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MECHANICAL DESIGN OF THE ACTIVE ORTHOSIS

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Abstract: *The paper proposes the design of mechanical components of the device for fully automated rehabilitation of elbow post intra-articular fractures further refered as the active orthosis. Motorized orthoses, which are at present used in physiotherapy, are mostly static and sturdy devices usually fixed with the chair. Active orthosis is (beside more efficient treatment) lighter, more comfortable and easier to handle with, which put specific requirements for its mechanical construction.*

Keywords: ***active, orthosis, rehabilitation, medical aid***

1. Introduction

Rehabilitation of human joints post intra-articular fractures is contemporary realized mostly with assistance of qualified physiotherapists providing full service during the whole process. Utilization of auxiliary electromechanical devices as motorized laths (Homma K., 1997) is ineffective primarily for their limited functions caused by the passive character of the joint movement realization and necessity of the professional personnel attendance. These devices are complex and robust, which makes them stationery therefore bonded to the medical area. The active orthosis is electromechanical device which main advantages are portability and more important active response on patient muscular activity providing assisted movement of the upper limb. Requirements for moderate dimensions, low weight and powerful technical solution make the mechanical design of the device complex task further described in this paper.

The main proposition while designing active orthosis is determination of the method of scanning action forces initiating the movement of the joint. There are several ways from direct sensing of the muscular activity using electromyographic (EMG) sensors (Mulas M., 1995) to indirect measuring of a physical quantity as for example reaction force in the body of the orthosis used in this solution. Requirement for the portability of the device significantly affects mechanical design of the body, especially the joint described in chapter 3. The body of the orthosis is subjected to ergonomic conditions necessary for all medical equipment. Indispensable parts of all devices utilized for health care are safety precautions. Active orthosis has multiple safety system where the mechanical section represents the final instance.

2. Analysis of action forces in the upper limb

Action forces in the upper limb were measured by unique device (Zezula M., 2009) which is able to record behavior of forces depending on actual angle of the elbow. Shape of the curve displaying acting force is flat, however the concept of mechanical solution is resistant to fluctuation of load. The table below shows results of maximal reaction force affecting the forearm 30cm from the elbow. According to figure 1 the fastening elements are similar to system of the active orthosis ensuring identical load.

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Tab. 1: Measured action forces

Force	Value	Torque
Direction up	70N	21Nm
Direction down	65N	19,5Nm

Measuring was executed to gain maximal torque which is possible to achieve in human elbow. These values have only informative character considering the various results from each measured person. Actual torque providing by the orthosis will be overdesigned to fit the biggest possible group of patients.

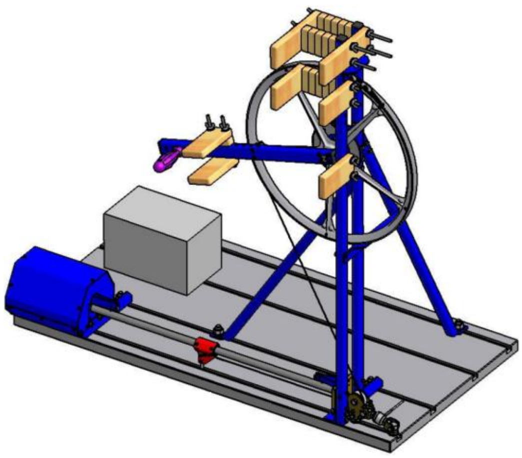

Fig. 1: Device for measuring of action forces in forearm (Zezula M., 2009)

3. Mechanical design

The final form of the mechanical design results especially from the requirement on portability which follows demands on low weight and moderate dimensions. The basic concept consist of the frame, mechanical rotational joint supporting the movement of the elbow, actuator and the fastening belts for fixing to the arm. The mechanical design overview is to be seen on figure 2.

