DEVELOPMENT OF A MEASUREMENT AND CONTROL SYSTEMS OF KNEE JOINT EXOPROSTHESIS BASED ON MAGNETORHEOLOGICAL DAMPER

PhD. Techn. Sc., Ass. Prof., Nochnichenko Ihor *National technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Ukraine*
E-mail: igornoch@gmail.com

PhD. Techn. Sc., Kostiuk Dmytro
National technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Ukraine

Student, Dovhopolyi Mykhailo
National technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Ukraine

Abstract
The aim of this work is to develop the measurement and control systems of the knee joint exoprosthesis. The exoprosthesis should be convenient for patient. Replacement and settings of these systems should be simple because of modular layout. Control system works automatically and patients should have the results of its work on their devices such as mobile phones or PCs. The measurement and control systems are battery powered and connected to patients' devices via Bluetooth or Wi-Fi.

Keywords – *magnetorheological damper (MR damper), operating conditions, acceleration, resistance force*.

INTRODUCTION

Nowadays many types of knee joint exoprosthesis are very useful. The bionic exoprosthesis is one of the best of these types, but that one is expensive for patients of many countries. The mechanical exoprosthesis are cheaper than bionic. The main part of these exoprosthesis is a hydraulic damper [1-2].

Damper takes the most loads and "softens" the prosthesis in the process of movement, and the accuracy of its design and execution should be very high. The principle of its work is to dissipate the energy of motion by viscous friction of the fluid in the throttle. There are two main disadvantages of hydraulic damper. The first disadvantage is changings of temperature of the working fluid. As a result, the viscosity of fluid changes during the movement of patient. The second disadvantage is changeable characteristic of human's movement. For example, the patient can walk or run with many variations of its velocity and accelerations [3-5].

It is necessary to provide the possibility of autonomous control of the characteristic of the damper, depending on the type of the human movement and the temperature conditions of operation, to reproduce the movement's realism due to the design of the prosthesis and damper. An analysis of recent researches shows a perspective of using magnetorheological fluid as working fluid in dampers. The main advantage of magnetorheological fluid is a possibility to change its viscosity and other rheological parameters by forces of magnetic field. The feature of the proposed magnetorheological damper (MR damper) is the ability to provide a rapid change in its characteristics [6-7].

The aim of the work is to develop the measurement and control systems that will use in knee joint exoprosthesis. The purpose of measurement system is reading data from sensors to obtain some characteristics of human's movement. The purpose of control system is changing characteristic of MR damper by influence of changeable magnetic field based on received data from sensors.

Setting objectives:

- provide an opportunity of simple online diagnosis of knee joint exoprosthesis;
- development of a regulation block diagram of the characteristic of the MR damper;

- development an opportunity to save electrical energy via improving the control system of MR damper.

Knee joint exoprosthesis must meet stringent specifications such as reliability, realistic motion reproduction, energy-efficient and adaptable to changing operating conditions (variable movements of patient and variable temperature of the magnetic fluid in damper during its viscous friction in throttles) etc.

EXPOSITION

The main indicator of all damping liquids, on which the resistance forces of dampers largely depends, is the kinematic viscosity [4]:

$$\nu = \frac{dP_\tau}{ds \cdot \left|\frac{du}{dz}\right| \cdot \rho},$$

where: dP_τ- force of viscous friction; ds the area of contact of the layers in the fluid portion; $\left|\frac{du}{dz}\right|$- speed gradient module;$du$ - the difference of speeds on the sliding planes of the fluid;dz - distance between planes.

It is necessary to provide the online diagnosis of human's knee joint exoprosthesis. It is possible to determine to characteristics of human's movement, Absolutely, it is possible to identify some situations when the control system could transfer in energy safe mode or switched off. If the control system is switched off it is necessary to check the sensors and the work of the prosthesis with the specified time intervals. This may be appropriate if the person is not in motion for a long time. The advantage of this method is to save as many electrical energy of battery as possible. Therefore, patient does not recharge the battery of knee joint exoprosthesis frequently.

There is the opportunity to improving the online diagnosis. Patient can check the effectivity of exoprosthesis and MR damper on some devices like mobile phone or PC. The information will convert from PLC to patient's devices via Bluetooth or Wi-Fi connection modules. Bluetooth modules need less energy (0.2…0.5W) than Wi-Fi modules (0.35…0.7W).

