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Successive Sinusoidal Motions of Open Kinematic Chains for Transportation of Mobile Self-Programming Robot-Technical Complexes

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I. Introduction

Typical traditional problems for open kinematic chains, which have found their practical application, are the problems of calculation of a “grate” type robot and “anthropomorphic” type robot (Fig. 1). The joints of individual links in most structures are of class V, but in practice there are also models where the joints are of a higher degree (for instance, of class IV or III).

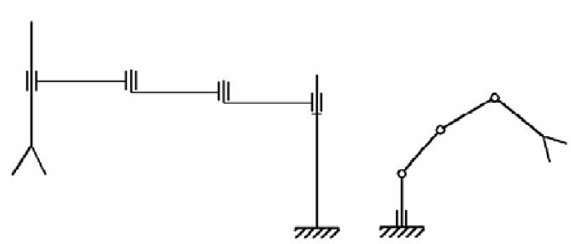


Fig. 1

The law of motion is expressed as

$$S = f(x, y, z, t).$$

There are several methods for solving the primal and inverse problems for the robots shown. A feature of those methods is that they have solutions that do not depend on the number of links and the type of joints. This feature makes them also applicable to a long kinematic chain.

A special feature of the long open kinematic chains ($n > 6$ degrees of freedom) is that there are more than one solution, i.e. the same result – position of the output link can be obtained with different configurations of the kinematic chain (availability of excessive degrees of freedom).

The logic of the solutions would be entirely different if during calculations we were not trying to find the output link position, but considering each successive link as an output link and investigating its interaction with the environment.

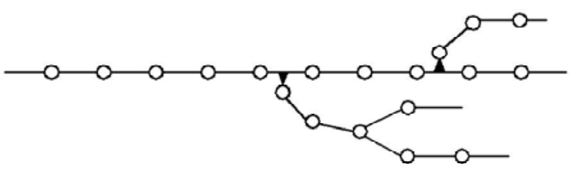
The problem discussed means that the commands are to be given successively to the first link at the support. After execution of the command, the same is given to the next link, the next command being given to the first link at the support, etc. This succession of the commands and their execution is the target of the problem of movement of mobile self-programming robot-technical complexes. This problem is discussed herein below.

II. Presentation

1. Long kinematic chains

Most mobile self-programming robot-technical complexes have a structure that is identical to that of a long kinematic chain. The herein-discussed long kinematic chains are open kinematic chains with branches and closed loops within them (Fig. 2). The kinematic chain links themselves can be both rigid solid machine elements, and integrated mechanisms, which could be considered for our purpose as one link of a long kinematic chain.

a



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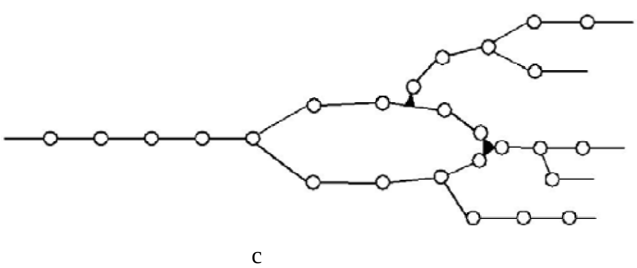


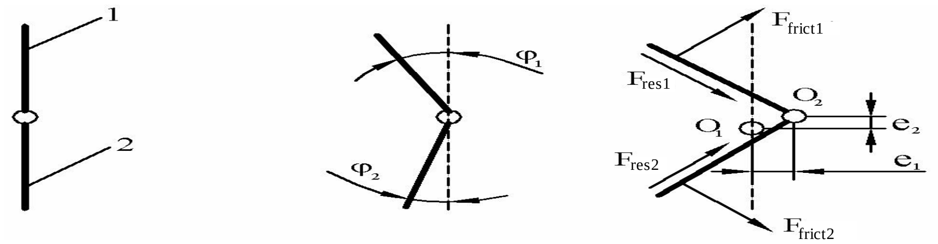
c

Fig. 2

The type of joints between individual links determines the kind of possible motions, which they could perform to each other, i.e. one motion is possible with joints of class V (rotation or translation), two are the possible motions with joints of class IV, three are the possible motions with joints of class III, etc.

