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CLASS V ROTATING KINEMATIC JOINT WITH SINGLE ROTATIONAL ADDED MOTION

JUNTA CINEMÁTICA ROTATIVA DE CLASSE V COM MOVIMENTO ROTACIONAL ADICIONAL ÚNICO

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Abstract
The rotary kinematic connection is one of the two possible kinematic connections of the fifth class. A method is proposed for the initial synthesis of sections of long kinematic chains without additional power drives, but with a single rotational added motion. It is shown how the ordinary rotary kinematic connection is transformed into a spatial mechanism of a closed type, using all the advantages of this type of mechanism. The methodology shows that similar mechanisms are also used in biokinematics in fauna.

Keywords: Kinematic Connection, Rotary Joint, Movement.

Resumo
A conexão cinemática rotativa é uma das duas possíveis conexões cinemáticas da quinta classe. Propõe-se um método para a síntese inicial de seções de longas cadeias cinemáticas sem acionamentos de potência adicionais, mas com um único movimento rotacional adicionado. Mostra-se como a conexão cinemática rotativa comum é transformada em um mecanismo espacial de tipo fechado, utilizando todas as vantagens desse tipo de mecanismo. A metodologia demonstra que mecanismos semelhantes também são utilizados na biocinemática em animais.

Palavras-chave: *Conexão cinemática. Junta rotativa. Movimento.*

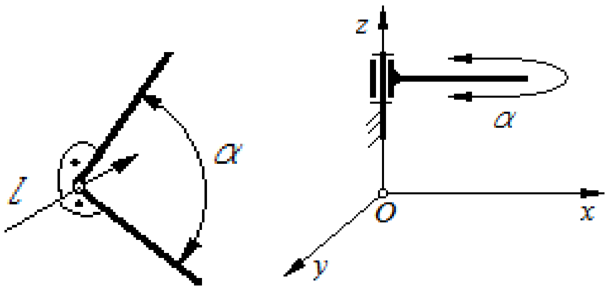
1 INTRODUCTION

Kinematic joints of the fifth class, according to Theoretical Mechanics [1,2], are of two types. One is a rotating kinematic joint, and the other is a sliding kinematic joint. These kinematic joints connect two links (bodies) that perform relative rotational or translational motion relative to each other.

A rotating kinematic joint of the fifth class has an axis of rotation perpendicular to the plane of motion of the links and passing through the point of rotation lying on the plane of motion “Fig. 1.a)”.

Figure 1

Fifth class rotating kinematic joint a) diagram of a rotating kinematic joint; b) rotating kinematic joint about the z axis of a coordinate system.



a) b)

The established dependencies of the rotating kinematic connection are shown in “Fig. 1.a)”. In order to take into account the kinematic dependencies of the movement, a coordinate system is set up. For the convenience and simplicity of the movement reading, it is extremely convenient for the rotation axis l to coincide with one of the axes of the coordinate system xOyz “Fig. 1.b)” (the z axis of the coordinate system is selected in the figure). Moreover, one link is stopped (only methodologically), thus the rotational movement is carried out solely by the other link.

In this way, the movement of the movable link is considered in the xOy plane.

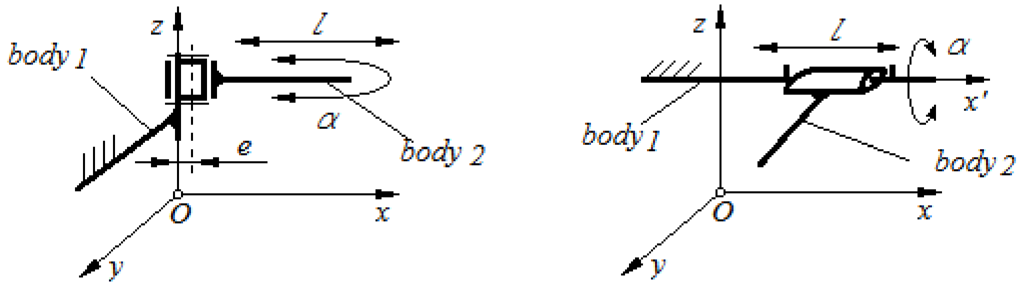
Thus, the task of the movement of the rotating kinematic link should not be considered in the xOz and yOz planes (here the projections of the movable link on these planes are ignored). The main argument for ignoring the projections of the movable link on the xOz and yOz planes is the fact that in these planes there is no consideration of angular movements, but only linear ones). This is the consequence of the choice of the position of the coordinate system to facilitate the methodological consideration of the movement of the rotating kinematic link.

