24th International Conference
ENGINEERING MECHANICS 2018
Svratka, Czech Republic, May 14 –17, 2018
Paper **#141**, pp. 497–500, doi: 10.21495/91-8-497

TYPE SYNTHESIS AND NUMERICAL RESEARCH OF A UPPER LIMB REHABILITATION SUPPORTING DEVICE

B. Lewandowski[*], P. Sperzyński[**], J. Bałchanowski[***]

Abstract: *In this paper a problem of supporting movement during rehabilitation of a human upper limb is described. Research are carried out on MD Adams model of a novel device for upper limb functional rehabilitation. Type synthesis of the model with necessary simplifications is conducted. The MD Adams model with supported movements is described. A method of preserving the mechanism from being damaged during exercise is demonstrated. Research with additional loads have been carried out. Additional elements were selected and examined. The results of mechanism with additional elements simulation is presented.*

Keywords: upper limb, wrist, rehabilitation, robotic-assisted movement

1. Introduction

Rehabilitation is a very important aspect of human wrist dysfunctions treatment. It is intended for people who have lost some motor function due to disease, injury, or their functions were limited due to birth defects. Rehabilitation helps to avoid potential complications associated with eventual surgery. The effectiveness of physiotherapy is significantly increased by the usage of dedicated supporting devices, which also contributes to a reduction in rehabilitation time and greatly enhances the final results. Research concentrating on increasing the effectiveness of rehabilitation has been carried out in many centers, among others in Germany, basing on the pioneering works at MIT (Krebs et al., 1999), where the Bi- Manu -Track system (Hesse et al., 2006) was invented and implemented. Other systems supporting rehabilitation that can reconstruct almost every movement of the upper limb are generally called exoskeletons (Nef et al., 2007, Xianzhi et al., 2010). Manipulator and robots can even echance surgical operations (Kulesza et al., 2017).

The device developed in 2014 in Wroclaw University of Science and Technology (Lewandowski et al., 2014) and then improved (Lewandowski et al., 2016) by additional sensors had to face the problem related to movement of patients after stroke. During the movements a strong force apperas due to incorrect movement. It is a result of helping the movement by using body weight. In this article the problem of sudden movements and jerks performed by patients with movements disorder is taken into consideration.

[*] Assis. Bogusz Lewandowski, MSc, Eng.: Wroclaw University of Science and Technology, Faculty of Mechanical Engineering, Department of Biomedical Engineering, Mechatronics and Theory of Mechanisms,.ul. Łukasiewicza 7/9, 50-371 Wroclaw, Poland; e-mail: bogusz.lewandowski@pwr.edu.pl

[**] Assis. Przemysław Sperzyński, MSc, Eng.: Wroclaw University of Science and Technology, Faculty of Mechanical Engineering, Department of Biomedical Engineering, Mechatronics and Theory of Mechanisms,.ul. Łukasiewicza 7/9, 50-371 Wroclaw, Poland; e-mail: przemyslaw.sperzynski@pwr.edu.pl

[***] Assoc. Prof. Jacek Bałchanowski, PhD, DSc., Wroclaw University of Science and Technology, Faculty of Mechanical Engineering, Department of Biomedical Engineering, Mechatronics and Theory of Mechanisms,.ul. Łukasiewicza 7/9, 50-371 Wroclaw, Poland; e-mail: jacek.balchanowski@pwr.edu.pl

2. Basic information and simplifications of the mechanical structure

The structure of human upper limb is complex, however analyzing performed movements and joint movements some simplifications can be made. The first and most important simplification is a constant axes of rotation. All supported movements are presented (Fig. 1): pronation/supination of the forearm, adduction/abduction and dorsal/palmar flexion. The forearm and wrist joints were analyzed, indicating their functions, degrees of freedom and ranges of motion. The axes of rotations for the device correspond to anatomical axes for a human, for that cause it is an exoskeleton type of a device.

a) b)

