AN ELECTROMECHANICAL FOREARM AND HAND

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Introduction

This is a design specification for an artifical forearm, wrist and hand (Fig. 1) preferably driven by four very small D.C permanent magnet servomotors used for the following movements.

1. The four fingers will be adaptable to the grasped article. Not only the finger units but also all the finger phalanxes will be independently flexed against the object. The flexion tendons are continuously force-controlled by an analogue servosystem.
2. The thumb will be controlled by a passively loadable mechanism which is velocity-controlled and rotates the thumb from extended position to any position between this and a limit stop in maximum opposition. In every position it will flex towards a resisting article. The hand will be able to make a fist.
3. The dorso-palmar flexion movement will be velocity-controlled and passively loadable. It will swing through a 90 deg. arc and can be stopped anywhere.
4. The prosupination mechanism will provide an active power output through a velocity-controlled 300 deg. swing. The palm is intended to concave gradually depending on the force of the thumb flexion tendon.

The servomotors will be supplied by transistor amplifiers controlled by, respectively, control site transducer or EMG-electrode and fed by NiCd-cells or a mains unit. The batteries may be worn in the paitent's pockets.

A functionally and cosmetically acceptable glove will cover the hand prosthesis. It will be developed by the Norrbackainstitutet and the SVCR in Stockholm.

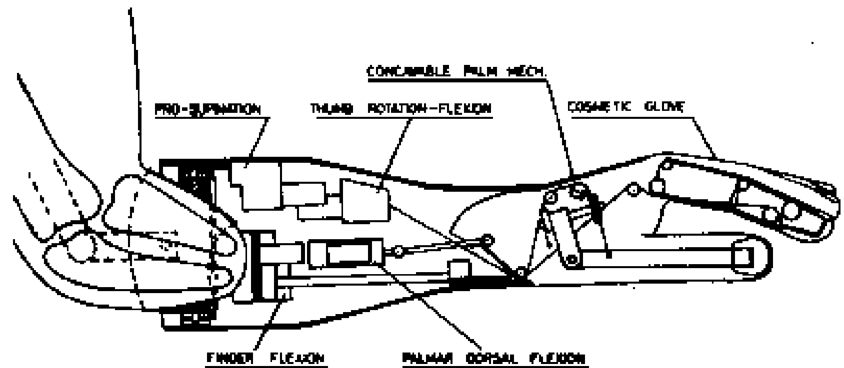

Figure 1. An electromechanical arm

The Design Specification

General

It is essential to make the specification acceptable from a medical, anatomical, and physiological point of view. Only thus can the technician be reasonably sure of a task leading to a real rehabilitation result.

The SVEN research group involves specialists of all professions connected with the development of the artificial hand project. Every decrease of the aim values, which may be needed because of technical or economical reasons, will be discussed by the group before deciding on further design work.

The main reasons for this job are not any extraordinary inventions or discoveries, but a trial to apply modern electromechanical servosystem components, miniature gear trains and steel wire technique to prosthetics. We also believe that an extremely light torque load on the elbow by the artificial hand and forearm is important to make this kind of external power prothesis wearable for several hours a day.

This group will immediately tackle the environmental and psychological problems (noise, cosmetic, and attitude aspects).

The SVEN group is connected to a neurophysiological EMG signal research group.

Environment

The components of the servomechanisms should be as good and well-known as possible. It will mostly be bought from military specified supply of servomotors, gear heads, and transducers. The military demands of environment tolerance stated for these components will be relevant also to the prosthetic system.

Temperature Range

It is difficult to get exactly the limit temperatures between which the component will work up to the catalogue quality tolerances. But experience gives the ambient temperature range of —10°C to +50°C. The temperature range usually mentioned (in the Mil. Spec.) is —55°C to +125° C for aircraft components. This, however, only means that the components will not be damaged between these temperatures.

Temperature Change

Since different parts of a component can be mechanically stressed by rapid temperature changes, military components are tested with respect to this consideration. An actual prosthetic situation is when the amputee comes from a normal temperature room of about +20° C to drive a car in the winter with a temperature of about —10° C.

Mechanical Shock

The demanded mechanical shock resistance of military servo components has always been a problem for the manufacturers. The requirement is about 200 G during one thousandth of a second. A blow of the artificial hand on a table takes more time than that. Here the limit of 70 G is adequate. This can be the most serious environment consideration for the prosthetic system.

Humidity

The hand prosthesis should be waterproof and tropic airproof. It will be covered with a long cosmetic glove, which will work as a wash-up glove. Tropic air humidity and fast temperature changes will require components resistant to corrosion and other damage due to moisture.

The Amputation Level

The artificial arm is designed for an amputee with a very short forearm stump or disarticulated elbow or to be part of a complete arm prosthesis.