2 CONSTRUCTIVE ADDITION OF MOTION TO A ROTATING KINEMATIC CONNECTION

The constructive addition of motion to a rotating kinematic connection is a geometric change in the shape of the links that changes the relative motion of the links between them.

Figure 2

Constructive addition of motion to a rotating kinematic connection



a) b)

The constructive addition of movement between the links of a rotary kinematic connection [3,4,5], by modifying link 1 is shown in "Fig. 2,a)", and by modifying link 2 is shown in "Fig. 1.b)" [6,7]. Similar rotary kinematic connections are often found in mechanical engineering [8,9,10] and can be considered as a type of development of rotary kinematic connections of V-class.

2.1 Exposition

In this article, added motion is understood to mean added motion that does not require additional drive with a separate power unit. That is, between the drive of the links of the rotating kinematic connection, in general, there is a certain nonlinear reversible dependence.

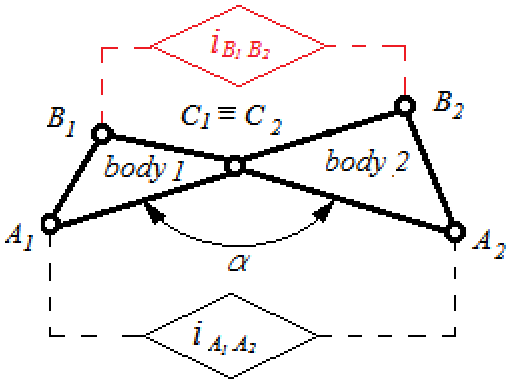
2.2 Kinematic addition of motion to a rotating kinematic connection

Kinematic addition of motion, in practice, represents the transformation of the rotating kinematic connection into a closed spatial mechanism. This is the initial stage of the synthesis of kinematic chains for various purposes in mechanical engineering.

In fact, between the two links of the rotating kinematic connection, an additional kinematic chain is added, which participates in the movement between the links of the primary rotating pair.

Figure 3

Conversion of a simple rotary kinematic connection into a kinematic mechanism.



The diagram of the transformation of a simple rotary kinematic link into a kinematic mechanism shown in "Fig. 3." demonstrates that the rotary kinematic link $A_1B_1C_1$ (link 1) is connected to $A_2B_2C_2$ (link 2) at points $C_1 \equiv C_2$ and, with respect to points A_1 and A_2, implements a gear ratio $i_{A_1A_2}$. It is important to note that links 1 and 2 of the rotary kinematic link are not binary, they are always branching (or collecting).

The method of initial synthesis of long kinematic chains begins from here. If necessary, to correct the movement of the rotating kinematic link, an additional kinematic chain is added, which takes movement from point B_1 of (link 1) and transmits movement to point B_2 of (link 2) through the gear ratio $i_{B_1B_2}$. The kinematic chain used between points B_1 and B_2 can be of any type (lever, gear, cam, belt or mixed, with or without added power motors). In this material, a restriction is placed on kinematic chains without added power action (motor-reducer groups).

Thus, the separate task already defines *a kinematic closed mechanism*, of which one branch is separated from the rotating kinematic link, and the other branch is built from an additional kinematic chain, which adds or subtracts movement from the main branch of the rotating kinematic chain.

The diagram of a rotating kinematic connection shown in "Fig. 1. b)" will represent a basic diagram for considering rotating kinematic pairs.

2.3 Added rotational movement between parallel axes

The task *is to show the main dependencies for synthesizing an additional, parallel kinematic mechanism of the main rotating kinematic connection, which does not have an additional power link, but corrects the movement between the two main links in an axis parallel to or coinciding with the main axis of rotation of the rotating kinematic connection.*

For convenience, two concepts will be introduced. One is a main kinematic chain, which actually represents the rotating kinematic connection and is conventionally assumed to be the power kinematic chain in the overall kinematic mechanism (in "Fig. 4. b)" is shown in black). The other is a *controlled kinematic chain*, which receives movement from one link of the main kinematic chain and controls the movement of the second link of the main kinematic chain (in "Fig. 4. b)" is shown in red).

