Production of Assistance Brake for Mechanical Wheelchair

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The paper deals with the proposal for the production of an assistance brake for a mechanical wheelchair, which will help the wheelchair users to move in the course of overcoming barrier-free and partially barrier obstacles. The introductory part of the contribution characterizes the basic requirements of the brake for a mechanical wheelchair, especially from a legal point of view and in terms of their safety. The practical part of the paper deals with the production of a prototype pair of assistance brakes in school conditions (workshop C2 of the Institute of Mechanical Engineering, Faculty of Mechanical Engineering, Brno University of Technology) using conventional machining technology (brake body production) and 3D printing technology (braking segment production). Part of the practical part also requires testing in typical / real wheelchair conditions. The contribution is completed by the technical and economic evaluation of the prototype pair of assistance brakes, which is related to the calculation of the total cost of their production.

Keywords: Emergency Brake, Mechanical Wheelchair, Braking segment, Wheelchair Access, Wheelchairs

1 Introduction

Currently, there is a large variety of accessories for wheelchairs that allow more efficient movement in common, that is partially or completely barrier environment. Barrier-free access is still not taken today as a matter of course, and not all, although wheelchair-adapted spaces, are quite appropriate. The wheelchair is not always able to overcome the pitfalls or obstacles in the environment. These may include oblique planes, small stairs and stairways [1].

The assistance brake principle for a mechanical wheelchair is to help overcome the above-mentioned obstacles. The assistance brake enables the wheelchair to move in one direction and is designed to prevent the wheels from moving in the opposite direction by means of a braking segment that is in constant contact with the wheels and its shape. Changing the movement causes the brake segment to jam and the wheelchair to stop. During the initial direction of travel, the wheel brake is released and the wheelchair is able to continue driving. The assisted brake prototype was tested according to the design under real conditions that wheelchair users normally encounter [1-3].

2 Production proposal of assistance brake

The basic problem of every wheelchair is, above all, its mobility. The design of the brake assist is designed to facilitate day-to-day motion in normal conditions. The design was developed according to wheelchair needs [1-3].

The following knowledge and criteria are based on the "EN 12182" standard. The basic requirements for the mechanical wheelchair brakes are reliability and functionality in terms of safety. An important parameter must be the location of the brake so as not to injure or catch a piece of clothing. It is also important that the brake is protected against possible damage during use and also fall. Safety features also include mudguards that prevent objects from being caught, such as fluttering clothing, etc. Another feature is edge sharpness that is not exactly specified by the standard, but needs to be addressed in terms of functionality. Rounded edges are preferred for more comfortable handling [1-3].

Other aspects of routine use of the assistance brake are that it must not interfere with the folding of the wheelchair during transport, eg. in the car. It must also not obstruct the backpack or bag which is the standard equipment for wheelchairs for the storage of personal belongings [1-3].

The use of the assist mechanical brake is to help overcome the obstacles the wheelchair needs to deal with every day. Although barrier-free modifications, according to Decree "No. 398/2009 Coll. About General Technical Requirements for Barrier-Free Use of Buildings ", are today in almost all places where it is possible, it is not always easy to overcome these obstacles due to high demands, non-compliance, etc. For these reasons, a prototype of the assistance brake consists of two main parts, which are shown in Fig. 1 and Fig. 2 [1-6].

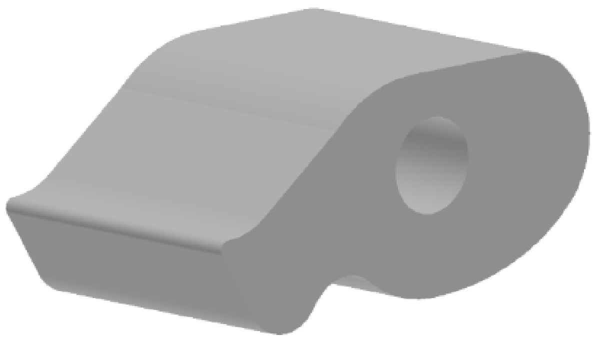

Fig. 1 *Design of the brake segment [1]*

The braking segment is in constant contact with the rotating wheel and its shape, when changing the direction of travel, ensures complete disengagement of the wheelchair. Re-launching the truck in the original direction will release the braking segment and continue driving. The design of the braking segment is shown Fig. 1 [1-6].

For production of the brake segment, production using a professional 3D printer Dimension uPrint using the Fused Deposition Modelling method was chosen. This 3D printer is designed to quickly produce precise and solid models by direct printing of a 3D digital computer CAD model [1, 7].

