METHODS OF DESIGNING AND RESULTS OF EXPERIMENTAL TESTS OF MOTORIZED ABOVE-KNEE PROSTHESIS

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Summary.

The available artificial lower limbs reproduce the supportive and swinging functions of the prosthesis over the support, but they do not provide the reproduction of the main walking function - the function of active propelling agent.As a result this function is fully transferred onto the remaining limb and onto the whole of the supportive-locomotor system,which does not allow to considerably reduce general energy expenditures of the organism and the overloading of the remaining limb,as well as to provide the dynamic and kinematic symmetry of gait.

Therefore an important problem of prosthesis designing is the reproduction of propelling function,which may be achieved by the use of external energy.

The paper contains the main principles of designing a motorized above-knee prosthesis that can reproduce propelling functions.This is achieved by means of accumulating the energy of the drive during the double-step period and its impulsive discharge during the "back-push" phase in order to perform sharp sole flexion of the foot at the moment of pushing away from support.

Experimental testing of amputee walking on the model of motorized above-knee prosthesis has shown that the use of such prosthesis considerably reduces the movement asymmetry,unloads the remaining limb and the amputee is unaware of the weight of the prosthesis.

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Introduction.

The existing artificial lower limbs reproduce the functions of supporting the prosthesis and swinging it over the support;however they do not provide the performance of the main function of walking - the function of active propeller.[x] As a result this function is fully transferred to the remaining limb and the whole of the supportive-locomotor system which does not allow to reduce to a necessary degree the organism general energy expenditures and the overloading of the remaining limb as well as to provide the dynamic and kinematic symmetry of walking and the related aesthetic qualities of gait.

As is known the propelling impulse in case of normal walking appears during the phase of the so-called "back push". Consequently for the effective reproduction of the active propelling function while walking on a prosthesis it is necessary to normalize the components of the support reaction in the given phase.Depending on the type of walking the participation of skeletal muscles of the body in the formation of the back push may vary in character.However,in a number of physiological and biomechanical studies / I-3 / it was discovered that in the process of normal natural walking the main energy contribution to the formation of the back push is made by m.triceps surae /m.gastrocnemius caput mediale et caput laterale,et m. soleus/.

The effort developed by m.triceps surae creates an interjoint moment in the ankle joint which provides for the foot the possibility of pushing from support by means of sharp sole flexion.

In the paper / 4 / supplied by extensive experimental data it is possible to vividly see the stability of the peak

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[x]By an active propeller we mean a device that combines a motor with a converter of its work that contributes to or provides the body displacement.

position of the muscle-force moment in the ankle joint in relation to the phase time of the double step. This position corresponds to the beginning of the foot sole flexion. It is notable that joint moments /especially in the hip and ankle joint/ are characterized by considerable variability / 4 /. However the peak of the ankle-joint moment directed at the sole flexion in the back-push phase, for all types of joint moments in normal walking, maintains a stable position in relation to the podogram and to the time of support reactions; it coincides with the phase of the back push.

Due to the stated importance of m.triceps surae for the provision of the propelling function in the process of normal walking great importance is attached to the task of reproduction in above-knee prosthesis of the efforts equivalent to the operation of m.triceps surae by means of an autonomous external energy source and a corresponding driving device.

For the reproduction of the back push by technical means it is of highest importance that the release of power of about I50-200 W must occur during a short time interval /8-I5% of the double-step period/, while the quantity of average double-step power is less by an order / 5 /. This allows to supply an artificial leg with a drive with low outlet power. The energy of the drive, together with the energy accumulated during the transition relative to the foot, is accumulated during the whole double-step period /or during a little shorter interval/ and is periodically discharged in the phase of back push in the form of an impulse, the power of the impulse by far exceeding the power of the drive. For accumulating the energy springy, pneumo-hydrolic and other types of accumulators may be used.

The energy released by the impulses should be spent on performing the sharp sole flexion of the foot by means of applying the appropriate moment in the ankle joint.

Taking into consideration the given papers / 6 /, the average power N during the swing phase / t=0,2 s/ is equal to I50 W. The walking tempo is taken as equal to 86 steps, which corresponds to the double-step period $T_{double\ step}$= I,4 s.