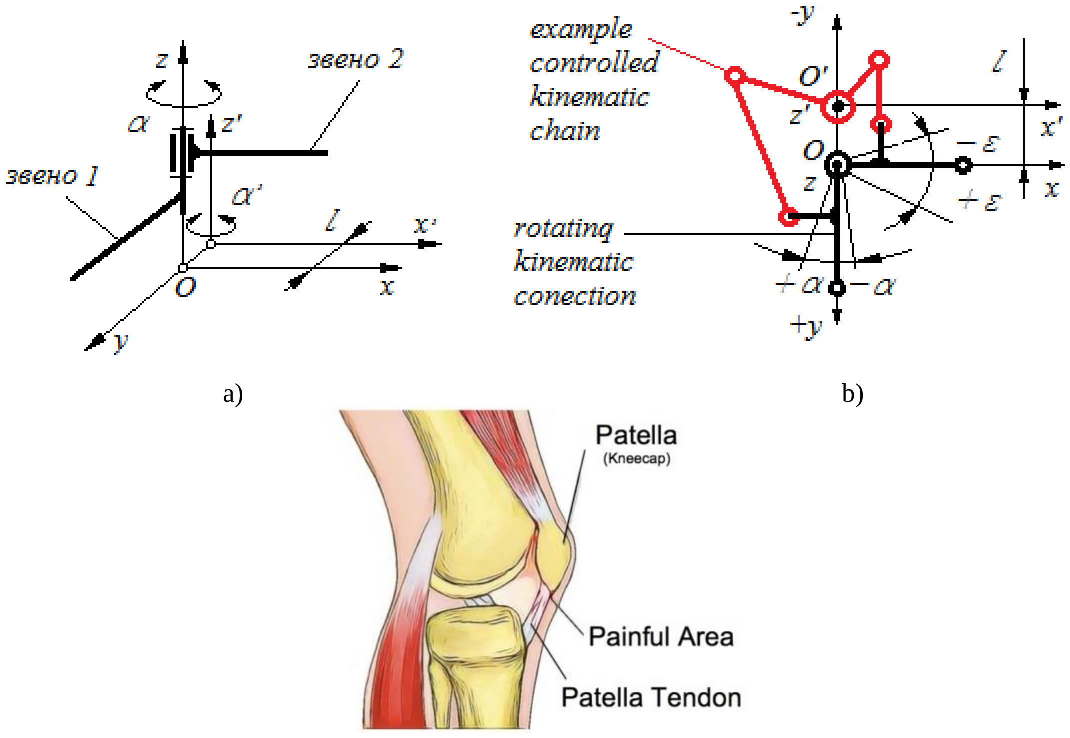
The movement will be recorded in the xOy plane "Fig. 4. a)". For convenience and clarity, it is assumed that link 1 is parallel to the ***y*** axis, link 2 is parallel to the x axis, and the axis of rotation of the main rotating kinematic connection coincides with the z axis. It is allowed that the parallel mechanism is moved away from the z axis of rotation (for example, to the ‘**z** axis), that is, the distance $l\neq 0$.

For methodological and illustrative reasons, in order to more easily explain the movements of the mechanism, it is assumed that the planar motion of the centers O and O' is stopped ("Fig. 4. b)"). Thus, if link 1 is deflected by ∢-α , by means of the controlled kinematic chain, link 2 will deviate from its initial position. The deviation can be zero, positive or negative (i.e. ∢ε = 0 ,∢ +ε or ∢ -ε), depending on the gear ratio $i_{B_1B_2}$ of the controlled kinematic chain in “Fig. 3. ”. Moreover, the controlling kinematic chain can create different motion of link 2 ’(“Fig. 4. b)”). depending on the different positions of the driving link 1. That is, the motion of link 2 is a nonlinear function of the motion of link 1.

$$\varepsilon = f(\alpha) \qquad (1)$$

Figure 4

a). Scheme of a rotary kinematic joint about the z axis and added motion about z'; b). Scheme of a rotary kinematic joint about the z axis, with added rotational motion in one plane; c) Knee joint.



a)

b)

c)