Due to the material used varies adhesion and friction coefficient. Due to the low friction coefficient, a slip may occur between the braking segment and the tire, which may result in a fall and consequent injury to the wheelchair. The basic materials for the assistance brake were selected [1, 7, 8]:

- ABS*plus* plastic - production of the brake segment (3D printing technology - Fused Deposition Modelling). This material was chosen for availability, strength and low weight,
- steel 12 050 - Assist brake body (conventional machining technology - milling, turning and drilling technology). This material was chosen mainly because of its availability in the school workshop of the Faculty of Mechanical Engineering of the Faculty of Mechanical Engineering of the Brno University of Technology,
- rubber band.

The coefficients of dynamic friction f_d between the assistance brake materials and the tires were recorded into Tab. 1 [1, 7, 8].

Tab. 1 *Dynamic friction coefficient f_d [1, 7, 8]*

Material	Steel	Rubber	ABS plast
Tire (rubber)	0.25	0.90	0.35

Depending on the dynamic coefficient of friction (it must be as high as possible), it is obvious that the most suitable material for wheel braking is rubber. Another possibility is to modify the surface of the applied material, for example by rubbing or sticking the rubber band onto the braking segment, which can be made of commonly available materials [1, 8].

Due to the high coefficient of dynamic friction f_d between materials such as tire and rubber, a lower thrust force will be sufficient. The positioning of the brake may be such that the braking segment is in contact with the tire without any greater thrust [1, 8].

To ensure the maximum dynamic coefficient of friction f_d, a suitable combination of contact materials must be chosen to suppress the development of a high force to overcome the tire pressure between the tire and the braking segment. For practical testing of functionality and finding a suitable combination of articulating materials, the braking segments were provided with a rubber band, which was adhered to the surface to maximize efficiency [1, 8].

To connect the braking segment and the chassis frame, it was necessary to produce the assistance brake body. Important aspects of the body of the brake are: size, weight, positioning and also location due to hand injuries during wheelchair control. To place the brake body, the back of the support frame was selected, where the brake would not interfere with the normal use of the wheelchair. The assistance brake body is shown in Fig. 2 [1-6].

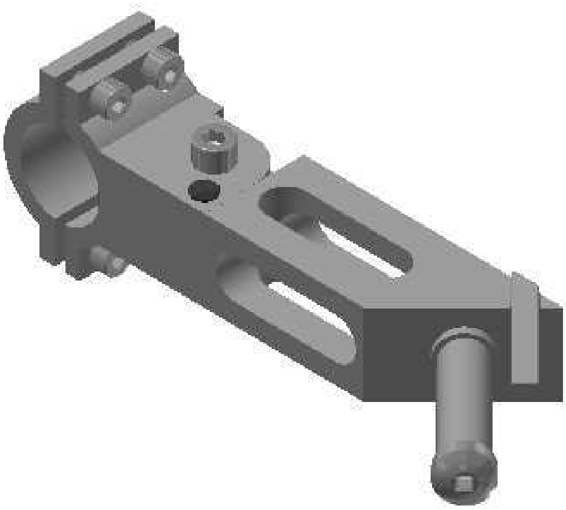

Fig. 2 *Design of the assistance brake body [1]*

For the production of the assistance brake body, conventional machines (milling machine, lathe, drilling machine) were chosen as part of the machine workshop of the school workshop of Institute of Mechanical Engineering, Faculty of Mechanical Engineering, Brno University of Technology. The final adjustment of the body of the assistant brake together with the assembly was solved at the manual workplace [1, 9-11].

2.1 Calculation of minimum forces for wheelchair handling

The calculation of the minimum force required for the ramp exit, see Fig. 3, is derived from II. Impuls theorem, which is based on the second Newton's law of accelerating bodies. The second impulse theorem solves the rotational movement of the body and is derived from the momentum of the accelerating body. If the body is moving from standstill, then the moment impulse is equal to the momentum of the momentum from the zero initial velocity [1, 8, 12].

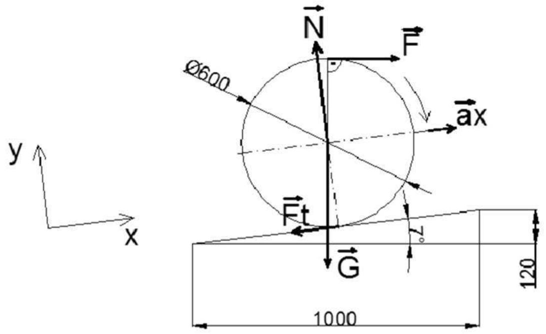

Fig. 3 *Driving the wheelchair on an inclined plane [1, 8, 12]*

II. Impuls theorem [1, 8, 12]:

$$\sum M = l \cdot \varepsilon = l \cdot \left(-\frac{a \cdot x}{R} \right) \quad (1)$$

Where:
M [N.m]– driving torque,
I [kg.m^2]– moment of inertia,
ε [rad.s^{-2}]– angular acceleration of the body,
a_x [m.s^{-2}]– acceleration,
R [mm]– wheel radius.