Another opportunity to save electricity is to improve the control system of the characteristic of the magnetorheological damper, consisting of coils, which are supplied with current. Due to the supply of current to the coils in the damper, the magnetic fields will emerge, which are turning the structure of the magnetic particles of the magnetorheological fluid. By this effect the tension of fluidity is changes. Current control is provided via PLC and step-up converters. So, in the usual configuration, the current is supplied to one large coil, which affects the characteristics of the magnetic fluid along the length of the MR damper. Therefore, it is proposed to divide the one large coil into several separate smaller coils, each of which is operated independently of one another. It is much more expedient to supply current only to those coil within which the piston of the damper device is located. This will only activate the magnetorheological fluid in the areas where the fluid is throttling. In other areas, where throttling does not observe, the fluid is inactivated or has a little influence from the forces of magnetic field of the neighboring coils. To do this, it is necessary to use a control driver that can be programmed and performed by the microcontroller. As a result, it is possible to reduce the electricity consumption of operating the control system.

The block scheme Fig.1 shows the modules which are in control system. The PLC, control driver, diagnostic module and all sensors need the supply of electrical energy for its work. As energy supply the li-ion battery was choose.

In construction of knee joint exoprosthesis is not enough place for more than two li-ion batteries (model 18650 or model 14500). On the other hand, addition weight of batteries can negatively affects on strength of exoprosthesis. It is an advantage for using some methods for recovering the energy. It may be possible to use piezoelectric elements in construction of MR damper or in some constructive elements near kinematic pairs of exoprosthesis.

That scheme can be modified by adding artificial neural network (ANN). The main advantage of ANN is a possibility to teach itself. After "study" the ANN can differ many regimes of knee joint exoprosthesis work. These regimes depend on temperature of magnetorheological fluid, accelerations and position of damper. Using the ANN will increase a reliability of prosthesis.

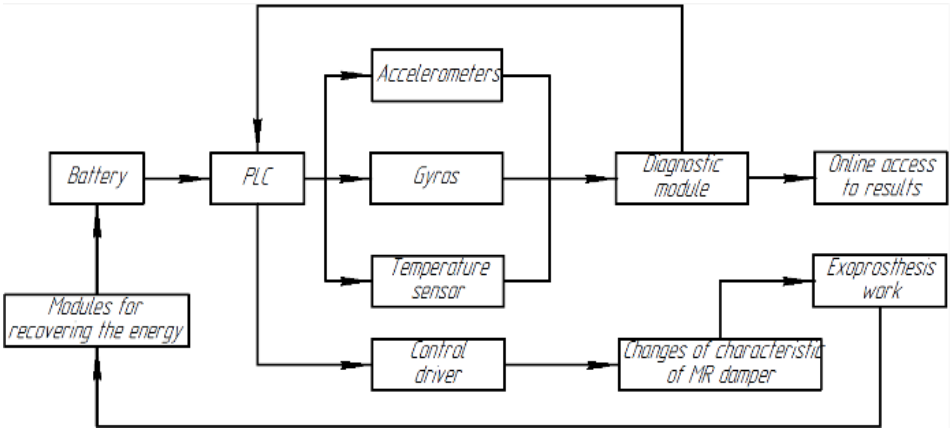
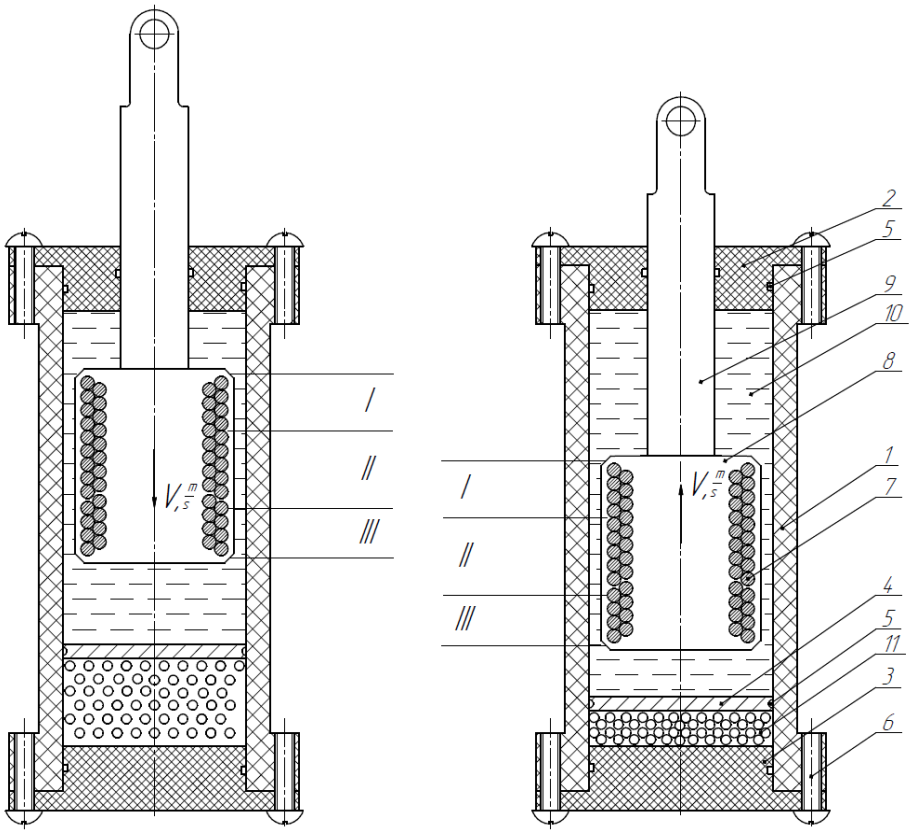