We assume for the sake of simplicity of presentation that the joints of the links of the kinematic chains are identical and are also on the same axes.

Now, let us examine a mechanism of two links that are interconnected by a swivel joint of class V and are working in a homogeneous medium of viscosity η (Fig. 3a). This problem can apparently be examined as a planar one.



a b

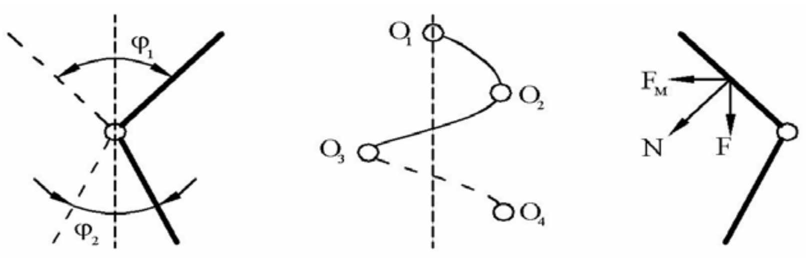


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Fig. 3

The following characteristics of links will be used:

– for link **1** – mass m_1, effective area of contact with the environment S_1, and volume V_1;

– for link **2** – mass m_2, effective area of contact with the environment S_2, and volume V_2.

When a driving force is applied to the mechanism's joint (Fig. 3b), the mechanism links **1** and **2** will start to approach to each other, by deviating respectively at angles φ_1 and φ_2 from their initial position. Besides, the swivel joint between them will also change its position by moving to the relative distances e_1 and e_2 from its initial position.

The driving force applied to the mechanism is balanced by the two resistive forces of the links (in this case, the frictional forces in the mechanism's joint are neglected as we assume that the joint is ideal and also that the links are infinitely rigid, i.e. there is no energy accumulation in them), i.e.

(1) $$F_{\text{driv}} = F_{\text{res1}} + F_{\text{res2}} + J_1 + J_2 + F_{\text{frict1}} + F_{\text{frict2}},$$

where:

$$
\begin{aligned}
F_{res1} &= f\,(S_1,\ \eta,\ \omega_1),\\
F_{res2} &= f\,(S_2,\ \eta,\ \omega_2),\\
J_1 &= f\,(m,\ \omega_1,\ \varepsilon_1),\\
J_2 &= f\,(m,\ \omega_2,\ \varepsilon_2),\\
F_{frict1} &= f\,(\eta,\ \omega_1,\ S_{real2},\ \xi_1),\\
F_{frict2} &= f\,(\eta,\ \omega_2,\ S_{real2},\ \xi_2),\\
\omega_1 &= d\varphi_1/dt,\\
\varepsilon_1 &= d\omega_1/dt,\\
\omega_2 &= d\varphi_2/dt,\\
\varepsilon_2 &= d\omega_2/dt,
\end{aligned}
\tag{2}
$$

and ξ is the surface smoothness.

Taking into consideration the Newton's law of proportionality of resistance in a fluid of geometrically similar bodies to the square of their linear dimensions, it follows that if

$$
\begin{aligned}
S_1 = S_2, &\qquad m_1 = m_2,\\
S_{real1} = S_{real2}, &\qquad \xi_1 = \xi_2,
\end{aligned}
\tag{3}
$$

hence $F_{frict1} = F_{frict\ 2}$ and consequently:

$$\varphi_1 = \varphi_2,\ \ e_2 = 0. \tag{4}$$

When one of the equations (3) is different, then the resistive forces of the links F_{res1} and F_{res2} will not be equal and, hence, the equations (4) will not be satisfied, i.e. $e_2 \neq 0$. Then the centre of gravity O (for the sake of simplicity in this case we choose that this point coincides with the swivel joint centre O) will move from point O_1 to point O_2 and the segment O_1O_2 is not perpendicular to a straight line from the mechanism's initial position.

