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CONTACT MECHANISM AND SELF-CENTERING

MECANISMO DE CONTATO E AUTOCENTRAGEM

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Abstract
The phenomena of self-centering accompany any contact of two bodies. For bodies with a small mass and low dynamic indicators, this phenomenon can be neglected. At high values of the dynamic indicators of the mechanical system and especially under periodic loading, the phenomenon of self-centering cannot be neglected, since its consequences accumulate. In modern society, when there is more and more talk about the space industry, the consideration of the contact between two bodies acquires particular importance. The material will shed a cursory light, without claiming to be exhaustive, on the phenomenon of self-centering in the contact of two bodies in the general case of this physical phenomenon. Two mathematical methods for sizing a contact mechanism will be described, taking into account the load on the bodies during contact.

Keywords: Contact. Support. Grip. Self-Centering.

Resumo
O fenômeno de autocentragem acompanha qualquer contato entre dois corpos. Para corpos com massa reduzida e baixos indicadores dinâmicos. esse fenômeno pode ser desconsiderado. Em valores elevados dos indicadores dinâmicos do sistema mecânico e. especialmente. sob carga periódica. o fenômeno de autocentragem não pode ser desconsiderado. uma vez que suas consequências se acumulam. Na sociedade moderna. em que se fala cada vez mais sobre a indústria espacial. a análise do contato entre dois corpos adquire particular importância. O material abordará superficialmente. sem pretender ser exaustivo. o fenômeno do autocentramento no contato entre dois corpos no caso geral desse fenômeno físico. Serão descritos dois métodos matemáticos para dimensionamento de um mecanismo de contato. levando em conta a carga sobre os corpos durante o contato.

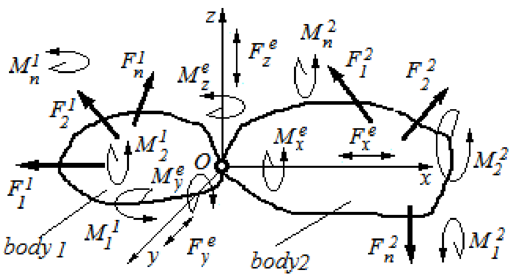
Palavras-chave: *Contato. Suporte. Fixação. Autocentramento.*

1 INTRODUCTION

The basis of solid mechanics is based on the contact of two or more bodies. On this basis. all chapters of solid mechanics have been developed. the dependencies of the motions of bodies. the forces acting on them and the secondary physical phenomena arising from this contact have been established [1.2].

Figure 1

Force diagram of contact between two bodies



The external forces and moments acting on the first body $\overrightarrow{F_1^1}.\overrightarrow{F_2^1}.\dots.\overrightarrow{F_n^1}.\overrightarrow{M_1^1}.\overrightarrow{M_2^1}.\overrightarrow{M_n^1}$. and the external forces and moments acting on the second body $\overrightarrow{F_1^2}.\overrightarrow{F_2^2}.\dots.\overrightarrow{F_n^2}.\overrightarrow{M_1^2}.\overrightarrow{M_2^2}.\overrightarrow{M_n^2}$. can be translated to a single coordinate system centered at point O . that is. the point of contact of the two bodies. The one shown in Fig. 1 scheme of distribution of forces and moments in the general case. at the moment of contact of the two bodies brought to the point of contact O are $\overrightarrow{F_x^e}.\overrightarrow{F_y^e}.\overrightarrow{F_z^e}.\overrightarrow{M_x^e}.\overrightarrow{M_y^e}.\overrightarrow{M_z^e}$. In this way. the set of forces and moments acting on the two bodies is reduced to six efforts [3.4]. *The translation of the force load scheme does not necessarily always have to be to the point of contact O. This can be any other point in the surrounding space (usually in the literature this point not coinciding with the point of contact is denoted by the Latin letter D). If this point D is from the space around the two bodies we say that it is an unreal point. or if this point D is from the bodies themselves we say that it is a real point.*

The forces and moments shown in Fig. 1 are not constants in time. they are variable quantities. that is. they are functions of time [5.6.].

