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ABOVE KNEE EXARTICULATION ACTIVE PROSTHESIS AND ITS EFFICIENCY EVALUATION TECHNIQUF

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Abstract

Design of an experimental prosthesis for hip exarticulation with an external energy source (EES) is described. The experimental prosthesis includes a mechanism for stance phase energy accumulation, designed to use this energy for movement realization during swing phase, a mechanism for hip joint movement control and a control system.

Imitational method for the experimental prosthesis efficiency evaluation is proposed. This method permits to increase the reliability of results and to reduce the amount of trials and time.

Basing on the obtained results, a conclusion is made about the proposed prosthesis effciency for hip exarticulation and advisability of lower extremity prosthesis designing for high amputation levels with the use of external energy sources.

Introduction

Hip exarticulation results in the most severe loss of human locomotor functions and the gait of the patients with high amputations, using the prosthesis of existing designs, is characterized by considerable rhythmic irregularity, movements asymmetry of both limbs, considerable amount of compensatory trunk movements, impairment of locomotive muscles activity and general increase of energy cost.

That is why the task of prosthetic fitting quality improvement for patients with hip joint exarticulations is very urgent and its solution requires to develop new highly functional prosthesis. The most efficient method to solve the task of prosthetic fitting quality improvement is the use of mechanisms operating with external power sources (EPS) in the designs of prostheses. Some practical results in this direction are obtained in AK prostheses designing /I,2,3/. The characteristic feature in designing of the prostheses for hip exarticulation is to provide active controllable mobility in the prosthetic hip joint (PHJ). That is why in the process of development of an active hip exarticulation prosthesis the following tasks were posed:

- to provide PHJ mobility,
- to provide active movement in the PHJ during swing phase,
- to realize movement correction and stability of the prosthesis when walking and standing.

Design of the prosthesis

Taking into account the requirements for the EPS prostheses, the following algorithm for the problems solution is proposed. During stance phase, the PHJ movement is to be inertial due to the residual limb work and potential forces involved in the angular body movement with respect to the hip portion of the prosthesis. Simultaneously, owing to auxiliary drive work and some of kinetic energy of patient´s body, energy is accumulated in spring accumulator. Accumulated energy is used for PHJ movement during swing phase. Speed correction and high stability must be proveded by a prosthesis control system via a hydraulic damper in the process of walking and standing.
Figure I shows kinematic diagram of the hip exarticulation prosthesis. The prosthesis includes foot (I) with ankle joint (27) shin tube (3), knee-joint (4), hip tube (5), hydraulic cylinder (6), a pin (7) with a piston (12) and a stop (9) connected via a hip joint (10) with a body jacket (II). There is a joint (8) on the external surface of the hydraulic cylinder, kinematically connecting it with the joint (14) via a brace (13). Hydraulic cylinder cavities are connected by the pipeline (15) and servo-motor valve (16), creating a closed hydraulic circuit. Besides, the prosthesis includes an auxiliary electromechanical drive, its output section has a cam (17), a lever (18) connected with a slider (19) which is mounted on a compression spring (20).

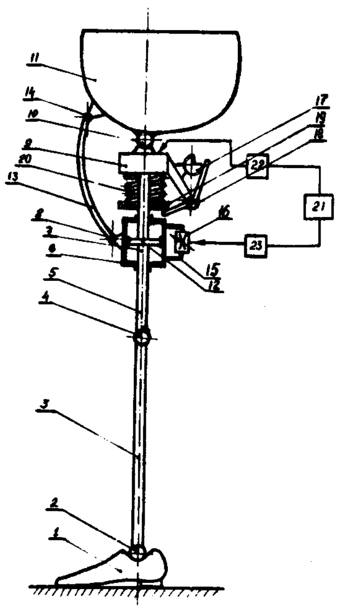
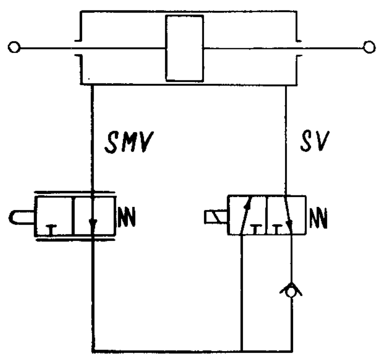


Fig.I

While working, prosthesis operation cycle is realized as follows. During initial contact with the ground at a signal from an information-logic units (21), the auxiliary electromechanical drive is switched on. It starts to compress the spring (20) by means of the cam (17), which revolves clockwise the lever and the slider. At that moment, servo-motor valve (SMV) and solenoid valve)SV) (Fig.2) are in their initial position, which permits to realize prosthesis revolving in the PHJ counter-clockwise. A back valve provides stability in the PHJ during stance phase. Simultaneously, a cylinder (6) goes up and compresses the spring additionally, interacting with the pusher.