If we examine the reverse process, i.e. we apply a driving force in reverse direction, i.e. we open the links already brought together, and bypass the mechanism's straight position (Fig. 3c), then we will have to exactly determine the initial moment of application of the reverse driving force.

With $m_1 < m_2$ it follows that $J_1 < J_2$. After the motion is finished, we have a residual moment of inertia, $J = J_2 - J_1$, that would continue to act on the system as an internal driving force.

The application of driving force in a direction that is reverse to the so-examined situation before damping the residual moment of inertia would transform the equation (1) to the following form:

$$F_{driv} = F_{res1} + F_{res2} + J_1 - J_2 + F_{frict1} + \mathrm{F}_{frict2}. \tag{5}$$

Consequently, the moment of inertia of the link with a greater mass (in this case, m) would add to the driving force at the beginning of driving, afterwards the discussions on the above case would repeat, however in reverse order.

Examining the normal reaction N of the fluid that acts on link 1, we can resolve it on the two axis of motion, namely:

$$F = N \sin\varphi, \qquad (6)$$

$$F_M = N \cos\varphi,$$

where F is the force by which the mechanism is moved ahead, i.e. the driving force, F_M – the force by which the system's centre of mass is moved off the axis of motion.

It is seen from (6) that the motion of the centre of mass is performed on the sinusoid (Fig. 1c).

Thus, the angle φ becomes a significant factor, on which the driving force F depends.

The driving force F may reach high values for certain values of the angle φ, which is in our interest. However, there are also other values of φ that may inverse the sign of the driving force F.

The magnitude of driving force F also depends on the number of half-waves in the long kinematic chain, i.e.

$$F_d = KF,$$

where: K is the number of half-waves realized by the long kinematic chain, and F_d is the driving (towing) force of the long kinematic chain.

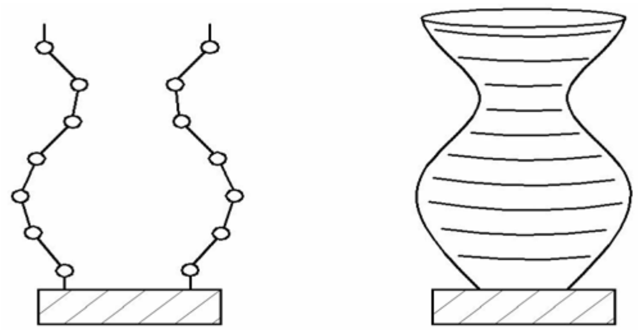

Fig. 4

Fig. 4 shows a mechanism that works with two kinematic chains as driving elements for movement.

The typical point here is that the two kinematic chains work in phase opposition to the wave, whereby the body M damps the side oscillations of its centre of mass.

When examining the spatial problem, the mechanism shown in Fig. 4a will transform to a peculiar tube (Fig. 4b) that would perform sinusoidal peristaltic motions. By taking into consideration the equations 1 and 2 as well as the conditions 3 and 4 for the spatial version, we will obtain the conditions that determine the driving force.

Similar mechanisms can be found in the living nature among the animal world. Such type of movement is performed by fish, snakes, worms, squids, frogs etc. Also similar are the movements of fluids within the living organisms (movement of food in the gastroenteric tract, movement of blood, in the lymph etc.).

This type of actuating mechanism for movement is characterized by its extreme silence of operation, constructional simplicity as well as the absence of swivel joints with a whole turn or more than one turn.

2. Application of the successive sinusoidal motions for the movement of mobile self-programming robot-technical complexes on various ways

The case discussed could be referred to one kind of motion, i.e. swimming in a fluid. Further to that kind of way there are also other kinds of ways, namely:

a) swimming in a fluid;
b) swimming on smooth fluid surfaces;
c) swimming on smooth fluid surfaces with waves;
d) smooth dry way;
e) a way with pits and bulges;
f) a way on a beam;
g) a way on an interrupted beam;
h) a way on an interrupted beam with spikes and branches;
i) a way with slight sinking;
j) a way with stalling;
k) a way through a farm;
l) a way through a network.