The applied force at point *O*. in general form. can be written as follows [7]:

$$F_x{}^e = f(t).\;\; F_y{}^e = f(t).\;\; F_z{}^e = f(t) \qquad (1)$$

$$M_x{}^e = f(t).\;\; M_y{}^e = f(t).\;\; M_z{}^e = f(t)$$

Or for some point *D*:

$$F^e_{D_x} = f(t). \ F^e_{D_y} = f(t). \ F^e_{D_z} = f(t) \quad (2)$$
$$M^e_{D_x} = f(t). M^e_{D_y} = f(t). M^e_{D_z} = f(t)$$

Of interest is the existence of a force or a component of a force that is directed from the bodies to the point of contact. It is understood whether there is an effort that does not become zero over time and attracts the two bodies to each other in the contact zone. Based on this effort. different types of physical phenomena of contact are distinguished.

- Support – contact of two bodies in the presence of an attractive force between them;
- Grip – contact of two bodies in the absence of an attractive force between them;
- Hybrid support – in the presence of an attractive force between the contacting bodies. in which the attractive force in the process of contact is zeroed or becomes negative. for certain intervals of time.

Support is a certain event that always occurs in the presence of the only condition for existence. namely the existence of an attractive force between the bodies.

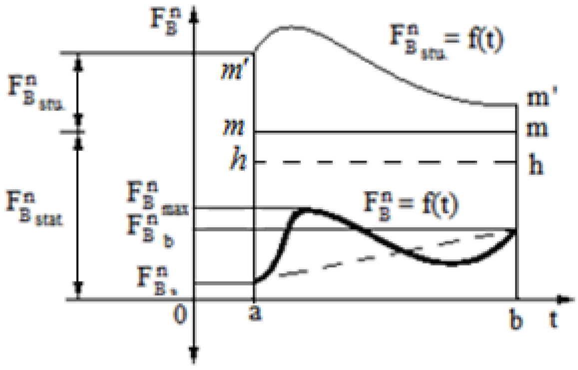
There are different types of classifications. but one of the most important is the one that characterizes contacts by their support points. that is. contacts can be single-point (idealized case). two-point. three-point and multi-point.

The diagram in Fig. 2 clearly shows the force $\overrightarrow{F^n_{stat.}} = const.$ which is the attractive force. along the normal *n – n*. at the point of contact and is indicated by the line m – m. As can be seen. the support force $\overrightarrow{F^n_B} = f(t).$ for the point of contact *B*. is always smaller for the entire interval *(a.b).* The line *h – h*. in this case is shown as a straight line. but it is actually the equidistance of the line m – m. and shows a critical level of increase in the force $\overrightarrow{F^n_B} = f(t).$ if it is reached. for a given moment. since after crossing the line *m – m* in height. the support. as a physical phenomenon. will cease to exist. for a given moment.

The curve *m'*- *m'*. Represents a change in time of the grip force between the two contact objects.

Figure 2

Diagram of an example of an attractive force position at support and grip



The grip. as a process. is a future uncertain event. unlike the support. There is a shock grip. which is a random natural phenomenon. subject to very specific specific conditions for its existence. The support grip is a consciously purposeful action subject to a certain technological process. previously created and provided with a certain kinematic structure. The purpose of the grip is to ensure the presence (or increase) of an attractive force. or a component of force. between the contacting bodies.

Whenever there is contact between two or more bodies. there are secondary physical phenomena. Such are impact. self-centering. thermal radiation. slipping. sinking. etc. Some of the secondary physical phenomena manifest themselves under certain conditions. while others accompany the contact always at every manifestation. The secondary physical phenomena that always manifest themselves are impact and self-centering.

The mathematical description of the impact is derived from the momentum of the two bodies. supplemented by the empirical relationships provided to us by Newton for the purpose of unambiguous description:

$$mu_n - mv_n = I_n^m \qquad (3)$$

$$mu_t - mv_t = I_t^m$$

$$\frac{u_n}{v_n} = \rho \;\; ; \;\; \frac{u_t}{v_t} = 1 - \lambda$$

The geometric arrangement of the velocities of the centers of mass of the bodies relative to the geometry of the physical phenomenon are obtained from the formulas (3).

Self-centering is a complex natural phenomenon. It can best be illustrated by the presence of an ankle joint in almost all limbs of locomotional living beings. The ankle joint creates a kinematic opportunity to establish full-fledged contact with the other body in accordance with the intended technology for its implementation. Self-centering also exists in the contact of bodies outside the created and regulated technology. The geography (shape) of the bodies in the contact zone is one of the main factors for the action of self-centering.