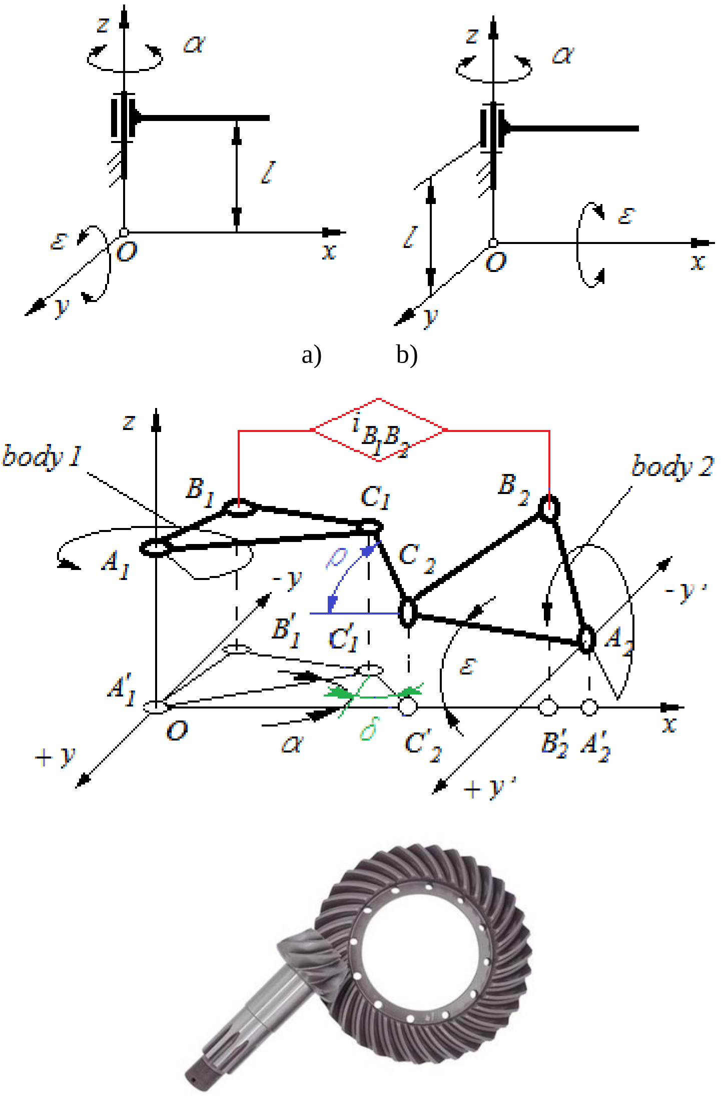
In "Fig. 4. c)" an anatomical diagram of a knee joint is observed [10]. The knee joint is a complex biomechanism, including many links and power connections. What is noticeable is that it is not a biokinematic connection of a simpler version, such as the elbow joints or the joints of the phalanges of the fingers. In-depth biokinematic analysis will show that the knee joint is not a rotating biokinematic connection, but a spatial biokinematic mechanism, where the main biokinematic connection and the controlling biokinematic chain are clearly outlined.

2.4 Added rotational motion between perpendicular axes

The addition or, respectively, subtraction of motion in mutually perpendicular planes of a rotating kinematic connection obeys the same laws as the addition of motion in parallel planes. The kinematic approach is identical, but the design solution differs due to the specifics of the machine elements and assemblies.

Figure 5

a). Diagram of a rotary kinematic connection with added rotary motion along the zOy axis; b). Diagram of a rotary kinematic connection with added rotary motion along the zOy axis; c). Diagram of a lever kinematic connection for rotary motion between two mutually perpendicular axes; d) Hypoid gear



a) b)

c) d)

When the axes of motion are perpendicular (regardless of whether they are in the *xOz*, *xOy* or *yOz* planes), the approach is identical “Fig. 5.a) and b)”. The contacting links $A_1B_1C_1$ and $A_2B_2C_2$ are located in mutually perpendicular planes “Fig. 5.c)” and the movement of link 1 can only be rotational around the z axis at point A_1, and link 2 can only perform rotational movement around the y’ axis at point A_2. In the indicated diagram, another third link C_1C_2 is noticeable, which performs complex spatial movement and is controlled by the angles d and r and the connections with links 1 and 2 are spherical. This link can be called a transmission or transformer. This link transforms the movement from one (driving) plane to the other (driven) plane of the rotating kinematic link. In many mechanisms where motion transformation in mutually perpendicular planes is required, the transformer unit is replaced by large and complex mechanisms including multiple links and kinematic connections. In “Fig. 5.d)” a hypoid gear is shown, which is a variation of the ordinary bevel gear, transmitting motion between two crossed axes. The complex profile of the teeth of these gears are a kind of cams that contact each other, describing a complex spatial surface, thus replacing the transformer unit C_1C_2 . The theory is extensive around the complex motion of the transformer unit “Fig.5.c)” and in this case it is not the subject of consideration in this material, there is an enormous amount of literature in the field. For the purposes of this material it is sufficient to know the nonlinear dependence (1).