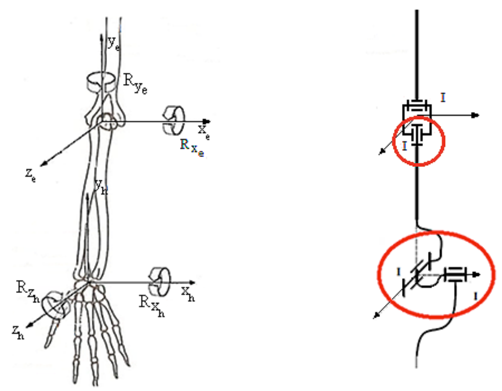

Fig. 1: Simplified mechanical structure of an upper limb

2.1. Elements of type synthesis of the device structure

As all human being are different, the device should be adjustable. The basic diameter is the length between center of rotation and the grip (Fig. 2a). The devices should have 3 DOF, same as the number of supported movements. There are two possibilities to achieve that, shown at figure (Fig. 2b, c). In the first one pronation/supination joint is situated behind the grip (Fig. 2b). In the second one the pronation/supination joint is in front (Fig. 2c). It is disadvantageous due to longer arm of force from weight of the device acting on joint B.

a) b) c)

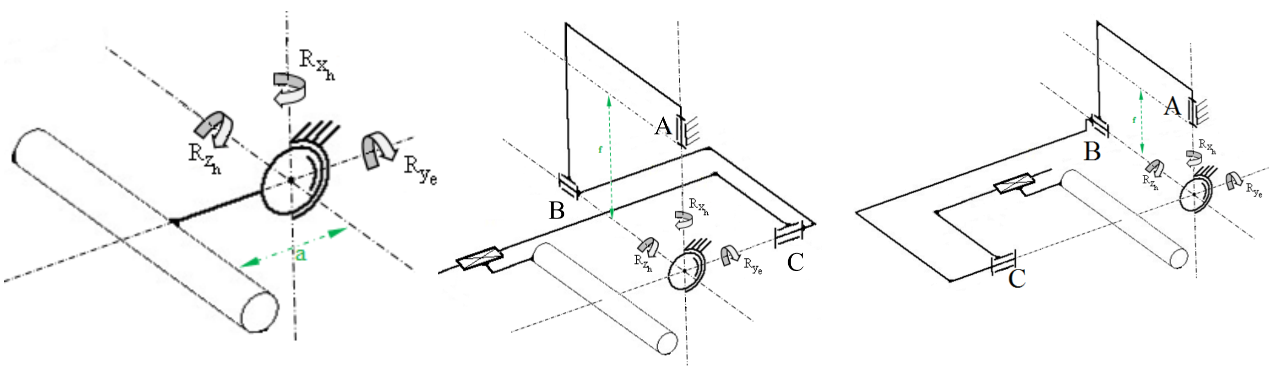

Fig. 2: Scheme of the device in two variants

3. Simulation research of the supporting device

For the purpose of simulation research scheme a (Fig.2 b) was chosen. The model has been created in MD Adams system. It has 3 DOF which correspond to anatomical axes of rotation for a human. The simulation will be carried out for three movements: pronation and supination of the forearm, adduction and abduction and dorsal/palmar flexion of the wrist. Motions were described as follow:

$$\varphi(t) = \varphi_{max}(\frac{t}{T} - \frac{1}{2\pi}\sin(\frac{2\pi t}{T})$$

Where: T- time-span, f – joint angle.

Each movement was divided into three phases: full range of motion movement for abduction in T_a = 2s, reverse movement to full range of motion of adduction T_b = 4s and reverse movement to neutral position T_c = 2s. Equations describing each of them are presented below:

$$\varphi(t) = \begin{cases} -\varphi_i\left(\frac{t}{2} - \frac{1}{2\pi}\sin\left(\frac{2\pi t}{2}\right)\right), for\ t \le 2s \\ (\varphi_i + \varphi_j)\left(\frac{t}{4} - \frac{1}{2\pi}\sin\left(\frac{2\pi t}{4}\right)\right), for\ 2s < t \le 6s \\ -\varphi_j\left(\frac{t}{2} - \frac{1}{2\pi}\sin\left(\frac{2\pi t}{2}\right)\right), for\ 6s < t \le 8s \end{cases}$$

Where: f_i – maximal range of motion for addution movement, f_j - maximal range of motion for abdution movement.

Due to collisions problem, joint C was modified in the model. It has been replaced with a gear in which the grip is mounted. Because of that, the hand is inside the bigger cogwheel. The model is presented at figure (Fig. 3).