2 EXPOSITION

The contact between two or more solid bodies in space leads to a number of secondary physical phenomena that create or extinguish numerous forces. The methodological interpretation and arrangement of the physical phenomena of contact between solid bodies gives a coherent theory of how to study and use various secondary physical phenomena to synthesize various useful technological processes.

As already noted in the introduction. the contact of two bodies in space is expressed in one of the following three ways. namely - support. grip and hybrid support. These are contacts that are reversible and have synthesized technologies and constructed kinematic chains for their implementation. In this material. the synthesis of technology and the construction of a contact mechanism (module) will be illustrated with a three-point support. respectively grip.

The kinematic scheme of the contact mechanism of the grip includes multiple kinematic links connected by kinematic connections. Each link represents a separate body that contacts the other bodies through the kinematic links. This practically shows that there is contact not only of one body in the system. but of multiple bodies. *The criterion that can be set to distinguish the two bodies from each other for the considered contact between them is the lack of a predefined kinematic connection between the bodies.* That is. all links in a kinematic chain are interconnected by inseparable kinematic connections that form a single mechanism (a common body of variable shape) and this is the body whose synthesis begins with the synthesis of the contact mechanism. The two contacting bodies may be monolithic. as shown in Fig. 1. or only one body may be monolithic. and the other may be some kinematic system performing a predetermined technology. or both bodies may be a kind of variable kinematic chains that at a given moment make contact with each other.

3 SYNTHESIS OF SUPPORT TECHNOLOGY

When synthesizing support technology. the main requirement for the realization of a support is the presence of an attractive force or a force component between the two bodies.

- In the introduction. it was explained and shown in Fig. 2 that the attractive force can be a constant value. but it can also be a function of time;
- The next stage of synthesizing support technology includes choosing a method for extinguishing impact forces and the vibration-exciting action of self-centering. These can be special devices. as part of the kinematic scheme of the contact mechanism itself or specialized behavior of the contact mechanism as a whole;
- Next. choosing the first contact point from the three contact support points.;
- Finding point *D* in space;
- Constructing a scheme of the contact mechanism.

4 SYNTHESIS OF GRIPPING TECHNOLOGY

The technology of the gripping process is very different from the technology of the support process. In gripping. it is not necessary for there to be an attractive force between the contacting bodies. Moreover. it is possible for there to even be a repulsive force between the bodies. There are many other conditions for the implementation of the gripping process. such as the shape of the contacting bodies in the contact zone. the type of materials from which the bodies are made. the force pattern and its change. the kinematic indicators. etc.

- The first stage of the gripping technology is the approach of the two bodies to each other;

- The second stage is absolutely identical to the second stage of the support process technology. This is the synthesis of a method for extinguishing impact forces and the vibration-exciting action of self-centering. These may be special devices. as part of the kinematic scheme of the contact mechanism itself. or specialized behavior of the contact mechanism as a whole;
- The third stage is the synthesis of possible methods of gripping and the construction of devices. as separate modules. for their implementation. These devices will subsequently participate in the kinematic scheme of the contact mechanism;
- Specifying the number of contact points of the grip and their oriented location in space;
- Finding the point *D* in space;
- Constructing a scheme of the contact mechanism. which also includes the gripping modules.

5 FINDING THE POSITION OF POINT *D* IN SPACE

Special attention will be paid to finding point *D*. since this is of utmost importance for the reliable operation of the contact mechanism. This task is close to the types of optimization tasks in mechanics and kinematics. but it also has its own peculiarities.

Two methods for finding point *D* are presented. depending on the desired conditions. Fig. 3. a) shows a visual diagram for finding the position of point *D* in space. The proposed methods are two iterative mathematical approaches. and the number of iterations depends on the desired accuracy of the desired results.

Figure 3

Finding the position of point D in space. a) diagram of the comfort image.

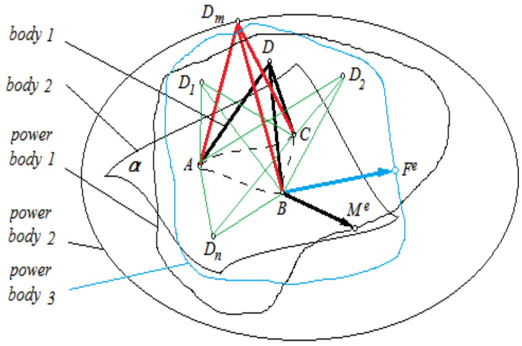


Figure 4

Finding the position of point D in space b) Pyramidal structure with one point for the vertex.