A small rotation ability of the forearm stump might provide a control site for the prosupination drive mechanism.

Materials and the Elbow Torque Load

Possible ways to make the prosthesis light and the elbow moment low will be seriously studied. The hand will not contain any drive mechanism.

The four servomechanisms will be placed as proximally as possible. Thus the wrist rotation drive will work around the end of the forearm stump.

Noise

No kind of sound from the prosthesis is desirable. In this design the run of the D.C. motors and the gearboxes will be the only serious aspects of this problem.

The consultant company will work on this problem and assist the drive mechanism designer simultaneously.

Adaptable Fingers, Controlled by a Force Feedback Servosystem

The maximum force of the flexion drive mechanism will cause about 12 kg tension in the tendon of each finger (Fig. 2). This means max. 2.5 kg in the three fingers' grip against the thumb. Because the requirement of force is usually big in this kind of grip, a high friction coefficient is desirable on the palm side of the glove. The maximum power grip between the four middle phalanxes and the palm will be 12 kg in a half-opened hand position. The analogue precision grip by the outer phalanxes against the thumb will not exeed 5 kg.

A safety release mechanism will prevent damage in this force region.

The maximum distally directed force which can be passively applied on the base phalanxes will be about 50 kg (the hook grip).

Extension locks in the base joints will take this passive force. The base joints will be unlocked when they become unloaded and controlled by an extension signal on the finger flexion servosystem.

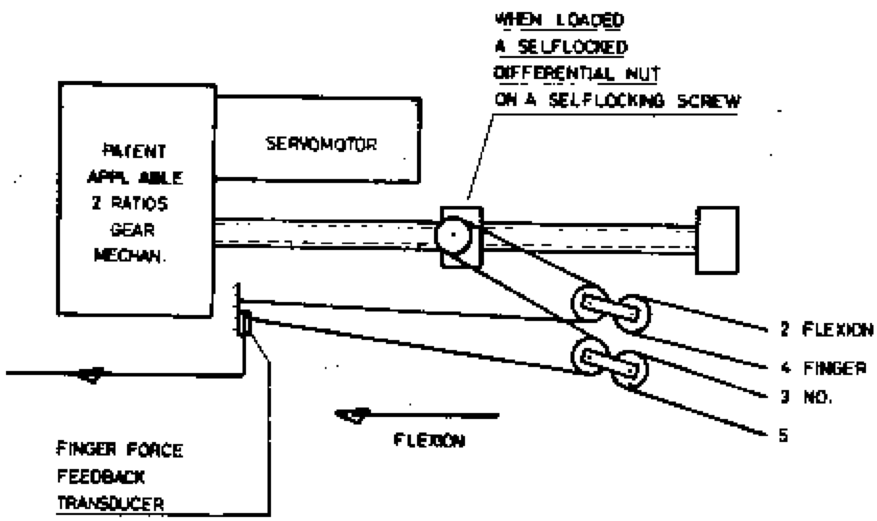

Figure 2. Four-fingers flexion drive mechanism

From the totally extended finger position the relative joint flexion sequence will start in the base joints and proceed to the outer joints. With no load a phase lag of 5 deg. between the base joints should be called for in the 2, 3, 4, 5 finger sequence.

In order to get an acceptable appearance the maximum extended middle joints will be about 20 deg. flexed.

The minimum time for moving a fully extended hand to the fist position will be 0.5 to 1.0 sec. The flexion velocity decreases proportionally to the load on the fingers. It is controlled continuously.

All the 12 finger phalanxes are independently adaptable to the shape of the grasped object. The disadvantage of instability between the fingers (caused by the tension equalizer pulley system) is removed by locking mechanisms in the pulleys, which are actuated when the fingers, after adaption, are loaded. In this moment the gear ratio of the flexion mechanism will increase automatically. This means a very big force ability, which is continuously controlled by a feedback force servosystem (Fig. 2). The input signal of this system can be a proportional electric signal from any type of control site, working on a high impedance transistor servoamplifier. The two-ratio gearbox system is designed to get the best out of the servomotor, which means minimizing the electrical input power requirement.

Finger Extension

Springs are supposed to provide the extension joint moment. The extension movement is controlled by reversing the flexion mechanism. The velocity will be continuously controlled for cosmetic reasons. The finger joint extension sequence will, for the same reason, be distal-proximal.

