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ALGORITHM AND ACTIVE PROSTHESIS CONTROL SYSTEM FOR HIP EXARTICUALTION

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Abstract

This work considers an approach to designing control systems for hip exarticulation prostheses. Information about speed that can be adjusted by a patient in the hip joint of the prosthesis during stance phase begining is used as a control signal. The control system includes three subsystems. The first subsystem controls the speed of energy accumulation, which is necessary to swing the prosthesis. The second subsystem controls prosthesis hip joint movements, depending on the walking rate, required by a patient. The third subsystem is information and logic unit It analyses the "man-prosthesis" system state and forms control commands for the first two subsystems.

Introduction

Future development of lower extremity prostheses is more and more connected with the use of external energy sources (EES).The prostheses with EES permit to reduce patient´s energy loss and to improve kinematic features of gait, which is confirmed by the experimental results. The experiments made also possible to outline clearly the problems, arising in the process of development and utilization of servomechanisms and control systems for prostheses.
This work considers a designing technique of the control system for hip exarticualtion prostheses.
We refused to use myoelectric control because the patients had to attract their attention constantly to a locomotor action, while working out control commands by means of voluntary muscle contractions. Besides, in myoelectric control, the delay time of the signal makes it impossible to carry out the prosthesis control at the speed required during certain gait phases. The facts, stated above, stress the urgency of the control systems development, which will permit the patients to control active lower extremity prostheses simply enough, efficiently and safely without special mental efforts.

During walking in the same conditions, a lot of human gait features are known to be repeated periodically with an insignificant deviation of parameters. This regularity can be used in the prosthesis hip joint (PHJ) control after hip exarticualtion. Hip joint movements are fully enough expressed by the joint angle dependence on time and by temporal characteristics of the stance phase. The angles goniometry analysis of the hip joint in the process of walking shows that the goniometry does not change considerably at certain speed range. If we take these curves in the same period, they will nearly conside, being superimpositioned. Consequently, we can make up a program, that will generate the hip joint angle depedence on time and use it for the PHJ movements control.

Program generation speed is to be determined by the patient, depending on the desired walking rate.
For walking rate control it is necessary to find a signal, that will depend on the walking rate and that can be altered by patients easily.
Angle speed on the PHJ can be such a signal at the begining of stance phase. When the PHJ is open at the given time moment, angle speed depends on the healthy limb push-off force which in its turn is determined by the walking rate. Thus, at the stance phase beginning the use of the signal about the PHJ movement speed will permit to control the movements of the joints according to the desired walking rate during following step phases.

The system, realizing this technique, is designed to control the above-knee exarticulation prosthesis, which has a PHJ mobility due to the servomechanisms. The prosthesis design is described in the previous work "Above-knee exarticulation active prosthesis and its efficiency evaluation technique". Proceeding from the prosthesis design and the type of its servo-mechanism, we worked out a control system, consisting of three subsystems. The first subsystem controls the energy accumulation device during stance phase, the second one is responsible for the hydraulic damper during stance and swing phases and the third subsystem is the information-logic unit, that can estimate the "man-prosthesis" system by the transducers signals and control the operation of the first and the second subsystems. Figure I shows the block diagram of the control system.

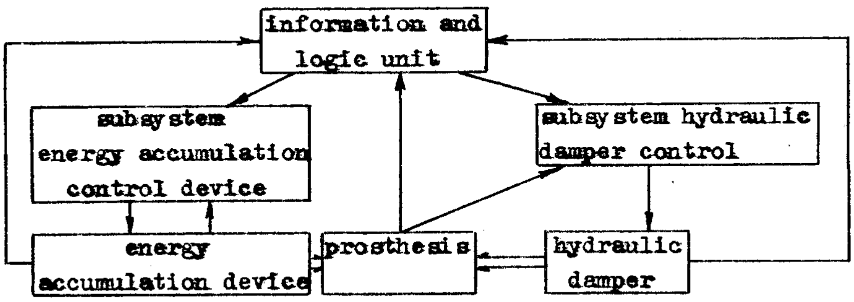


Fig.I

Energy accumulation, which is necessary to swing the prosthesis, is realized during stance phase. It is carried out due to some of patient's mass kinetic energy and due to accumulator spring compression by the drive mechanism. The need for the accumulator drive is explained by the fact that, starting from certain walking rate, the energy, accumulated due to patient's mass kinetic energy, may become insufficient to maintain the required walking rate. Energy accumulator is designed in such a way, that, from the prosthesis stance phase beginning till its vertical position, the spring can be compressed only due to the servomechanism of the accumulator.

Then, from vertical position till prosthesis-off, energy is accumulated owing to the servomechanism and patient´s kinetic energy. The first subsystem consists of walking rate determining unit, program generator control unit for the energy accumulator and a servosystem to realize this program, with servosystem controlling the accumulator servomechanism, i.e. switching it on, when the energy, accumulated due to patient´s mass kinetic energy is not enough for the desired walking rate. Walking rate determining circuit registers the angular speed of the PHJ at the residual limb-off and, according to the speed value, it forms a signal, corresponding to the patient´s walking rate. This signal controls the speed of program generating.