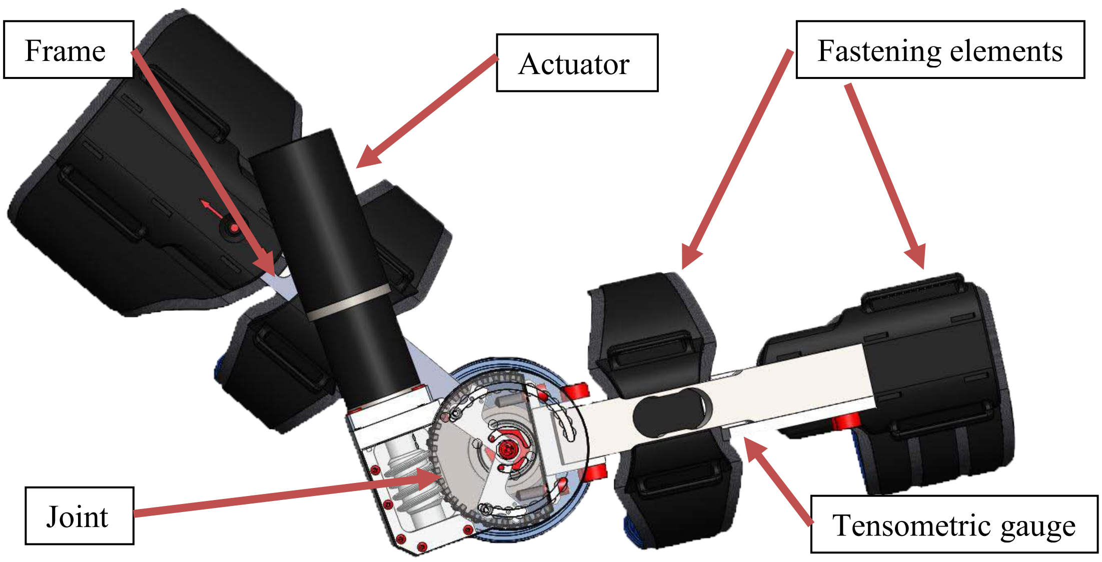

Fig. 2: Mechanical design overview

Before the detailed mechanical solution will be proposed, the function of the device is shortly described:

The active orthosis provides assisted movement of the upper limb fixed in the fastening elements. The device is able to react on patient muscular activity through tensometric gauge (see picture 2). This sensor is part of the frame and it measures patient's effort to move the injured elbow. Based on this information the actuator helps to move the orthosis through mechanical joint in desired direction and range with according sensitivity.

3.1. Frame

The frame of the active orthosis comes out of classical immovable orthosis frequently used to fix position of the joint. It consist of 2 aluminum splints, 4 steel sleeves and tensometric gauge (see chapter 4). Splints are connected through the mechanical joint realized by worm gear described in detail further in this chapter. Design of the frame needs to be adjusted to both requirements for low weight and rigidity. It has to provide full fixation of the arm in all positions.

3.2. Joint

The mechanical joint of the orthosis is realized by worm gear as shown on figure 3. This solution is utilized mainly for self-locking feature and sufficient gear ratio in spite of huge loss caused by friction. Self-locking mechanism allows fixing location of the arm in all position of the operation range. The joint ensures movement of the forearm splint which is bonded to the wheel. The worm embedded it the body of the joint is driven by DC actuator with planetary gearhead (see chapter 4).

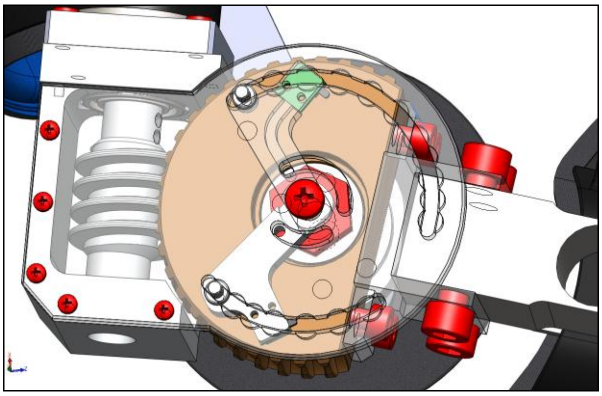

Fig. 3: Mechanical joint

Worm is embedded in radial ball and axial needle bearings as shown on figure 4a. Actuator is connected with the worm using setscrew bearing on the facet in the planetary gearhead shaft. Figure 4b shows bedding of the wheel which is centered on the body of the joint. The joint is equipped with mechanism for adjusting the operation range of the orthosis. The mechanism consists of two handles embedded in the main joint pivot. Each handle is possible to rotate separately around the joint axis and delimit maximal angle of the range. Definition of the proper position is realized by button in the end of the handle, which fits to the round canal on the periphery of the joint cover.

a.) b.)

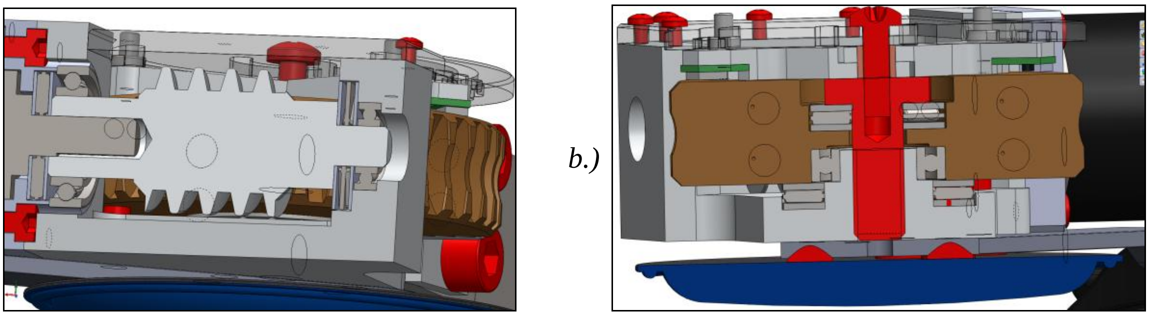

Fig. 4: Mechanical design of worm gear

4. Actuator and sensors

The active orthosis as the electromechanical consist of various electronic devices. The body of the orthosis comprehends also design of cable canals feeding all the electronic from the drive to small printed circuits for the micro switches (see figure 4). In this chapter are briefly described 2 main electronic parts, the actuator and the tensometric gauge.