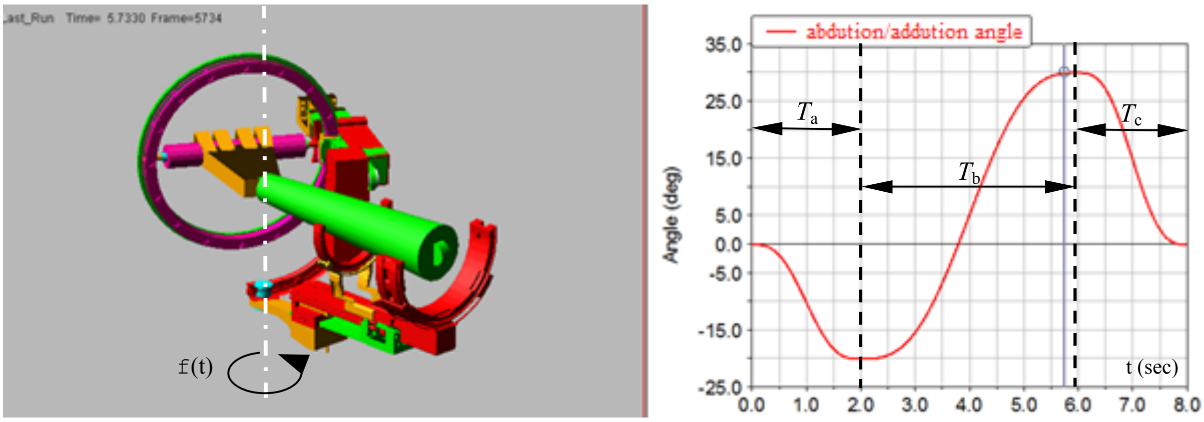

Fig. 3: Simulation model view

During the observations of people after stroke while rehabilitation it was noticed that their movements were often assisted by bodyweight. In order to solve this problem and secure the device from being damaged the grip was mounted on two springs (Fig. 4). In order to simulate the movement with patient applying sudden force, three forces were added to the model: $\boldsymbol{F_x}$, $\boldsymbol{F_y}$, $\boldsymbol{F_z}$. The assumption was that they were all acting in the same period of time, and with the same value equal 150N (Fig. 5). The springs were calculated taking into account the distance between the grip and cogwheel and simulation results.

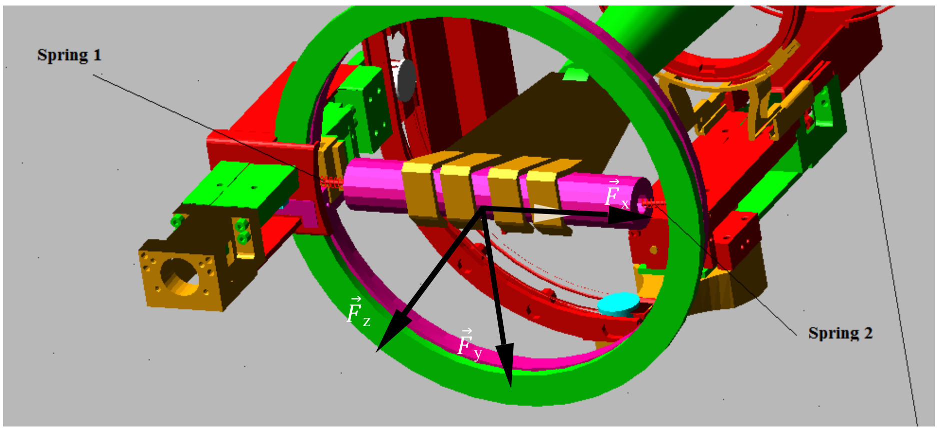

Fig. 4: Overview of the model with springs included

After applying patients force spring deformation does slightly exeed 2 mm. The forces starts acting in t = 2s. The results of patient assisted movement (adbution/addution) are shown in fugure (Fig. 6).

