DESIGN OF A TRANSMISSION INTENDED TO WHEELCHAIRS FOR DISABLED PEOPLE

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Abstract. *In this paper are presented the authors contributions on designing and evaluation of a mechanical transmission intended to be used to wheelchairs for disabled people. In most cases the wheelchairs propulsion system solution consist of two DC motors, mounted on wheels shafts directly, or by means an intermediary transmission with chains or belts. In this case the wheelchair must be equipped with a controller, generally based on a PWM technology. Proposed solution consists of a mechanical transmission based on differential gears, which uses two motors, for steering and for propulsion. For this design architecture the control solution is much simple and easy cost to design, consisting in one servo controller for two motors. Based on dimensional synthesis of transmission gears, is developed the design solution of the robotic wheelchair. The wheelchair motion simulation is studied in Adams software, for the case of traction, steering and combined motion. From Adams simulations are obtained the wheelchair motion trajectories, kinematic and dynamic parameters. Obtained results are analyzed and compared to other wheelchairs design solution, concluding that proposed design solution of this transmission can be successful used to a wheelchair experimental prototype.*

Keywords: Wheelchair, dynamics, structural analysis, motion study.

1. INTRODUCTION

This paper is structured in four sections. Upon the introduction section is presented a kinematic characterization of a proposed wheelchair transmission. The third part presents the design solution in Solid Works of a wheelchair differential transmission. In the last parts is presented the kinematical characterization of the wheelchair, by motion simulation in Adams, in case of steering and straight line displacement.

Wheelchair is still the best transportation means for disabled people, since its invention in 1595 (called an invalids chair), for Phillip II of Spain by an unknown inventor. Since, they have become complex mechanical and electro-mechanical devices and robotic systems [1]-[2].

The propulsion system of powered wheelchair typically consists of a pair of motors, one for each drive wheel, and a drive train consisting of gears, belts and other mechanical elements that couples the motor's shaft to the drive wheel shaft. Speed and torque generated by each motor is controlled by modulating the pulse width (PWM) [3]-[7]. This research brings arguments for a mechanical transmission that achieves the differential movement. The traction and steering components are controlled by separately motors with suitable synthesis of transmission chains to achieve the proper angular speed difference of wheels. The model will be equipped with a motion controller, using a pulse width modulated DC to DC converter (PWM).

2. KINEMATIC STUDY OF WHEELCHAIR TRANSMISSION

Kinematic scheme of wheelchair transmission is presented in Fig.1. Worm pinion 6 is actuated by straight line displacement electric motor M_1, and steering is performed by motor M_2 which rotates bevel pinion 8 (shaft V). Bevel gears, (10, 12) and (10', 12') are planetary gears and they are mounted on shafts (IV, III), respectively (IV', III'), with pins assembly.

Bevel gears, (11, 13), and (11', 13') are satellites gears. Satellites gears are mounted on needle bearings to axes fixed on differential casing, and achieve a planetary motion.

To calculate the transmission ratio, the principle of motion reversing is applied (called Willis principle). To straight line displacement the traction wheels of the wheelchair spin at the same angular velocity. The motion is transmitted from worm gears 6-5 to the shaft II and by means of final transmission with cylindrical gearings 4-2 to wheelchair wheels.