The resultant of the forces compiled according to Fig. 3 [1, 8, 12]:

$$x: -F_t + F - G \cdot \sin\alpha = m \cdot a_x \quad (2)$$

$$y: N - G \cdot \cos\alpha = m \cdot g = 0 \Rightarrow N = m \cdot g \cdot \cos\alpha \quad (3)$$

Where:
F_t [N]– friction force,
N [N]– normal force,
m [kg]– total wheelchair weight + wheelchair,
g [m.s^{-2}]– gravitational acceleration,
α [°]– ramp angle,
G [N]– gravitational weight of the body.

Friction force calculation [1, 8, 12]:

$$F_t = f_s \cdot N \quad (4)$$

Where:
f_s [N]– coefficient of friction.

Since the wheelchair is moved from a standstill, the acceleration $a_x = 0$ can be considered until the minimum force is exceeded and the truck is moved [1, 8, 12].

After expressing the unknowns and putting them back into the force result equations, the relation for calculating the minimum necessary force to move the F_{min} was expressed. The coefficient of shear friction was used according to Decree "No. 398/2009 Coll. About general technical requirements ensuring the barrier-free use of structures", where the minimum coefficient of shear friction $f_s = 0.5$ was given. Weight is taken as the sum of the average wheelchair and wheelchair weights: 70 + 13 = 83 kg [1, 8, 12].

$$F_{min} = F_t = f_s \cdot m \cdot g \cdot \cos\alpha = 0.5 \cdot 83 \cdot 9.81 \cdot \cos 6.5° = 4045 \text{ [N]} \quad (5)$$

The force of 404.5 N is required to move the truck along a ramp where the assistance brake is applied as the wheelchair can always release the hoops while the brake segment is stuck in the tire when the brake moves back. When overtaking this minimum force, the wheelchair is able to continue driving again [1, 8, 12].

The following calculation determines the minimum required force F_{min} that is required to exit the staircase at a height of 150 mm as shown in Fig. 4 [1, 8, 12].

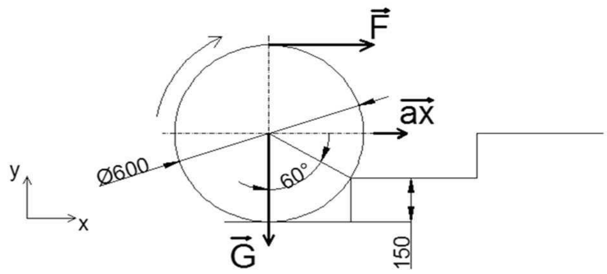

***Fig. 4** Drive the wheelchair to the stairs [1, 8, 12]*

The calculation is based on the moment of movement of the wheel to the stair [1, 8, 12]:

$$M = R \cdot F_{min} \Rightarrow R \cdot G \cdot \sin\alpha \quad (6)$$

$$F_{min} = G \cdot \sin\alpha = m \cdot g \cdot \sin 60° = 83 \cdot 9.81 \cdot \sin 60° = 705.14 \text{ [N]}$$

The force of 705.14 N is required for the wheelchair to go up the stairs. Depending on the size of the calculated minimal force, it is clear that the ramp and the stairs are very demanding. The assistance mechanical brake does not reduce the difficulty of these actions but can prevent possible collisions and injuries caused by unwanted movement, e.g. due to exhaustion or lack of physical fitness [1, 8, 12].

2.2 Deformation / displacement of the design brake assist during load

Fig. 5 shows the deformation of the assisting brake during a ramp racing that is loaded with a force of 404 N. This force is a load that the wheelchair must overcome in order to be able to move. A displacement of 0.1 mm or more is indicated by red color. The displacement may cause the brake not to be in close contact with the braked wheel, thereby causing the brake segment and wheel to slip. At the point of force, the displacement is approximately 0.05 mm, which is negligible and does not affect the function of the brake [1, 13].