The work performed $A=N\cdot t=30$ J. It is notable that this roughly coincides with the work performed to effect the vertical displacement of the general mass center /z/ in the process of normal walking of a person with mass P=700 N /the elevation during one step only considered.

When $z=0{,}045$ m, $A=P\cdot z=3I{,}5$ J.

As is seen from the data / 7 / the coefficient of energy recovery K_n^r in the process of walking with optimal speed is equal to 65 %. Considering the decrease of the coefficient of energy recovery as a result of walking on a prosthesis we take $K_{pr}^r=50\%$. In order to provide the stated energy recovery the prosthesis design should have the possibility of accumulating a certain amount of energy in the "front-push" phase and during the subsequent swing relative to the foot.

Considering the accepted value of K_{pr}^r and the efficiency of a springy accumulator /0,95/ the quantity of useful work performed by the drive during one double step will be equal to:

$$A_{drive}=30\cdot 0{,}5\cdot\frac{I}{0{,}95}\doteq I6\ \text{J}.$$

Accepting the time of energy accumulation in the accumulator equal to $t_{ac}=I{,}2$ s/the double-step period minus the time of operation of the springy accumulator in the back-push phase/, we shall receive the following value of the outlet power of the drive:

$$N_{drive}=I6:I{,}2=I3{,}3\ \text{W}$$

The drive with such outlet power has a quite acceptable size and weight that permit to place it in the proximal part of the shank in the above-knee prosthesis. In this case requirements to rational mass distribution in the prosthesis should be taken into account.

The autonomous power-source is placed on the waist and on other articles of clothes and provides the operation of the drive for one day (estimating the distance covered as 6-8km).

Thus, the suggested method of motorizing a lower-extremity prosthesis envisages as one of the basic principles of its design the principle of preliminary accumulation of energy and of subsequent concentration of energy discharged by impulses at the required moment and in the required unit /or element/ of the prosthesis. Such trend is in accordance with the bionic approach to the normalization of walking on the prosthesis, as in literature on physiology great attention is drawn to the fact that in the process of walking the activity of the majority of muscles is comparatively short-termed and has ballistic character. The ballistic regime of muscle operation has a number of advantages as compared with continuous activity / 8 /. According to Scherrer / 9 / there often occurs a so-called "activity burst" in m.gastrocnemius.

Because of the limited energy resources of the motorized prosthesis the external energy should not be used in cases when it may be replaced by the operation of dissipative forces, e.g. for slowering the movement of shank with foot in certain step phases friction forces may be used.

The use of external energy should also be combined with the use of resiliency forces of buffer devices, which allows to provide the springy mobility of appropriate prosthesis parts, the shock-absorbing of jerks, the accumulation and conversion of energy /buffers, shin-swinging devices, rotation devices/. In particular, to permit walking with various speeds it is necessary to envisage in the prosthesis a resilient restrictor of shank-flexion angle in the swing phase. The device plays the role of a buffer and energy converter.

For the purpose of optimal use of gravity forces and forces of inertia of moving links the mathematical and physical models of the motorized above-knee prosthesis should be designed so that the movements of the artificial limb /within the limits of the envisaged range of speed changes/ are performed in the resonance regime, in which case the period of proper oscillations of the three-link artificial leg / $T_{a.l.}$/ corresponds to the duration of the locomotor cycle. This may be achieved by automatic trimming of $T_{a.l.}$ to the walking speed by means of appropriate change of mass-inertial characteristics of the artificial leg on the whole and external conditions of movement.

While designing the motorized above-knee prosthesis together with the reproduction of the propelling function it is possible and necessary to comprehensively provide by various mechanisms: the observance of 5 regimes of foot operation (sole flexion in the front-push phase,dorsal foot flexion in the process of swinging relative to the ankle joint during the one-support phase,stabilization of the inter-link ankle angle at the end of the one-support step period,sole flexion in the back-push phase and dorsal foot flexion with the aim of functional shortening of the prosthesis in the swing phase).It is also possible to provide sufficient stability,equal lengths of the prosthesis and the sound extremity,as well as the possibility to adjust the prosthesis.

The indispensable feature of the design of a motorized above-knee prosthesis is the fact that in case the external energy source is switched off the prosthesis is automatically converted into an ordinary one without any mechanical changes. The invalid is supposed to switch on the external-energy system mainly in the process of covering comparatively long distances when it is important to reduce the overtension of the remaining leg and of the organism on the whole in order to prevent fatigue and other unwanted affects.