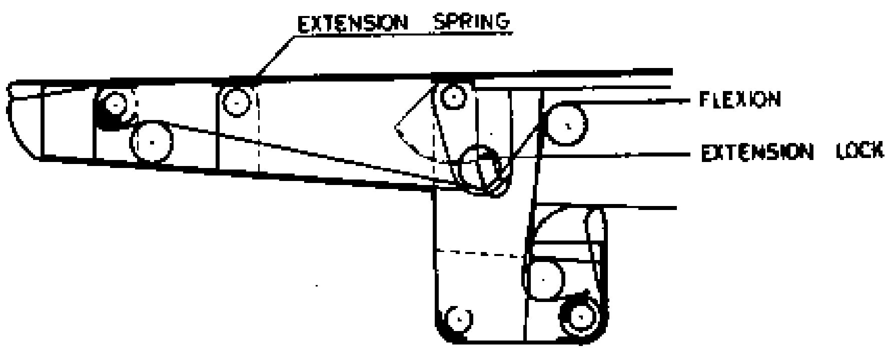

Figure 3. Finger flexion and extension

Finger Adduction-Abduction

The base joint of the forefinger or the middle finger is intended to be fixed to the dorsum. In the first case, fingers 3, 4, and 5 will be attached to the dorsum by a passive and hard spring-loaded abduction joint. The metacarpals are short and supported in the middle area of the dorsum. This arrangement is needed to avoid damage of the hand by an article pressed between two fingers.

The abduction angle will be about 5 deg. between the extended fingers. These angles can be eliminited passively by handshaking for instance.

The Cosmetic Glove and the Soft Tissues

Two types of material for the cosmetic glove are considered: plastic and rubber. This will mean quite different manufacturing methods, but the requirements of the glove versions are the same.

The intention is to obtain a cheap glove for short-time use, i.e., about 3—5 days. It must be thin in order not to load the low friction flexion mechanism and make it insensitive. The palm side should have very high friction but the dorsal side low friction in order not to feel uncomfortable in contact with cloth pockets for instance.

Artificial Sensing

The desire for some kind of tactile feedback information from the prosthesis is well-known. This project, however, does not yet involve the solution of this very hard problem.

Wrist Rotation

The desired total prosupination angle is ± 150 deg. The angle velocity is intended to be continuously controlled up to max. 180 deg. per second. The maximum active torque will be about 0.5 kgm. The mechanism is self-locked and the maximum output power is available at 0.25 kgm and 90 deg. per second. Because of stability problems this mechanism should at first be part of an open-loop system. The supination might be the most important movement.

One or two slim ball bearings are placed over the stump socket. This arrangement will make the prosupination independent of forces in the proximal-distal direction.

Thumb with Rotation and Flexion Mechanism

The relaxed thumb lies in the plane of the fingers, 45 deg. abducted and 45 deg. radio-palmar rotated compared to the fingers. This applies to both thumb joints.

Pulling the thumb tendon causes radio-palmar rotation from 90 deg. to 135 deg.

The thumb movement should be a self-locked idling motion with small active power. It will, however, make it possible to place the thumb in the adequate position for the desired grasp. There the self-locked thumb will provide a fixed platform for the force of the fingers which is then increased to the intended value, without the thumb being electrically activated. The self-locked thumb must withstand a force of at least 6 kg on the tip (the combined maximum of the fingers in a precision grip).

A decription of the thumb mechanism is found below, Figure 4a. The distal thumb joint could be movable as shown in Figure 1 of the FOA 2 report C 2129-234. Experiments will show if that arrangement is justified.

The thumb motions (Fig. 4a) are:

1. Radio-palmar (inward) rotation — ulno-dorsal (outward) rotation.
2. Flexion — extension.

The positions A, B, C, and D are regarded against the tips of the fingers.

A: Thumb outward rotated and extended (relaxed position).

B: Thumb inward rotated as far as possible. Adequate position for grasping a large object (as shown at E).

C: Thumb inward rotated and flexed as far as possible. Adequate position for a pinch. The middle finger will pass the thumb.

D: Thumb inward rotated as far as possible but not completely flexed. Adequate position for a 3-jaw chuck grip, which will not become entirely perfect around a small object. The middle finger *may* pass.