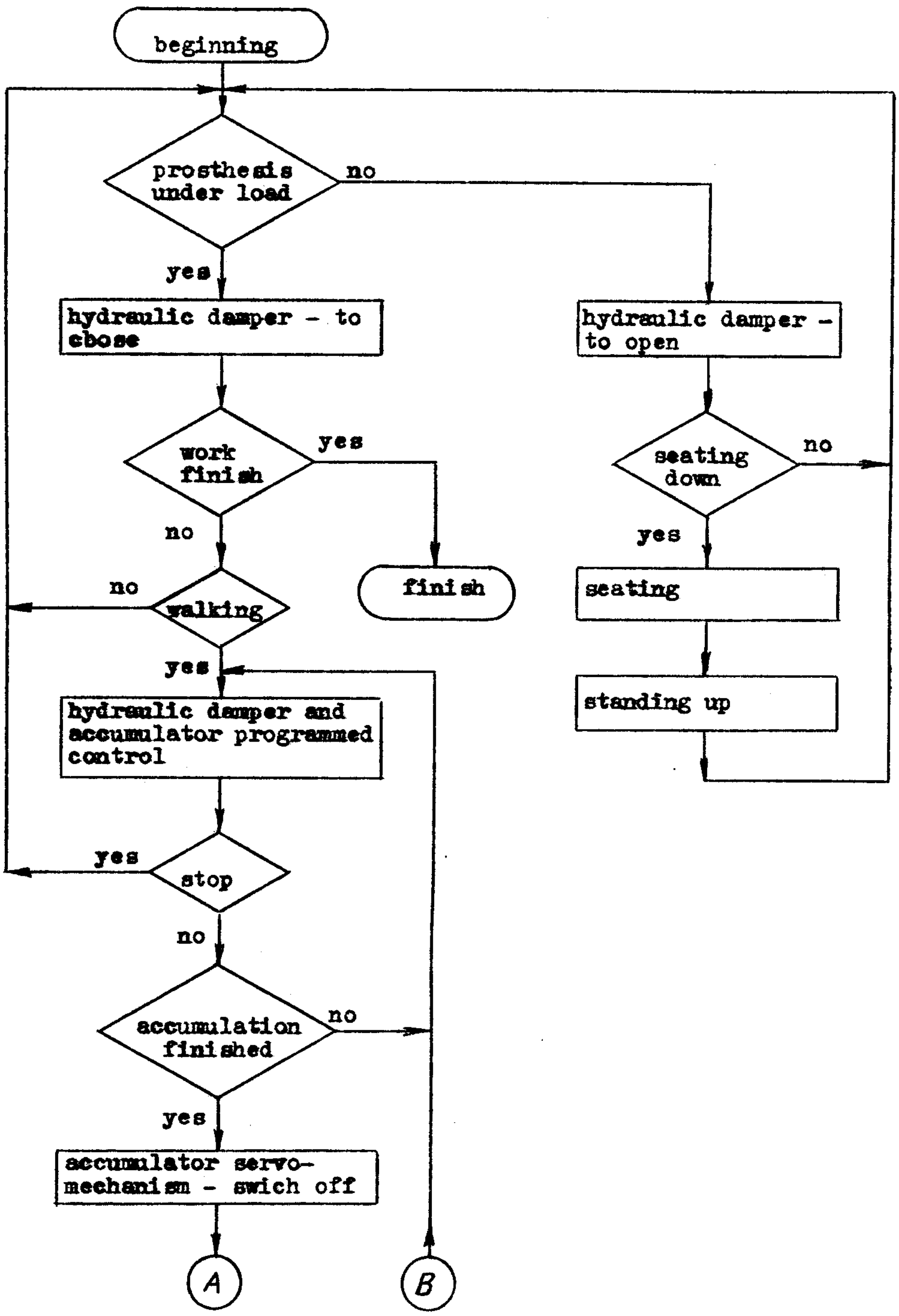
The second subsystem controls the hydraulic cylinder work. In the process of walking, this subsystem provides movements characteristics, that are close to the programmed ones. Program generation speed depends on the signal, which is formed by the walking rate determining circuit that is a part of the first subsystem. Depending on the prosthesis operation mode walking/ or standing and on the prosthesis movement phases, the first and the second subsystems must receive the appropriate commands,i.e. these subsystems must work by the definite algorthm. Prosthesis control system algorithm is to reflect all possible prosthesis states and their interrelation. Here, we give prosthesis operation description.

Initially, when the patient is standing on the prosthesis with the power source switched on, PHJ must be closed. PHJ closing is carried out by means of a main closing between the hydraulic damper cavities. Situations may arise, when the prosthesis position with respect to the PHJ must be altered in the process of standing. It is necessary to provide opening of the hydraulic damper in such cases. For this purpose the hydraulic damper slide is put in appropriate position. As the accumulation of energy is necessary only during walking, the accumulator servomechanism is always switched off during standing. Under certain conditions the prosthesis is to be put from standing position to walking.