Fig. 1. *Block scheme of work the knee joint exoprosthesis based on MR damper*

The constructive scheme of MR damper Fig.2 shows the main parts in construction. In this damper piston area of magnetorheological fluid and gas charge are isolated by gas charge piston. The gas charge uses for compensation of pressure drop during compression moving. activate. If the piston take part in rebound moving, the third coil "III" will activate. The electrical current changes in diapason of many values. If it is impossible to provide a required motion law via one coil, the second coil "II" will work too. In situations when the applied



a) *b)*

Fig. 2. *Constructive schemes of MR damper during its work:*
a – compression moving, b – rebound moving
(1—cylinder tube; 2—cover of rod part; 3—cover of piston part; 4—gas charge piston;5—impact rings; 6—screws; 7—coils; 8—piston; 9—rod; 10—magnetorheological fluid;11—gas charge)

The coil separated into 3 coils. An electric current controlled in each of the coils via control driver. If the piston take part in compression moving, the first coil "I" will to rod force is maximum allowable all of the coils will work. Using of this method makes the possibility for saving electrical energy.

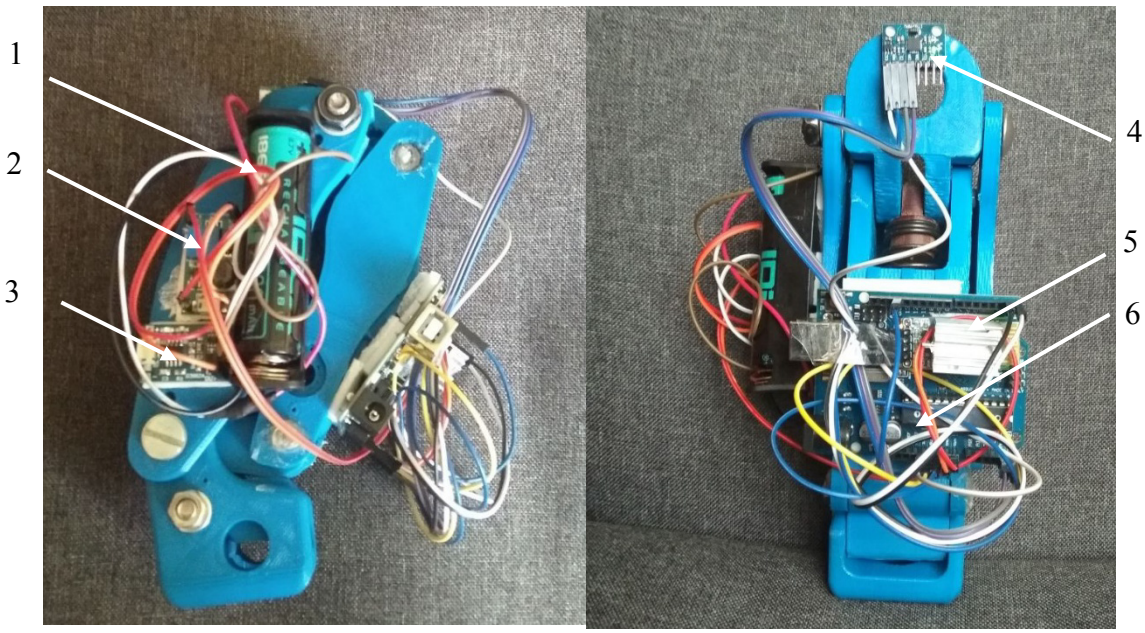


Fig. 3. *Knee joint exoprosthesis with elements of control system:*
(1—li-ion battery type 18650 (2800mAh); 2—current mode step-up converter MT3608;
3—1A standalone linear li-ion battery charger TP4056 with battery protection DW01+;
4—accelerometer and gyro MPU-6050 GY-521; 5—Bluetooth module HC-06;
6—microcontroller based on ATmega 328P)

The illustration Fig.3 shows the prototype of knee joint exoprosthesis with control system. The voltage and currency from battery is not enough for stable work of all modules. This problem was solved by adding current mode step-up converter. Therefore, it is not matter what is the charge of the battery, all of the electrical modules will work correctly.

