MECHANICS OF THE BELGRADE HAND

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Summary

This paper presents the development of the basic mechanical elements of the Belgrade hand. The kinematics of the mechanism for finger drive, as well as the mechanism itself are described. The kinematics has been arranged in such a way that a rotational motion is converted into a circular one which is in turn converted into a fore-aft motion. Mechanical amplification of force for finger movement has been achieved in this way. In addition, this solution offers complete flexibility of the mechanical system with a reliable hand squeeze in all positions. Further, such kinematics enables full mechanical adaptation of each finger about an object. With the latest model the grasp function has been improved due to the placement of sponge rubber on the fingers thumb, and hand body. Thus a hand has been obtained very similar to the human one at least in a mechanical sense.

The mechanical hand is an electromechanical mechanism. The power source is an electric motor running at 5000 r.p.m. from a 12 V battery. A 10 : 1 gear ratio is used to reduce the motor speed and multiply its torque. A worm gear is connected to the gear box output. This worm provides an automatic lock when the motor stops. This allows the finger mechanisms to keep their position and hold onto an object firmly when the power is removed from the motor (Figure 1).

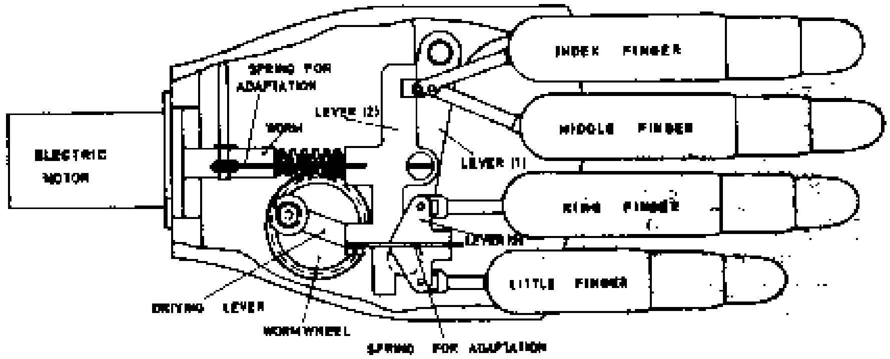

Fig. 1.

Force trasmission to the finger mechanism is realized by a connecting rod which is on a crank on the wormwheel. The other end of the connecting rod is linked via the joint to a "pulling horse" system through which movement of the fingers is achieved. In addition to force transmission to the finger movement, this system is designed to allow complete adaptability of the fingers to an object. The whole system is shown in Figure 2.

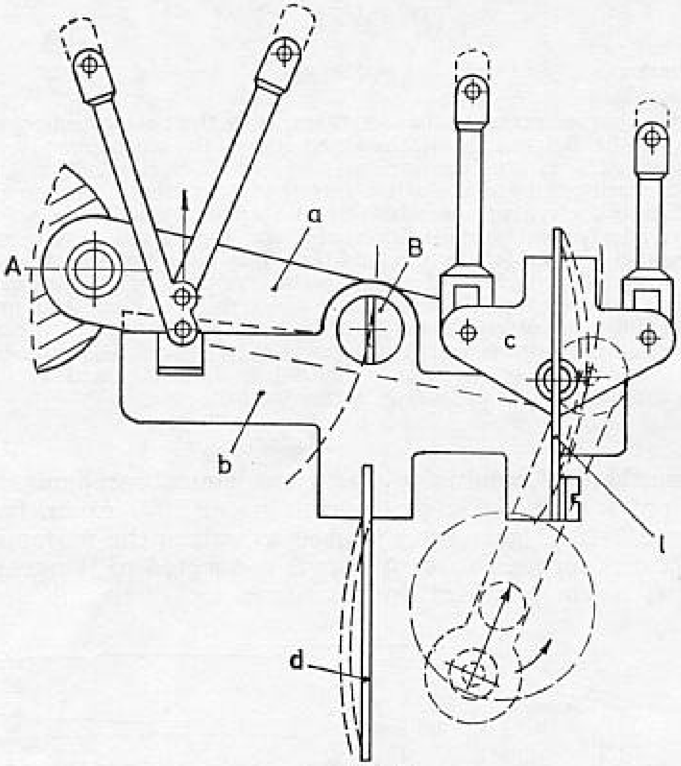

Fig. 2.

One end of the connecting rod transmits the rotary movement of the wormwheel to the end (c) of the lever (a). The other end of (a) is rotated round the socket A mounted in the hand body. The lever (a) and thus the end (c) and the point B produce arcs. A bearing has been placed at the point B, whose axis links levers (a) and (b).

In this way the lever (b) at the point B moves in an arc produced by the point B during the movement of the lever (a). This circular arc may be regarded as a straight line trajectory, since the radius of the arc in relation to the trajectory is large. In addition to this movement which approximates a linear one, and which has no influence on the finger movement, this design also provides an amplification in force. The force needed for movement acts at the point c of the lever Ac and is transferred to the point B of the lever b. In this model, the amplification ratio is 2 : 1, i.e. a force for the finger movement is obtained which is twice as great as that which would occur if direct transfer were effected. Furthermore, this design provides free rotation to the lever (b) around the axis at point B. Complete mechanical adaptability of the fingers linked to this lever is achieved if a laminated spring (d) is added. The lever (b) is connected to the lever (c), which rotates around the point D, to which the little and the ring fingers are attached and the spring for adaptation (e). The adaptation in both cases is complete and has been achieved by laminated springs which allow an independent movement of two levers set up one above the other (see Figure 2). When grasping an object, if any finger meets a protruding part of an object it stops moving, while the remaining fingers continue to move. Another finger then meets a protruding part, the other fingers continuing to move, thus grasping the object. This continues in turn, until the fourth finger, being the last, stops moving as well.