The stated bioengineering principles of designing a motorized lower-extremity prosthesis that can reproduce propelling functions were taken as a basis for constructing an experimental above-knee prosthesis.

Experimental research have been carried out in the process of amputee walking on a special track that has length IO m in order to record the time parameters of walking.

In the process of walking on experimental above-knee prosthesis we registered podograms and support reactions on the remaining leg and on the prosthesis (when the drive is switched on and off).

Besides,we recorded electromyograms of I2 muscles of the remaining limb and of the amputee's body,we also investigated the changes of muscle activity in the process of walking on the model of above-knee prosthesis when the drive is switched on and off.The walking tempo was chosen by the amputee at will and was maintained constant during the whole cycle of experiments.

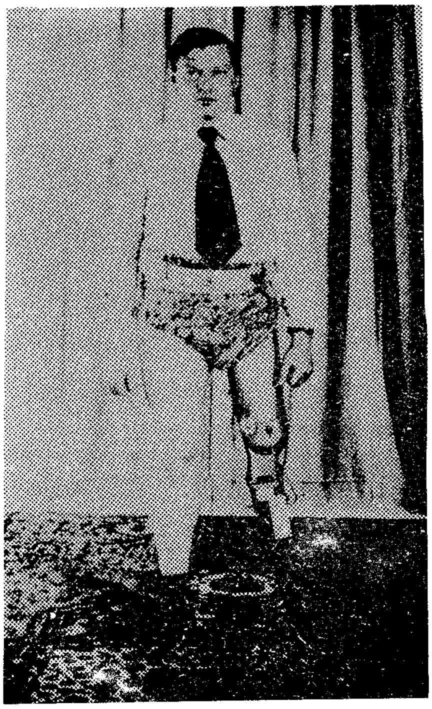

Fig.I - The scheme of above-knee prosthesis with active propelling function

The investigations discovered the decrease of support-reaction vector on the remaining leg by 6% and the increase of support-reaction vector on the prosthesis by I2% in the process of walking on the prosthesis when the drive was switched on.This led to the decrease by 68% of the asymmetry of support-reaction vectors on the remaining limb and the prosthesis, that is more than thrice.

Electromyographic investigations have shown the decrease of the electrical activity of the main muscle groups of the remaining limb and the body,which indirectly reflects the reduction of overloading of the remaining leg in the process of walking on the motorized prosthesis.

Subjectively the amputees reported the presence of a propelling impulse in the direction of motion when the foot of the prosthesis pushes away from support.They also marked the absence of the sense of the prosthesis weight,involuntary wish to go faster,the reduction of effort on the part of the remaining leg.

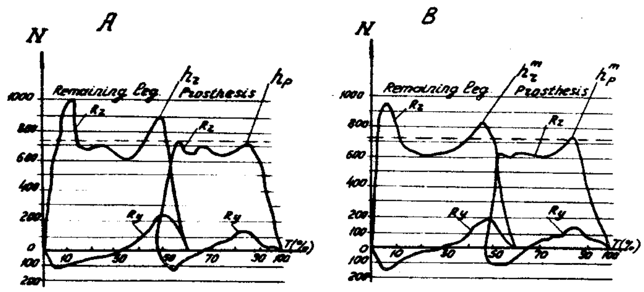

Fig.2-Experimental motorized above-knee prosthesis with active propelling function

Besides the functional advantages of the motorized prosthesis,its use may also be of importance for invalids after amputations due to various vascular deseases.For these amputees the reduction of stress on the remaining leg and on the cardiovascular system is a matter of vital importance.

The fact that the prosthesis is provided with an external energy source will allow to increase the number of locomotor types available to amputees (fast walking,slow running,walking along inclined planes,skiing,etc.).However,in this case biomechanical peculiarities of performing each of these functions should be taken into account while designing the prosthesis.

The stated principles of designing a motorized above-knee prosthesis may also be extended on prostheses after hip disarticulation,after two-sided above-knee amputation,upon lower-extremity braces,etc.

Considering the general tendencies of modern science and engineering the prospects of creating and implementation of motorized lower-extremity prosthese are very real.

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