4.3. Actuator

Design of the power system is difficult task considering there are strict demands on low weight and high power. Based on the calculation comprising all the physical influences the actuator Maxon RE 32 with DC motor of power 70W has been chosen. Actuator consist of planetary gear (66:1) and incremental sensor. The power supply voltage is 24V. Constant torque of the actuator is 2,25 Nm which gives total torque of the device about 50 Nm considering high loss of the worm gear. The value of the maximal torque is overdesigned on purpose. The orthosis is designated for wide spectrum of patients producing various values of load.

4.3. Sensor

For sensing the patients effort to move the arm the tensometric gauge is implemented as a part of the frame. It substitutes the forearm splint where the strain is most significant. Based on information about tension in the sensor is possible to determine the value and direction of the force affecting the forearm. Utilized sensor HBM PW6KRC3 is high sensitive device applicable for forces up to 400N.

5. Safety precautions

Movement of the orthosis out of desired range could harm the patient which is inadmissible. The range is adjustable by mechanism described in chapter 3. In addition to this function handles have also safety character. It serves as bedding for micro switches which stop the movement immediately as the forearm splint reach the boundary position. The mechanism described on figure 5 shows handles and also micro switches (green).

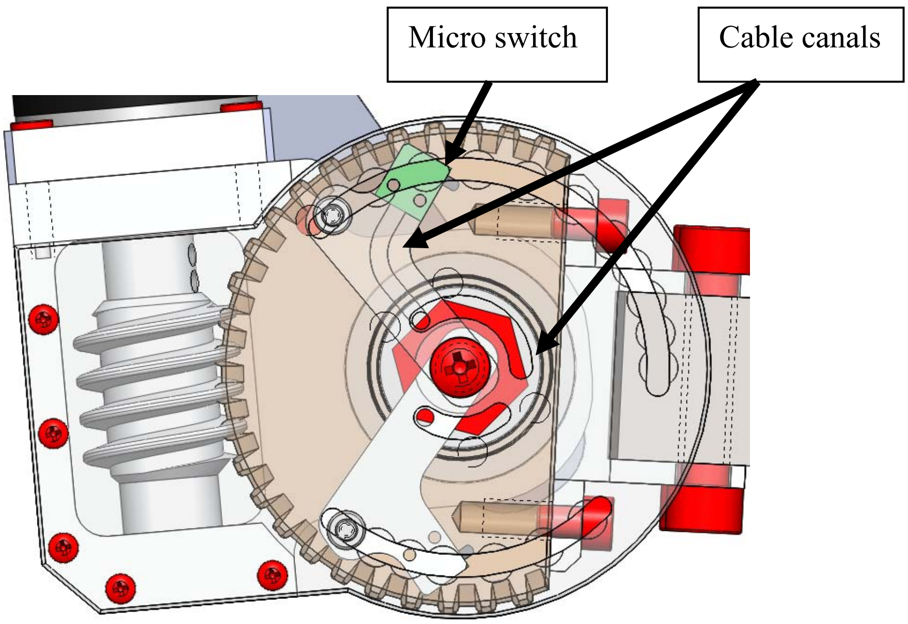

Fig. 5: Electromechanical safety mechanism

Mechanism showed on figure 3 is final instance of safety system, where the high level software represents the main control unit.

6. Conclusions

This paper describes mechanical design of unique medical equipment designated for rehabilitation purposes. Active orthosis is easily portable and compact device allowing fully assisted movement of the upper limb on qualitatively higher level than contemporary rehabilitation aids. Using tensometric gauge as the sensor of patients effort to move the arm it allows sensitive and effective treatment of intra-articular fractures.

The mechanical design fulfills requirement for low weight and moderate dimensions making the device easy to transfer and to manipulate with. The main parameters of the orthosis are in table 2.

Tab. 2: Basic parameters

Basic parameters	
Main dimensions	420x130x120mm
Weight	2,2
Voltage	24V
Actuator	DC motor Maxon RE 32 70W
Sensor	Tensometric gauge PW6KRC3
Maximal torque	50Nm
Operation range	100°
Rotation velocity	3rpm

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