach angle.

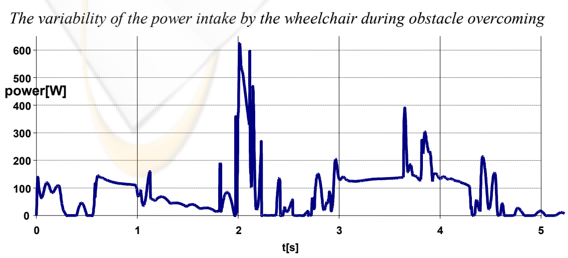

Figure 3: The variability of the power intake by the wheelchair during obstacle overcoming.

The scope of variability of individual parameters will be determined during simulation tests.
Examples of simulation results are presented below. The variability of power consumption while overcoming a 220 mm obstacle was determined.

5 CONCLUSIONS

The paper presented a constructional concept and simulative studies of a new generation wheelchair for motional disabled persons. Taking in consideration the wide range of studies and analyses the new construction is submitted to before it can be introduced into production, it should be acknowledged that this paper could be very helpful when creating the real wheelchair construction.
The most important elements of that study include:

- A study of the advanced schema of wheelchair construction,
- a study of the nominal model of the construction above,
- a proposal of the control algorithm when coming across a barrier,
- a construction of the simulative model in the Adams program.

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