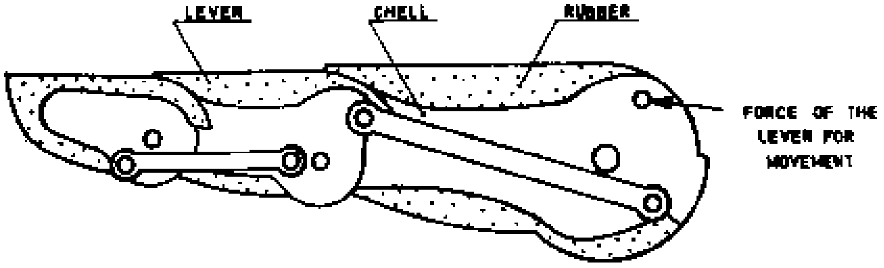

Fig. 3.

In this way an object is grasped very safely irrespective of its shape. However, in an older model, because the fingers, the thumb and the palm were made of metal, the object tended to slip and drop out, particularly with smooth objects. To improve this, the fingers were designed in shell shape whose exteriors were lined with a sponge rubber (Fig. 3).

This shape of the fingers, firstly, has greatly reduced the weight of the fingers, (approximately 60 gms), at the same time the grip area of the fingers has been increased, This has reduced slipping and the dropping of the objects from the hand. Finger movement, even in the new model, has remained with levers linked to each phalanx separately, which provides for movement of each phalanx similar to that of a natural finger.

The mechanism of the index finger of the artificial hand is diagramatically shown by the system in Figure 3. The lengths of particular levers, characteristic distances and angles are given in the table (Fig. 4).

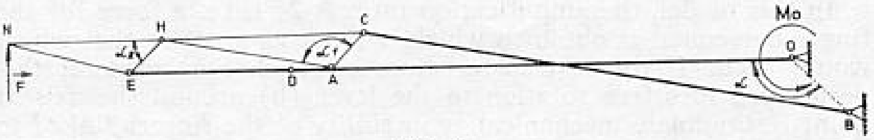

Fig. 4.

$\overline{OD}=4.90$ cm

$\overline{BD}=4.70$ cm

$\overline{DE}=1.60$ cm $\qquad \alpha = 3\,\frac{\pi}{4}$

$\overline{OB}=0.75$ cm $\qquad \alpha_1=2.16\ \text{rad}=124^{\circ}$

$\overline{AD}=0.40$ cm $\qquad \alpha_2=\frac{\pi}{4}$

$\overline{HE}=0{,}45$ cm $\qquad AH=1.70$ cm

$\overline{AC}=0.50$ cm

$\overline{HN}=1.50$ cm

If we assume that force F and the tip of index finger always act vertically upwards, we can apply Lagrange's principle of virtual displacements in the form of:

$$-F\,\delta y+M\,\delta\varphi=0 \tag{1}$$

where y is the coordinate of the point of attack N of force F, M being the turning torque at the end of lever $\overline{OD}$, and φ the angle over which the lever $\overline{OD}$ turns. The weights of system elements have been ignored (Fig. 5).

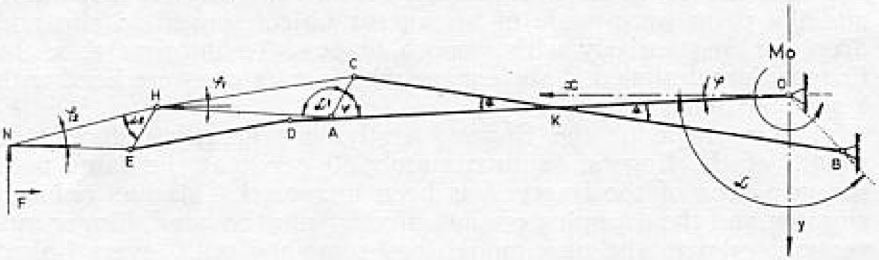

Fig. 5.

From Equation 1, considering that this concerns a system with one degree of freedom and that

$$y = \overline{OA} \sin \varphi - \overline{AH} \sin \varphi_1 + \overline{HN} \sin \varphi_2$$

that is,

$$\delta y = \left(\overline{OA} \cos \varphi - \overline{AH} \frac{d\varphi_1}{d\varphi} \cos \varphi_1 + HN \frac{d\varphi_2}{d\varphi} \cos \varphi_2\right) \delta\varphi$$

we obtain directly the equilibrium equation:

$$M = F \left(\overline{OA} \cos \varphi - \overline{AH} \frac{d\varphi_1}{d\varphi} \cos \varphi_1 + \overline{HN} \frac{d\varphi_2}{d\varphi} \cos \varphi_2\right) \qquad (2)$$

Expression 2 provides the moment required at each finger. The adaptive mechanism through the levers b and c provides a distribution of forces to each finger tip. Thus the force is supplied to the four active fingers.

The thumb moves on a separate mechanism driven directly from the worm gear. Since it is not articulated its motion is straight forward and fixed. It provides the opposing force for which the four fingers act. Thus an object is grasped between the thumb and the four fingers as in a natural hand during the grasping mode.

The thumb also has a second mode of operation. This mode allows the prosthesis to perform a clasp or fist. This is accomplished simply by delaying the thumbs motion and allowing the four fingers to close onto the palm of the hand. This dual mode is the same as in an earlier model.