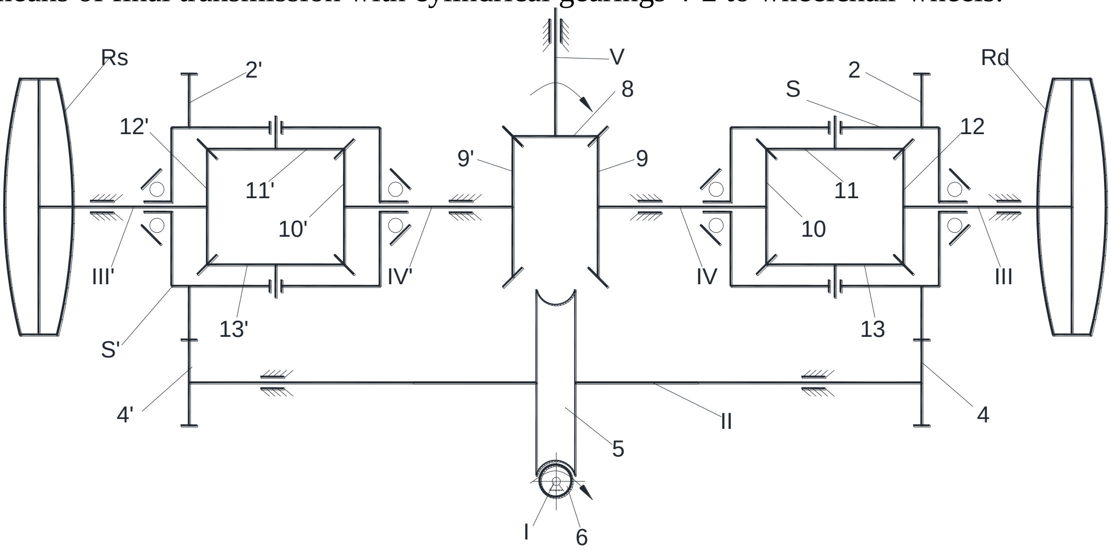

Fig. 1. Kinematic scheme of wheelchair transmission [1].

For steering, the motion is transmitted from motor M_2 to shaft V, trough bevel gears (8, 9), (10, 11), (11, 12) to semi-axis III, respectively to motor wheel Rd. For left wheel Rs the transmission flow go through bevel gears (8, 9'), (10', 11'), (11', 12') to semi-axis III'. The wheelchair wheels Rd and Rs will spin with the same angular speed and opposite rotation sense. The wheelchair moves in a circle. Casing S, S' and spur gear (2, 2') are not moving (the motor M_1 is turned off).

The motion transmission chain for straight line displacement and the motion transmission chain for steering, of the wheelchair, are expressed by relation (1).

$$\begin{matrix} M_1 - I - i_{65}^{w} - II - i_{42}^{c} - III - Rd \\ M_1 - I - i_{65}^{w} - II - i_{4'2'}^{c} - III - Rs \end{matrix} , \begin{matrix} M_2 - V - i_{89}^{k} - IV - i_{10\ 11}^{k} - i_{11\ 12}^{k} - III - Rd \\ M_2 - V - i_{89'}^{k} - IV' - i_{10'\ 11'}^{k} - i_{11'\ 12'}^{k} - III' - Rs \end{matrix} \quad (1)$$

Where: M_1- traction motor; i_{65}^{w} -worm gear ratio; i_{42}^{c} -final transmission ratio; Rd and Rs, right and left wheel, I, II , III and IV – transmission shafts, M_2- steering motor; $i_{89}^{k}, i_{89'}^{k}$ bevel gear ratio; $i_{10\ 11}^{k}$ -bevel gears 10, 11 ratio; $i_{11\ 12}^{k}$ - bevel gears 11, 12 ratio.

For wheelchair straight line displacement when both drive wheels encounter the same resistance to ground, is valid relation (1). For steering, the governing equations of the wheels angular velocity are deducted in the following. In case of steering motion, the angular velocity of differential casing is:

$$\omega_s = \frac{\omega_{10} + \omega_{12}}{2} \tag{2}$$

ω_{10}, ω_{12} -absolute angular velocity of bevel planetary gears 10 and 12, considered in relation to differential casing;

ω_S - is absolute angular velocity of differential casing upon wheelchair frame.

From Eq. (2) is concluded that the angular velocity of the central gear (planetary) is twice the angular velocity of the differential box. If the steering motor is turned off, then $\omega_{10} = 0$, from Eq. (2) it is obtained:

$$\omega_{12} = 2\omega_s = 2\omega_2 \tag{3}$$

In the same way: $\omega_{10}^{'} = 0$, it is obtained: $\omega_{12'} = 2\omega_{S'} = 2\omega_{2'}$

Taking into account the gears ratio, is obtained the equation (4):

$$\omega_s = \frac{\omega_{M_1}}{i_{65}^{w} \cdot i_{42}^{c}} \left[rad / s \right] , \tag{4}$$

Where: ω_S is the motion received from the traction motor.