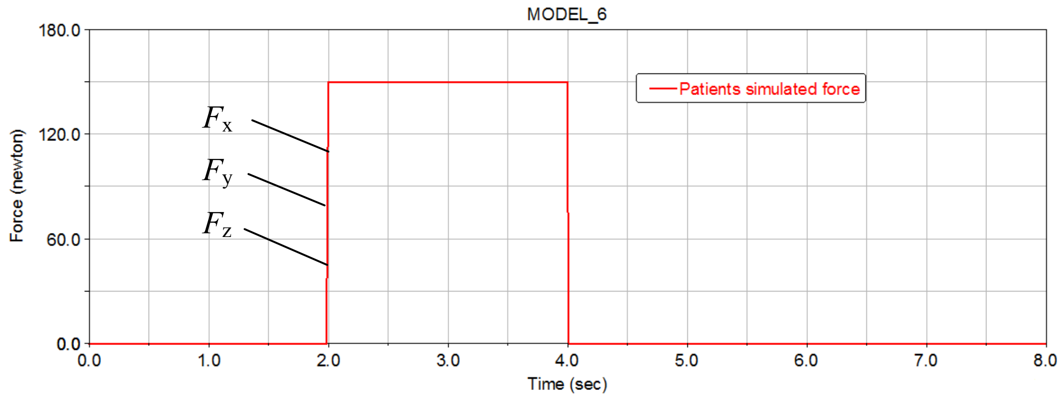

Fig. 5: Applied force F_x, F_y, F_z

The impact on the movement at the start is inconsiderable. However when the forces stopes acting, oscilations from 4 till 6 s of the movement can be observed.

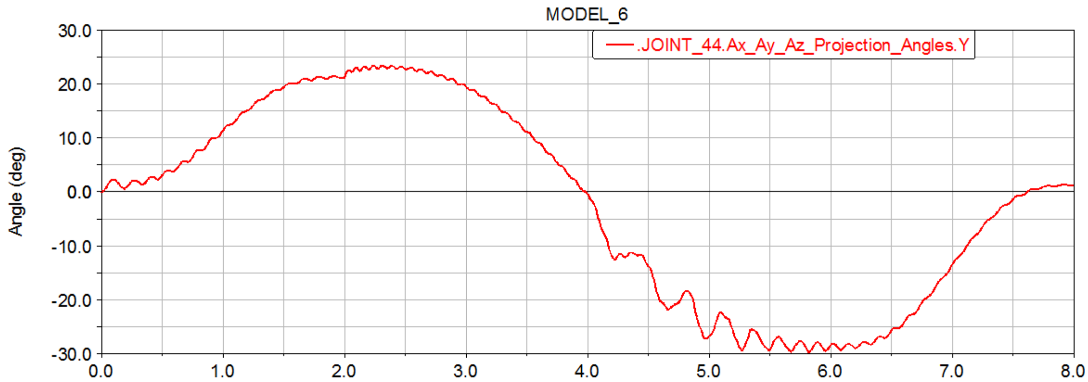

Fig. 6: Obtained results

4. Conclusions

The demonstrated model was validated and fulfill all the assumptions that have been made. It ensures movement support in all wanted joint movements. Numerical research confirmed and validated that usage of spring mounting for the grip helps to protect the device from being damage during unwanted force generation by the patient. This is very important because it also influents the safety of the patient. This fact results in a good prognoses for the device in the future. The next step is to verify those research on a prototype version of the device.

References

Hesse S., Schmidt S., Werner C. (2006) Machines to support motor rehabilitation after stroke: 10 years experience in Berlin. *Journal of Rehabilitation Research & Development*, Vol. 43 No.5, p. 671- 678.

Krebs Hi., Hogan N., Volpe Bt., Aisen Ml., Edelstein L., Diels C. (1997) *Overview of clinical trials with MIT-MANUS: a robot-aided neuro-rehabilitation facility*. Technol Health Care 1999;7: 419.

Kulesza, Z.; Trochimczuk, R. (2017) Dynamics of multibody surgical robotic single incision laparoscopic surgery tool. In: *Engineering Mechanics 2017*, Brno University of Technology, Brno, pp. 558-561.

Lewandowski B.,Olinski M., Gronowicz A. (2014) A novel device for functional rehabilitation of a human wrist. *Mechatronic systems and materials, MSM 2014 : 10th international conference*, Opole, Poland, pp. 1-12.

Lewandowski B.,Olinski M., Wudarczyk S., Gronowicz A. (2016) A conceptual project of a device for human wrist functional rehabilitation. *International Journal of Applied Mechanics and Engineering*. vol. 21, nr 4, s. 923-932.

Nef, T.; Mihelj, M.; Kiefer, G.; Perndl, C.; Muller, R.; Riener, R. (2007) ARMin - Exoskeleton for Arm Therapy in Stroke Patients. Rehabilitation Robotics. ICORR 2007. *IEEE 10th International Conference*, pp. 68 – 74.

Xianzhi J., Caihua X., Ronglei S., Youlun X. (2010) Characteristics of the Robotic Arm of a 9-DoF Upper Limb Rehabilitation Robot Powered by Pneumatic Muscles, In: Liu H., Ding H., Xiong Z., Zhu X. (eds) *Intelligent Robotics and Applications. ICIRA 2010*. Lecture Notes in Computer Science, vol 6425. Springer, Berlin, Heidelberg, pp 463-474.