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BIOMECHANICAL CHARACTERISTICS OF THE HAND MOVEMENT IN THE MAN AND MACHINE SYSTEM

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ABSTRACT

The work discusses methods for determining the biomechanical characteristics for describing hand movements. The motion and physiological state of the hand are analysed.

Methods for measuring the state of the hand are also analysed. The hand is assumed as an open kinematic chain with numerous degrees of freedom.

In contrast to the complexities of the anatomy and work functions of the human hand which have long been recognized, there exists no analytical model of the hand movement. This paper presents a simple model of the geometry, motion characteristics and dynamic properties of the human hand. This model makes possible the evaluation of the internal forces in the hand joints in several plane motions. The method we used consists of two parts. The first is an observational technique for evaluating the working sequences of the hand. The second part of the method is a set of criteria for the ergonomic standards recommendations. This part of the method consists of simple mechanical observations. The next step is to consider such factors in relation to health and safety.

STRUCTURAL HAND MODEL

For a theoretical study of the moving hand physical and mathematical models of the system must be constructed. Considering certain simplifications of the open kinematic chain and neglecting interjoint translations, we can suppose 29 degrees of freedom in a normal, healthy hand. It is obvious that such a system cannot be described, because of the great number of motion degrees which make a mathematical model highly complex. The model we used was therefore kept as simple as possible, with due regard to the technically required accuracy. The next step in our rational simplification was to choose the typical working postures of the hand. As the first we chose the plane motion of the kinematic open chain.

In the present series of preliminary experiments we observed twenty male students, younger than 24.

For our biomechanical considerations we selected ten different typical motions. The subjects' weights, heights and lengths were recorded, and on this basis we determined the mean values according to the data obtained by Dempster. The mean mass of the subjects was $G^* = 75.2$ kg, and so we have:

$$
\begin{aligned}
l_1 &= 350 \text{ mm} & G_1 &= 2.025 \text{ kg} \\
l_2 &= 280 \text{ mm} & G_2 &= 1.185 \text{ kg} \\
l_3 &= 170 \text{ mm} & G_3 &= 0.4725 \text{ kg}
\end{aligned}
$$

One of these characteristic hand motions, which will be described here, is shown in Figure 1. The whole motion consists of two parts: 1st part from 0° to 90° foreward and 2nd part from 90° to 180° foreward.

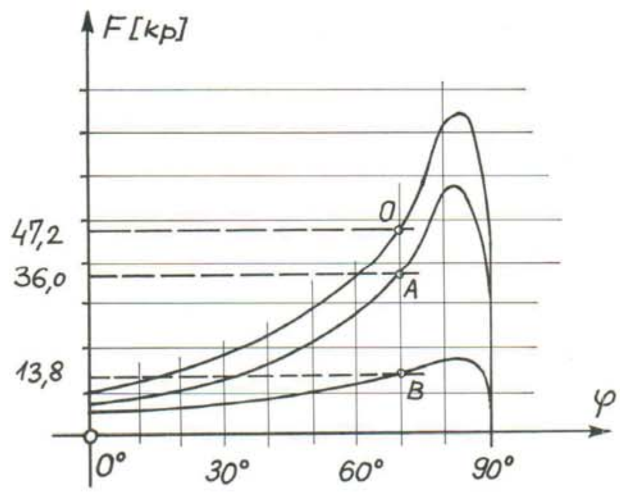

FIG. 1 – Characteristic hand motions N° 1 and N° 2.

All motions start from zero position and go on to 90° and then from 90° to 180°. Then next supposition is that motion of kinematic chain is plane curvilinear (circular) motion.

In this way we came to a very simple mechanical model. We used such a simple mechanical system in order to show the measuring method as clearly as possible. However, the practical method must include the following criteria: a) it must be simple enough to be easily applied by ergonomically untrained people; b) it must provide unambiguous answers, even if it results in a very great simplification, and c) it must offer possibilities for correcting such a simple approach.

*For description of symbols consult glossary at the end of the paper.

DESCRIPTION OF MOTION Nº 1

A schematic presentation of the system model of the hand movement is shown in Figure 2.

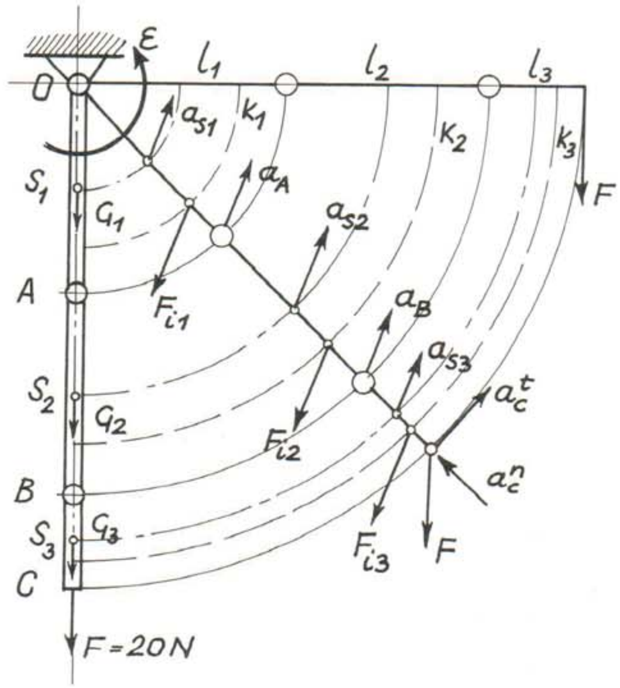

FIG. 2 – Schematic presentation of the system model.