In Eq. (4) used notations are:

ω_{M_1} -is traction motor angular velocity; i_{65}^{w} -worm gear ratio; i_{42}^{c} -spur gears 4-2 transmission ratio.

In case of steering motion of the wheelchair, is obtained the equation (5):

$$\omega_{10} = \frac{n_{M_2}}{i_{89}^{k}} \ ; \omega_{10}' = \frac{n_{M_2}}{i_{89'}^{k}} \tag{5}$$

ω_{10} is the motion received from steering motor M_2.

Assume that the right wheel Rd is outside the curve, in this case the pairs of satellite gears (11, 13) respectively (11', 13') will spin. Is distinguished: the absolute motion of planetary gears, transportation movement of differential casing and relative movement of satellites gears towards differential casing S or S'. In this context, the distribution of velocities in absolute motion of a planetary gear, is:

$$\omega_{10} \cdot R_W = \omega_S \cdot R_W + \omega_{11} \cdot r_W \tag{6}$$

If is considered the Eq. (2), is obtained the angular velocities for satellite gear (11) and planetary gears (10) and (12):

$$\omega_{11} = \left(\omega_{10} - \omega_s \right) \frac{R_W}{r_W}, \ \omega_{10} = \omega_s + \omega_{11} \frac{r_W}{R_W}, \qquad \omega_{12} = \omega_s - \omega_{11} \frac{r_W}{R_W} \tag{7}$$

Where: R_W -is the rolling circle radius for planetary gears 10 and 12; r_W - rolling circle radius for satellites gears 11 and 12.

Relations deducted above are helpful to the kinematic synthesis of wheelchair transmission. They are used to establish gears ratio, upon is designed the 3D model. Design solution of the wheelchair is developed in Solid Works.

3. SOLID WORKS DESIGN OF WHEELCHAIR TRANSMISSION

Gears and parts modeling are made with Gear Trax and Solid Works. The assembly models of transmissions, is shown in Fig. 2. Gears dimensions and ratios are presented in Table I.

TABLE I Gears ratios and dimensions

Gear pair	Gears ratio[-]	Gears module [mm]	Gears rolling diameter [mm]
$Z_2=34$ $Z_4=18$	1,88	3	$dw_2=54,84$ $dw_4=101,5$
$Z_8=13$ $Z_9=33$	2,538	3	$dw_8=39,0$ $dw_9=99,8$
$Z_6=1$ $Z_5=17$	17	3,5	$dw_6=26,25$ $dw_5=58,8$
$Z_{10}=16$ $Z_{11}=10$	1,6	2,5	$dw_{10}=40$ $dw_{11}=25$
$Z_{12}=16$ $Z_{13}=10$	1,6	2,5	$dw_{12}=40$ $dw_{13}=25$

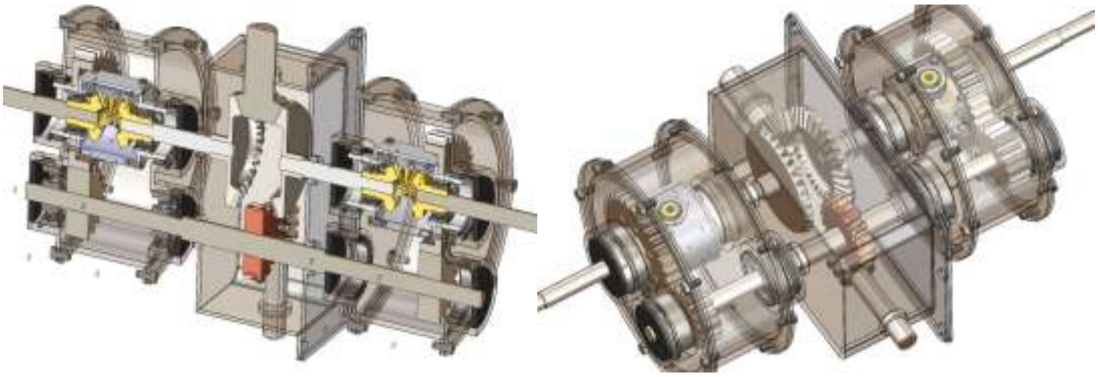

Fig. 2. Transmission assembly (with section).