The character of successive sinusoidal motions is kept during movement of long kinematic chains (mobile self-programming robot-technical complexes) on some of the above-mentioned ways, i.e. as this concept has gained currency acceptance – a running wave.

However, the different ways impose some requirements to the structure of mobile self-programming robot-technical complexes for the availability of different types of kinematic joints between the links, oriented on different axes so that the successive sinusoidal motion is able to increase the driving force F_d.

The availability of more than one degree of freedom between the links enables the performance of successive sinusoidal motions also on other axes in the space (Fig. 5). This increases the stability of mobile self-programming robot-technical complexes and enables a better control on the motion.

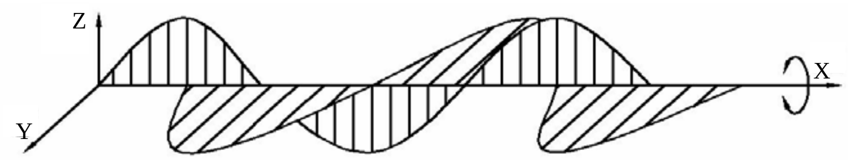

Fig. 5

Such cases are found with the higher vertebrates, where in addition to one main successive sinusoidal motion there is also a successive sinusoidal motion of twisting around the axis of the long kinematic chain as well as a slight successive sinusoidal motion that is parallel to the former one. As it can be seen, this completely covers the degrees of freedom of the joints of the individual vertebrae (n = 3).

3. Auxiliary means of long kinematic chains in their movement through various types of ways

Auxiliary means of long kinematic chains are links or kinematic chains that are attached to the main long kinematic chain. In most cases these are branches of long kinematic chains.

A special feature of the branches is that their relative motions are also successive sinusoidal motions that are caused by the main long kinematic chain and transformed by the connecting mechanism [14].

The absolute motions of the auxiliary means are the sum of the relative motion of the auxiliary motions and the motion of the long kinematic chain at certain moment. Such auxiliary motions in the nature of the living organisms are the limbs (Fig. 6).

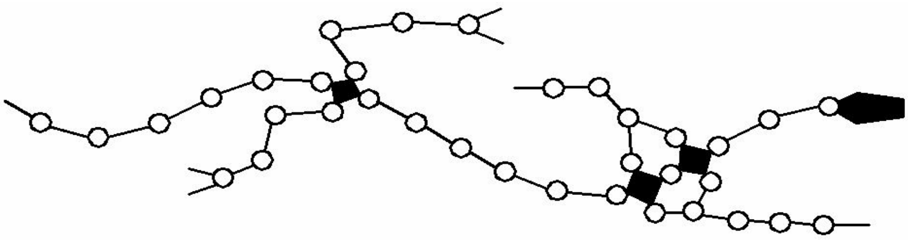

Fig. 6

III. Conclusion

Successive sinusoidal motions are a powerful method of movement of mobile self-programming robot-technical complexes on different kinds of ways, which has been taken from the nature of the living organisms. This method of movement does not lay down conditions and requirements to the way, but conforms a part of the kinematic scheme of the mobile self-programming robot-technical complex to the traveling conditions.

Designing the “limbs” of a mobile self-programming robot-technical complex requires conformity to the situation, in which it will exist and work, as well as to the ways on which it will move.

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Конструирование синусоидальных движений кинематических цепей для передвижения мобильных самопрограммируемых робото-технических комплексов

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(Р е з ю м е)

Конструирование мобильных самопрограммируемых робото-технических комплексов (МСРК) является большой и сложной задачей. Важным моментом в этом конструировании со своей стороны является выбор походки передвижения МСРК. Этот выбор дает отражение на их конструкцию. Существенным моментом при выборе походки МСРК представляет необходимость учета всех условий и требований окружающего пространства и выбор пути в нем.