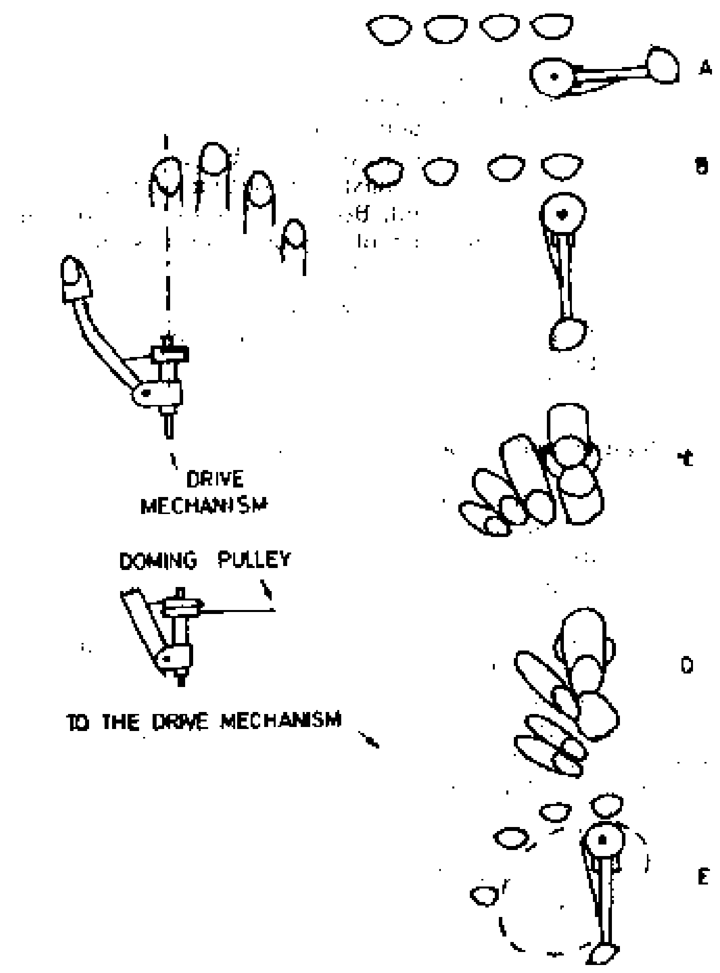

Figure 4a. Thumb mechanism

It would be better if the thumb tip moved ulnary when being extended from the maximally flexed and inward rotated position, as shown in Figure 4b, but it does not look natural.

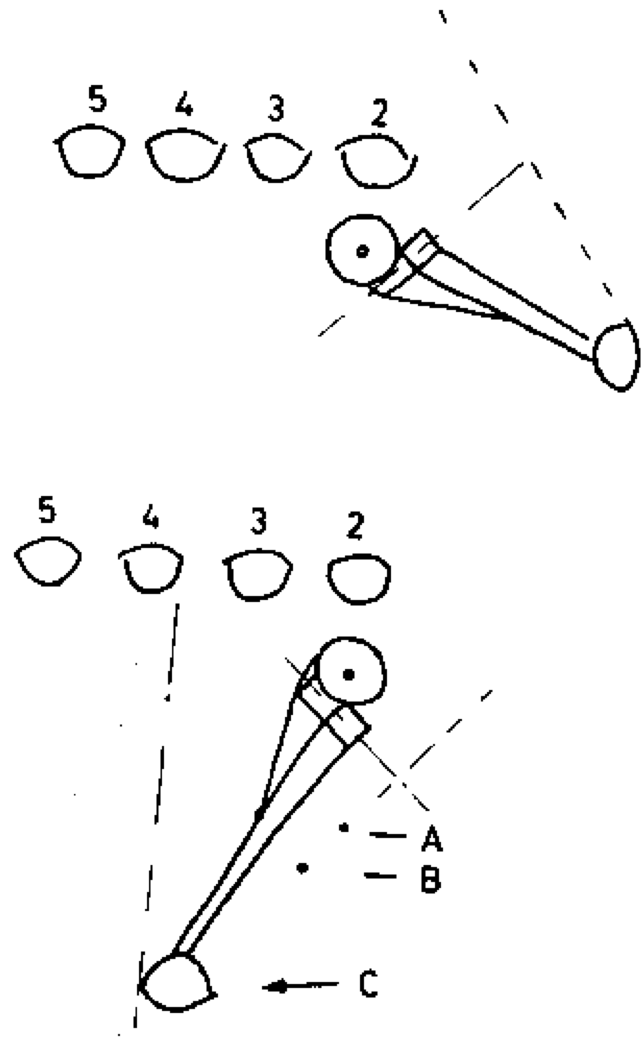

Figure 4b. Thumb mechanism. An oblique thumb flexion joint provides a good pinch at point A, a nearly perfect chuck grip at point B, and a full hand grasp with the thumb at po nt C. The motion pattern is not as natural looking as in Figure 4a

To provide a good pinch, the index finger should be the one rigid against side forces. The middle finger is not suitable for the pinch.

Doming the Dorsum

To make a natural precision grip around (for example) a washer, it could be desirable to hollow the palm as in a natural hand. This could be obtained by means of the thumb tendon as shown in Figure 4a, lower left. The dorsum could be a flexible plate fixed around the wrist, and opposing the doming force by its natural spring action.

Wrist Adduction-Abduction

At this stage a rigid 15 deg. adduction is suggeted. An active or passive adduction-abduction joint will make the construction so complicated that it will probably have to be excluded.

Dorso-Palmar Flexion

This should be an active self-locked idling motion. A small, at the moment not specifiable, active torque can be exerted. The limits should be ± 45 deg. The joint mechanism must passively withstand a 300 N force, dorsal or palmar, at the knuckles. Maximum angle velocity 90 deg./s. attenuable in an open servosystem by means of a simple transistorized circuit.