In the process of walking, starting from the second step, at the stance phase beginning, the angular speed is measured in the PHJ. And its value determines the hydraulic damper and the accumulator control programs. During stance phase beginning, the hydraulic damper is fully open, in order not to effect the speed value, measured in PHJ. At the moment of stance phase beginning the signal, switching over the spring action to the PHJ, is sent to the accumulator servomechanism.

The necessity to fix the PHJ arises, when the program is altered suddenly and when the walking mode is followed by the standing mode.

Thus, we have major algorithm stages of prosthesis controlling system operation. Figure 2 shows the algorithm block diagram. The transducers, evaluating the "man-prosthesis" system state, the device transforming the transducers information into the required form, and the device for generation of the subsystem control commands by the transducers data are necessary for the realization of the system operation algorithm. In the standing mode it is necessary to have the information whether the prosthesis is stressed or unstressed. Such information is received by means of pressure transducers, that are located in toe and heel


beginning
prosthesis under load
no
yes
hydraulic damper - to close
hydraulic damper - to open
work finish
yes
no
seating down
no
yes
finish
walking
no
yes
seating
standing up
hydraulic damper and accumulator programmed control
stop
yes
no
accumulation finished
no
yes
accumulator servo-mechanism - swich off
A
B

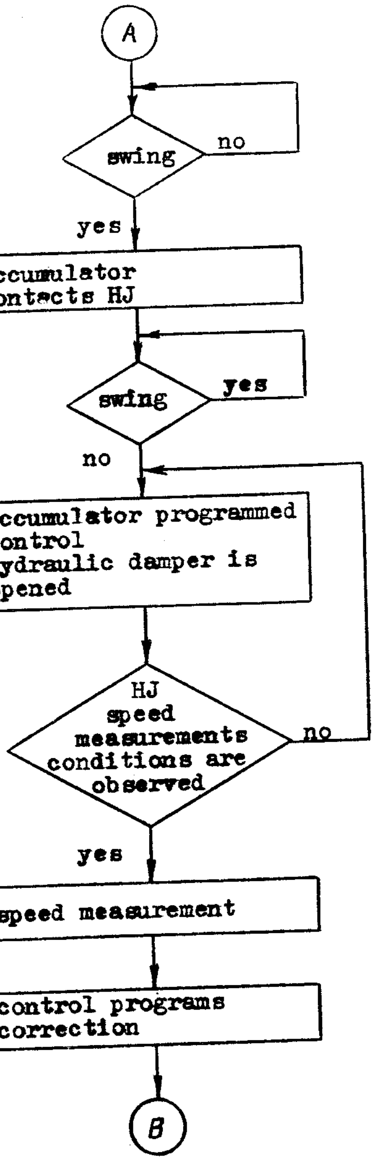

A
swing
no
yes
accumulator
contacts HJ
swing
yes
no
accumulator programmed
control
hydraulic damper is
opened
HJ
speed
measurements
conditions are
observed
no
yes
speed measurement
control programs
correction
B

Fig. 2

parts of the prosthesis. The energgy level in the accumulator is measured by means of a linear potentiometer, which is connected with the spring. This potentiometer is used as a feedback transducer in the accumulator subsystem. The angular speed in the PHJ is measured within certain range of angle values, corresponding to the stance phase beginning. The measurements are conducted by the angular potentiometer, which also is a feed-back transducer in the hydraulic damper control system.

Thus, the control system has to analyse a series of input signnals to evaluate the state of object. To formalize the algorithm we can introduce certain symbols for these signals. For example, X_1-heel support, X_2-accumulated energy peak level and so on. Transducers signals are used as input signals. Depending on the input signals combination, the information-logic unit forms the output signals for the subsystems control which determines the work of the servomechanisms and the prosthesis as a whole.

It follows from the prosthesis operation algorithm that the information-logic unit is to form the series of output signals (commands). For example, y_1- to switch on the peak control voltage for the accumulator servomechanism, y_2-to send the signal corresponding to the slide-open position to the hydraulic damper servomechanism.

We have to make up the logic circuit truth table in order to define the logic circuit type (terminal automatic device with memory or combination circuit).

There are all combinations of input signals in the left part of the truth table and there are output signals at the given input combination in its right part. We designate the signal as "I", and its absence as "O". The input combinations number depends on the output signals number and is equal to 2^P, where P is the input signals number. In our case P=7. To identify each of these combinations it is necessary to use a great number of elements while realizing the system. Part of these combinations are either not found or not used practically. For example, in the standing mode the system is indifferent towards the accumulator spring state, that is why the accumulator transducer signal is not used in this mode. There are certain difficulties beside simplifications.

This is explained by the fact, that the same input combinations must form different output combinations depending on the prosthesis operation mode. For example, during standing, when the prosthesis is load-free because of some reasons, the input combination

is the same as the one at the walking mode stance phase. But in the first case the hydraulic damper is closed constantly and in the second case it must work as programmed. We code all possible prosthesis operation modes because of the ambiguities. Thus, the information-logic circuit must be designed as a terminal automatic device with memory.
The output functions dependences on the input signals are minimized, taking into account the elementary base, the logic expressions are transformed into an easily realizable form.
The trials of the prosthesis for the hip joint exarticulation confirmed the possibility to utilize the stated above approach in practical realization of the control systems.