In Figure 2, s_1, s_2 and s_3 are positions of the mass centres of the hand elements: G_1, G_2 and G_3 are the weights of the hand parts with its centre of gravity. O, A and B are the joints. The force F = 20 N at point C is the load which was in the hand. The accelerations in the centres of gravity are a_{si} (i = 1, 2, 3), and the accelerations in the joints are a_A, a_B and a_C. F_{ij} (j = 1, 2, 3) are intertial forces acting on the distances k_1, k_2 and k_3 measured from the origin O. On the basis of the data obtained as:

$$a_c^t = 4[ms^{-2}]$$
$$v_c = 6[ms^{-1}]$$
$$\varepsilon = 5[s^{-2}](\text{constant})$$

a computer based method was used to establish the related reactions in the joints for each successive 15°.

If the program is given in coordinats of the type

$$\varphi_\sigma(\xi^p, \dot{\xi}^q, t) = 0$$

we may write it as

$$\varphi_\sigma[\xi^p(\gamma_i^\mu), \dot{\xi}^q(\gamma_i^\nu), t] = 0$$

or as

$$\varphi_\sigma(\gamma_i^\mu, \dot{\gamma}_i^\nu, t) = 0$$

Thus the equations of the motions of the model are

$$m_1\ddot{x}_{11} = F_{11} + R_{11} + P_{11}$$
$$m_1\ddot{x}_{12} = F_{12} + R_{12} + P_{12}$$
$$m_2\ddot{x}_{21} = F_{21} + R_{21} + P_{21}$$
$$m_2\ddot{x}_{22} = F_{22} + R_{22} + P_{22}$$
$$m_3\ddot{x}_{31} = F_{31} + R_{31} + P_{33}$$
$$m_3\ddot{x}_{32} = F_{32} + R_{32} + P_{32}$$
$$J_1\ddot{\varphi}_1 = M_1 + L_1 + N_1$$
$$J_2\ddot{\varphi}_2 = M_2 + L_2 + N_2$$
$$J_3\ddot{\varphi}_3 = M_3 + L_3 + N_3$$

After some simplifications we calculated the forces in the joints as a function of the hand angles. The respective results are shown in Table 1, and the graphical functions can be seen in Figure 3.

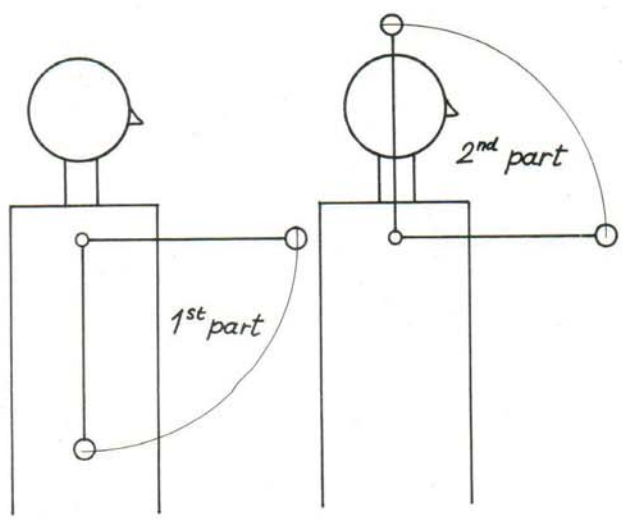

FIG. 3 – Forces in the joints O, A, B as a function of angles.

TABLE 1
Forces in the hand.

Force angle	0°	15°	30°	45°	70°
B	24.7 N	37	54	76	138
A	36.5	73	112	180	360
O	56.8	77	133	229	472

EXPERIMENTAL PROOF OF THE RESULTS

In order to test the validity of our calculation results shown above we carried out some combined experiments. By means of accelerometers we measured the accelerations at characteristic points (centres of gravity), and at the same time photographed the observed motion with an ordinary film camera. The camera speed was 48 prints per second, but in the analysis we used only every sixth or eighth print so that the time intervals were 0.125 and 0.166 s. Each motion was filmed in two directions (upward and downward). Linking together the characteristic points of the hand elements, we determined their paths in the time function. Thus we found the following laws of motion:

$$s = s(t) \text{ or } v = v(t) \text{ or } a = a(t)$$

CONCLUSION

Theoretical and experimental studies carried out on persons and on the basis of proposed mathematical and dynamic models indicate that during motion forces in the joints at first increase but at the end suddenly decrease.

Although the motion is not circular as we supposed, the results of theoretical and experimental studies differ by no more than 5%. The influences of friction, vibration and mass distribution are present only in combined motions, for example in a combination of motions N° 1 and N° 2, where they must be taken into consideration in the analysis.

GLOSSARY

φ	angle of rotation	
ω	angular velocity	$[s^{-1}]$
ε	angular acceleration	$[s^{-2}]$
m_i	mass of kinematic chain members	$[Nm^{-1}s^2]$
l_i	length of chain members	$[m]$
a_{si}	acceleration of the mass center of the i-th member	$[ms^{-2}]$
a_O, a_A, a_B	accelerations in the joints	$[ms^{-2}]$
F_{ik}	inertial forces of the chain member	$[N]$
G_i	weight of the chain member	$[N]$
ξ^p, η^v	generalized coordinate	
$\dot{\xi}^q$, $\dot{\eta}^v$	generalized velocity	

t	time	[s]
F, F_{ij}, R_{ij}, P_{ij}	forces	[N]
$\ddot{x}_{ij}$	acceleration	[ms^{-2}]
J_i	moments of inertia	[Nms^2]
M_i, L_i, N_i	moments	[Nm]