Fig. 3. Detail of a differential transmission.

Designed transmission are mounted on the wheelchair frame, the assembly view is presented in Fig. 3. The obtained 3D virtual prototype is important because it will be used to simulate in Adams the wheelchair motion trajectory and study of motion dynamics. Also the virtual prototype is useful in further design studies, to optimize the construction (minimize weight, ergonomics studies).

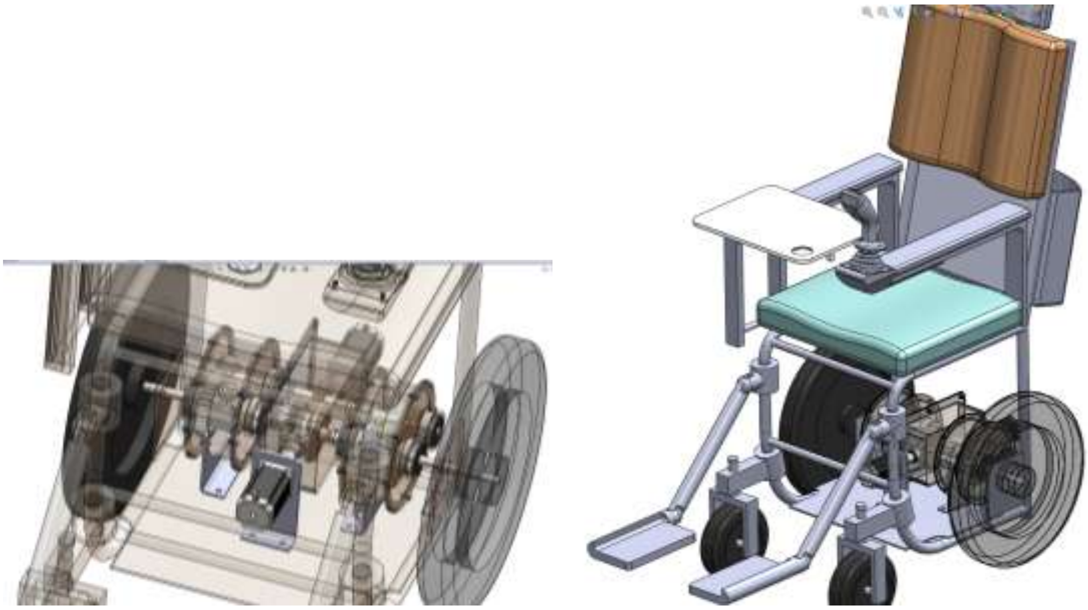

Fig. 4. Wheelchair assembly.

4. Wheelchair motion simulation in Adams

The virtual prototype of the wheelchair, presented in Fig. 4, is transferred into Adams multi-body model, using the transfer interface embedded in Solid Works.

It is achieved robotic system workspace analysis in Adams, in first case for a combined trajectory, composed by a straight line motion and steering. Functions used in Adams to define straight line motion and steering motion are given by Eq. 8.

IF(time-2 : 30, 0, IF(time-4:0 , 32, 32)) – traction motion

IF(time-2 : 0 ,0 , 3.2) – for steering motion (8)

In the second case of simulation, is active only the steering motion, with value $\omega_2 = 3,2 \text{ rad/sec}$ (applied to shaft V). The simulation is made using WSTIFF solver with SI2 integration. The wheelchair motions trajectory obtained in both cases are presented in Fig. 5.