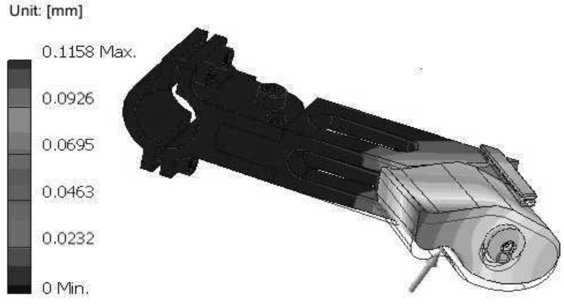

Fig. 5 *Deformation / displacement under load of 404 N [1, 13]*

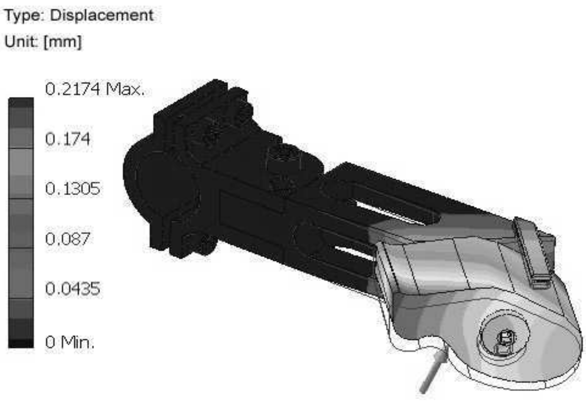

Fig. 6 *Deformation / displacement under load of 705 N [1, 13]*

Fig. 6 shows the deformation / displacement under load during leaving step. The severity is considerably higher and the displacement at the loading point is approximately 0.13 mm. The displacement is greater due to the elasticity of the material but does not affect the assistance brake function [1].

3 Assistance brake testing

The basic requirements for the mechanical wheelchair brakes are safety and reliability in terms of safety. An important parameter is the location of the brake, which must be such as to prevent injury or trapping of the part of the garment shown in Fig. 7, and also to protect the brake against possible damage during use or fall, see Fig. 8 [1-6].

Fig. *7 Position of the assistance brake in terms of possible injury [1]*

Fig. 8 *Positioning of the assistance brake for possible damage during use or fall [1]*

Fig. 9 *Fold ability of the wheelchair with assistance brakes during transport [1]*

Other aspects of the usual use of the assistance brake are that it must not interfere with the folding of the wheelchair during transport, e.g. in the car see Fig. 9 [1].

During testing, the assistance of the mechanical brake was proven. The function and the principle of movement using the assistance brakes during the ramp exit are shown in Fig. 10. The exit of the barrier-free ramp is more difficult without the use of the assistance brake because during attachment of tires the wheelchair moves downward automatically as a result of gravity [1].

Fig. 10 *Braking segment movement during braking [1]*

It is clear from Fig. 11 that the difficulty of pulling the wheelchair down is less in the sense that it is not necessary to take account of balancing with the carriage (the movement is more stable and safer). Once all the prerequisites for the correct operation of the mechanical assistance brake have been met, it is possible to solve the more complex optimization of the design and thus improve the design of the brake for easier, more efficient use and its effectiveness [1].

Fig. 11 *Exit the wheelchair using the assistance brake [1]*

An important parameter for braking is the inflation of the brakes. Testing included winter and summer bike variants. The range of inflation is shown in Tab. 2 [1].

Tab. 2 *Inflation range of tires [1]*

Wheel type	Summer	Winter
Inflating	6 up to 10 at	2.5 up to 4.5 at

Failure to comply with a given range of tire inflation may cause undesired braking. Under-inflation may cause tire squeezing and subsequent slipping due to insufficient tire pressures. Slipping can cause unwanted movement of one wheel and consequent injury. Tire inflation will cause the brake segment to become insufficient because of the high tire pressures and thus the brake loses its efficiency and can cause injury [1].

4 Technical and economic evaluation

The total cost of producing brake assist brakes is only indicative. The cost estimate was made according to the preliminary price calculation. The resulting cost calculation only includes the price for the material, the work on conventional machines and the 3D printer [1, 14].

The total cost of making emergency brakes is 88 EUR. For a more complete solution to the cost of producing the brake assist, it would be necessary to determine the series of products and calculate the total cost per pair or per brake, which could then be compared with the available brakes (market marketing survey). It should be added that the resulting cost calculation of costs is calculated for both assistance brakes (one pair) [1, 14].

5 Conclusion

The exit of a barrier-free ramp without the use of an assistance brake is much more demanding than its use. The brake helps stabilize the exit of the ramp, which is physically very demanding. It also prevents backward downward ramping and possible injury. Another assistant brake may be easier to handle with a wheelchair for the person assisting at the exit. The movement is much more stable and there are no unintentional back movements. For this reason, it is possible to use the assistance even from a person who has no direct experience of helping this kind.

The exit of the stairs is physically much more demanding for wheelchairs, and more people need assistance. Exit is possible without the help of other people, but the methodology of this trip is physically very demanding and few can handle it. Using the assistance brake, the stairs can only be driven by one person or, in some cases, only by wheelchair users. The benefit of the assistance brakes during the exit of the stairs is very similar to the exit of the barrier-free ramp (stability, avoidance of backward movement and possible injury).

A wider research would be needed to find a more comprehensive solution to this issue. The functionality of the design brakes during testing has proven its worth.

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