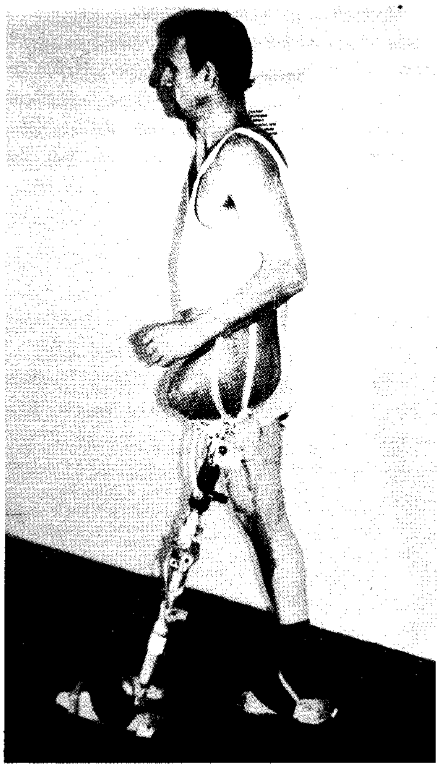


The hydraulic cylinder speed and speed of the prosthesis is controlled by the SMV due to the control system (23)commands. During back push-off phase, cylinder (6) reaches its upper position, with the spring (20) compressed strong enough to carry out further prosthesis swing above the support. After the command of the control system, the cam makes a turn and releases the spring (20). When the stress is taken off the prosthesis, a signal is sent to the SV. The spring force is transmitted to the cylinder (6), which is kinematically connected with axis (14). And the energy, accumulated during stance phase, realizes the movement of the prosthesis, providing the swing. At the end of the swing phase, cylinder (6) is in its lower position, the spring is fully released.

- experimental prosthesis with active PHJ;
- conventional exarticulation prosthesis;
- AK prosthesis.

Gait parameters divergence of the enumerated prostheses permits not only to evaluate the active PHJ application efficiency in comparison with a conventional prosthesis, but also to estimate how close active PHJ walk is to AK prosthesis walk. Besides, these parameters divergence makes possible to determine biomechanical significance of an AK stump for a locomotor action (by means of comparing the research results of the conventional exarticulation prosthesis walking with AK prosthesis walking).

To increase the reliability of results and to reduce the amount and time of research work, all experiments were made with one patient, who was amputated in the middle of the hip and now uses an AK prosthesis. This amputee could use exarticulation prostheses because he was provided with a specially designed body jacket, which excluded the stump from prosthesis control, fixing it flexed by 90^0.



The use of this research methodology provided the same experimental conditions while walking with the prosthesis, having different functional potentials.
Besides, in the process of research, hydraulic damper, auxiliary electromechanical drive and control system modes of operation were worked out and defined more exactly.
The trials were carried out on the level surface at the rates of 40, 60 and 80 steps a minute.
In the process of experiments, some specific features were discovered. The most significant change in gait parameters, comparing different prosthesis designes was reflected by the following:

- amplitude of side trunk inclinations in sagittal plane during walking with a conventional exarticulation prosthesis is 4 times wider and with an experimental active prosthesis 1.5 times wider, than with an AK prosthesis;
- vertical center of mass displacements for the mentioned prostheses are correspondingly 2,2 and 1,4 times greater, than for an AK prosthesis;
- movement characteristics of a residual limb, while using experimental exarticulation prosthesis are similar to those, obtained during walking with an AK prosthesis, which is not observed with a conventional hip exarticulation prosthesis.

Controlled mobility and high stability in the hip joint of the experimental prosthesis (35^{o}-40^{o}) allowed the patient to make prosthesis step length close to that of the residual limb and also to carry the load from the residual to the prosthetic limb more rhythmically.
The prosthesis received a high appraisal by the patient. He noted, that during swing phase the prosthesis control became easier, the prosthesis does not require considerable force application. Negative feelings of the prosthesis mass are reduced. Smooth movement of the joints and high stability provide confidence while using the prosthesis.

This study showed perspectives of the prosthesis development for high amputations, first of all the possibility of using the energy, accumulated during stance phase in the EPS prosthesis.

Conclusion

Biomechanic significance and technologic means for the development of lower limb prostheses, using the external sources of energy in combination with the energy, accumulated in flexible elements of the prosthesis, was demonstrated by the experimental EPS prosthesis for hip exarticualtion amputees. Above-knee stump function realized in the hip joint allowed to make gait characteristics of such a prosthesis close to the characteristics, obtained with an AK prosthesis. The imitational technique for gait examination of patients under various conditions gives the opportunity to increase reliability of the results and to shorten the time of the experiments.

Literature:

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