Power supply connected to microcontroller's board via battery charger and current mode step-up converter. Other modules are connected to board. Every 0.05 seconds the accelerometer and gyro measure the angles and acceleration, after microcontroller calculate that characteristics. The results can be studied on mobile phone or PC via Bluetooth.

The dependence Fig.4 shows the changes of horizontal and vertical angles during the work of the exoprosthesis. That angles define the state of prosthesis, and depending on it, the state of patient. Operated on increases and decreases of both of angles it is available to make the conclusions about the characteristic of movement.

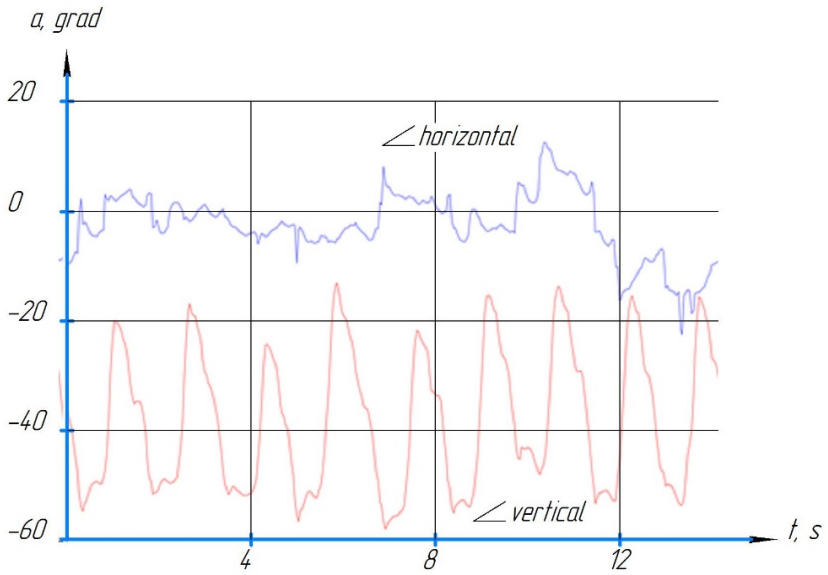


Fig. 4. *Dependence of angles during the imitation of walk*

CONCLUSION

The block scheme of work knee joint exoprosthesis based on MR damper, including online access to results, online diagnosis, modules for recovering the energy and original method of controlling the characteristic of MR damper, was developed.

The problem of saving electricity was solved. At first, it is possible to recover the energy of movement by using piezoelectric elements, which convert the mechanical energy to electrical energy. At second, the idea of separating the coil into many small coil can help to save the energy of the li-ion batteries.

The characteristics and dimensions of MR damper, which will use in knee joint exoprosthesis, was calculated. The idea of modification the prosthesis by including the ANN is very actual. The main advantage of system with ANN will be the possibility for developing much more prosthesis working modes. The limits of each of the mode will be more accurate than in system only based on microcontroller.

REFERENCE

[1] A. LaPre and F. Sup, "Simulation of a Slope Adapting Ankle Prosthesis Provided by Semi-Active Damping," Mechanical Engineering, pp. 587-590, 2011.

[2] R. C.Wang, D. W. Jin. Research and development of bionic and intelligent limb prosthesis. China Medical Devices Information, vol. 15, no. 1, pp. 35, 2009. (in Chinese).

[3] Uorden, K., (2006) "Novye intellectualnye materialy i konstrukcii. Svojstva i primenenie [New intelligent materials and structures. Properties and applications]." 1st ed., Moscow: Tekhosfera, [in Russian].

[4] Shul'man, Z.P., & Kordonsii, V.I. (1982), "Magnitoreologicheskii effect [Magnetorheological effect]." Minsk: Nauka I tekhnika [in Russian].

[5] *Wang X., Gordaninejad F.* Flow Analysis of Field-Controllable, Electro- and Magnetno-Rheological Fluids Using Herchel-Bulkley Model // Journal of Intelligent Materials, Systems and Structures. 2000. No. 2. P. 87-121.

[6] Dovhopoliy M.M. Vykorystannya mahnitoreolohichnoyi ridyny v dempferi endoprotezu dlya hasinnya vibratsiynykh kolyvan' /Nochnichenko I.V.// Vseukrayins'kyy naukovo – tekhnichnyy zhurnal Vibratsiyi v tekhnitsi ta tekhnolohiyakh.– 2018.– # 3 (90) – S-127-134.

[7] Nochnichenko I.V., Yakhno O.M. Zastosuvannya yavyshcha perenosu ta informatsiynoyi entropiyi do analizu povedinky mahnitoreolohichnoho dempfera / Naukovi visti NTUU «KPI»: naukovo-tekhnichnyy zhurnal # 4 (120)"2018. – str.54-62. doi: 10.20535/1810-0546.2018.4.141241.