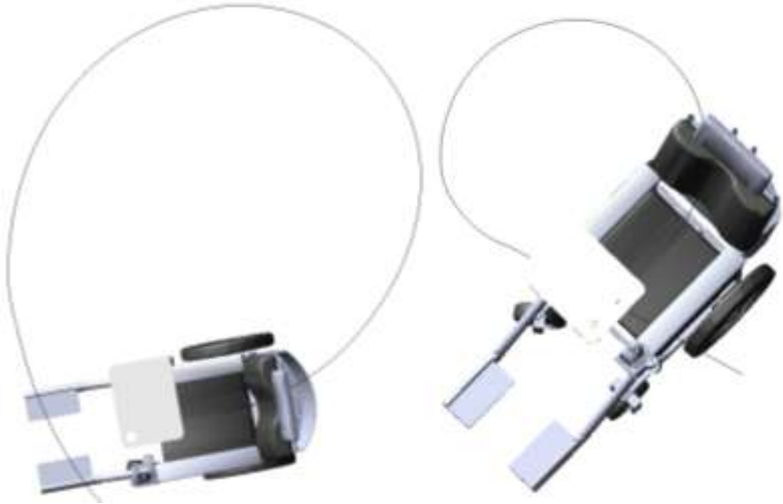

Fig. 5. Wheelchair motion trajectory computed in Adams.

The right and left wheel angular velocity obtained by motion simulation are presented in Fig. 6.

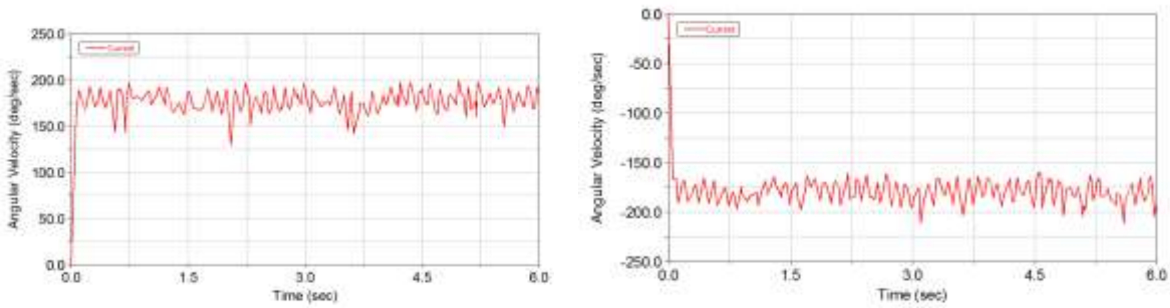

Fig.6. Right and left wheel angular velocity, in case of steering motion.

5. CONCLUSIONS

This paper proposes to develop a kinematic analysis model of a robotic wheelchair. Proposed transmission uses differential gears for steering. The virtual model of the wheelchair is designed in Solid Works and upon this model it will be developed the dynamic model in Adams. Proposed solution uses two kinematic chains, one for straight line motion and second for steering motion. From Adams simulation is determined that the propulsion necessary torque, when the wheelchair carries a 70 kg human, is 12Nm and the steering torque is by 8Nm. Future studies, will consist in a transient structural analysis of gears transmission, which reveals the gears solicitations. As a conclusion, in situation when the wheelchair is moving on a flat surface, the necessary torque for traction and steering are relatively low. Much greater values are expected in case of a hill climbing.

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REFERENCES

1. Geonea I., Dumitru N., Design and motion analysis of a powered Wheelchair, Applied Mechanics and Materials,Vol.772(2015), pp.613-620, doi:10.4028/ www.scientific.net/ AMM.772.613
2. Geonea I., Dumitru N., Motion analysis of a robotic wheelchair, Proceedings of 24 International Conference Robotics in Alpe Adria Danube -RAAD 2015, 27-29 May, Bucharest, Romania (to be published).
3. Kumar Vijay, Assistive Devices for People with Motor Disabilities, Wiley Encyclopedia of Electrical and Electronics Engineering Assistive Devices for People with Motor Disabilities, 1997.
4. Modak G. S., Review Article: Evolution of a Stair-Climbing Power Wheelchair, IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), pp. 36-41, 2009.
5. Pires G., Autonomous Wheelchair for Disabled People, Proc. IEEE Int. Symposium on Industrial Electronics (ISIE97), Guimarães, 797-801, 1997.
6. Salmin H., Design and Implementation of an Electric Wheel-Chair to economize it with Respect to Bangladesh, International Journal of Multidisciplinary Sciences and Engineering 2014.
7. R.F. Edlich, K.P. Nelson, M.L. Foley, R.M. Buschbacher, W.B. Long and E.K. Ma, Technological advances in powered wheelchairs, J. Long. Term. Eff. Med. Implants, vol. 14, pp.107-130.