The kinematic rotary joint could operate in the above-mentioned scheme in a certain range of angles a and e, without the presence of an additional control kinematic chain. When the dependence $i_{A_1A_2}$ from "Fig.3." does not satisfy the needs of the designer, he has the freedom to transform the rotary kinematic joint into a closed spatial kinematic mechanism by adding to it a control spatial kinematic chain with a gear ratio $i_{B_1B_2}$ from "Fig.3.", where:

$$i_{B_1B_2} = \frac{\varepsilon}{\alpha} \qquad (2)$$

where:

$i_{B_1B_2}$ is the gear ratio between the set angle ∢ α and the resultant motion calculated by ∢ ε .

Functions (1) and (2) represent the main functions for the synthesis of control kinematic chains for rotating kinematic connections.

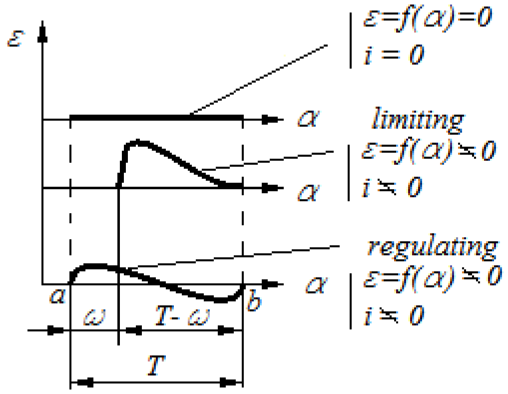
2.5 Functions of the control kinematic chain

The control kinematic chain (in "Fig. 5. c)" is shown in red with a general gear ratio $i_{B_1B_2}$, which can have the following functions:

- *Limiting* – in this case, the control kinematic chain limits the range of action of the setting argument (in the presented case it is α);
- *Regulating* – regulates the change in the setting argument.

Figure 6

Limiting and regulating function of the control kinematic chain.



The graphs shown in “Fig.6.” clearly demonstrate the limiting and regulating functions of the control kinematic chain.

The first graph where $\varepsilon = f(\alpha) = 0$ shows that the movement of the setting link when rotating around the second link does not cause movement of the resultant link. The equation $i = 0$ shows that the control kinematic chain does not exist. In general, this graph corresponds to “Fig.1.b)”, a rotating kinematic connection in which one link is fixed stationary, and the other performs unlimited rotational movement.

The second graph in “Fig.6.” shows the limiting function of the control kinematic chain. The equations $\varepsilon = f(\alpha) \neq 0$ and $i \neq 0$ show that a control kinematic chain is added to the rotary kinematic link, the action of which limits the movement of the rotary kinematic link in the period T with the interval w . This is best illustrated by the biokinematics of the knee joint of each person. The cap (patella) is part of the control biokinematic chain of the horse's rotary biokinematic link, limiting its movement in bending and forward.

The third graph in "Fig.6." shows the regulating function of the control kinematic chain. As in the second graph, here too the equations $\varepsilon = f(\alpha) \neq 0$ and $i \neq 0$ show that there is a mechanism composed of the rotary kinematic link and the control kinematic chain. The regulating function of the control kinematic chain consists in the fact that the function $\varepsilon = f(\alpha)$ has no special points or points of discontinuity. Throughout the period T the function has a smooth change in a positive or negative direction.

It is of great interest if in the additional kinematic chain $i_{B_1B_2}$ there are additional motor-reducer groups placed, which add additional movement to the mechanism. In this case, the limiting and regulating curves of Fig. 6. are transformed into planar or volumetric figures (depending on the mechanism), in whose zone the regulation of the movements of the entire mechanism can be obtained.

3 CONCLUSION

1. The presented method for the synthesis of a rotating kinematic connection with a single added rotational motion is a starting stage for the synthesis of long kinematic chains in various fields of industry.
2. At its core, the method for synthesizing kinematic chains provides an easy way to synthesize closed kinematic structures for performing various operations. This makes it possible to use the advantages of closed kinematic structures over open kinematic chains.
3. This synthesis method finds application in robotics (locomotion, prosthetics, synthesis of exoskeletons, etc.)
4. The presented method also provides explanations for a number of biokinematic structures, their construction and presence in certain places in the fauna. As an example, one can point out why there is a cap (patella) on the human knee joint, while there is no cap on the elbow joint.

All this confirms the importance of the specified method in the synthesis of the lowest level of long kinematic chains.

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Authors’ Contribution

All authors contributed equally to the development of this article.

Data availability

All datasets relevant to this study’s findings are fully available within the article.

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