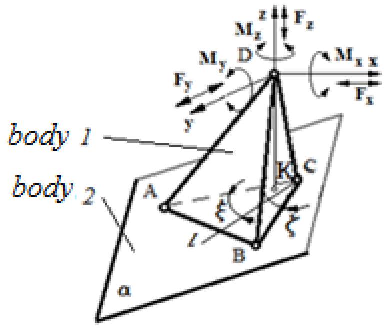


Figure 5

Finding the position of point D in space. c) Pyramidal structure with a segment for the vertex.

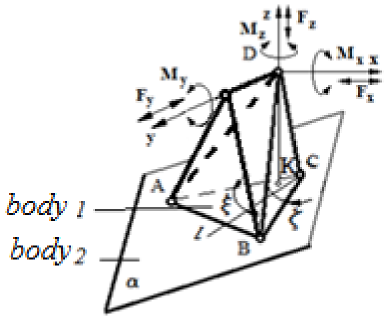
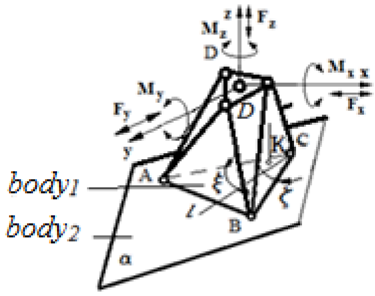


Figure 6

Finding the position of point D in space. d) Steward's platform.



The methods start with establishing the goals of the task. The goals can be both optimization in the field of geometry (distances. orientation. positions. etc.) and in the field of kinematics (forces. movements. speeds and accelerations).

The first method starts by iteratively examining the applied force (1) at the point of contact. which is a function of time. for its change in the vicinity of point *O* in Fig. 1 or point *B* in Fig. 3. The peaks of the force load (1) describe force bodies. In Fig. 3. force bodies 1 and 3 are described by the peaks of the force load summarized in the vectors $\overrightarrow{F^e}$ and $\overrightarrow{M^e}$. The shown example curve of one component of the forces $F_A^n = f(t)$ at point *A* (Fig. 2.). namely along the normal *n – n* (Fig. 4). demonstrates that this is a curve of the second and higher order. for the interval *(a. b)*. that is. the force bodies 1 and 3 are not constant in time. Thus. for each iteration. the force bodies obtained at the maximum of the functions (1) are taken into account.

The translation of the force (1) from the point of contact *B* to some point of the surrounding space will lead to a change in the force picture at this point. The presented iterative method of studying the load functions in spherical potential surroundings of the point *B* helps to find a close neighborhood of points in the surrounding space. where the set geometric-kinematic conditions of the task can be maximally satisfied.

The next stage of the iteration method is not mandatory. but it is very convenient in terms of calculations. this is changing the argument of the efforts (1) from functions of time *t* to functions sequentially of the coordinates of a given coordinate system (for example. Cartesian. cylindrical or spherical coordinate systems). After studying the functions with the new arguments. the appropriate areas for locating the point *D* in space are found. then a return is made to the initial argument. namely the time *t*.

The second method for finding a suitable location of the point D in space is by using the method of the comfort image known from mathematics. The body described by the load vectors (1) is transformed into another body by a transformer function. which has simpler computational expressions. A body with even simpler computational expressions is sought. which body would wrap the thus found body from the comfort image (in Fig. 3 this is the force body 2. which. as can be seen. is an ellipsoid). In this way. the security of the contact is guaranteed. The comfort image method requires significantly fewer iterations than the argument change method.

Due to the change in force load (1) over time. more than one result is obtained for point D. i.e. $D_1 . D_2 . \dots . D_n$ From all suitable points. one point D_m is selected. Translating the load (1) to the already established point D_m and studying these functions over time at this point provides the basis for synthesizing the conditions for constructing the contact mechanism between the two bodies. In this way. the type of contact mechanism is unambiguously determined. whether it will be a support. a grip or a hybrid mechanism. Moreover. the study of the reduced loads at point *D* also determines how many contact points the contact mechanism should have and its method of operation.

With the determination of point *D*. the schematic construction of the contact mechanism module is completed. The figures shown in Fig. 3 b). c) and d) three-point kinematic scheme of a support or grip mechanism demonstrate how a scheme of a kinematic mechanism with one vertex (point *D*) can be transformed into a two-point vertex or a three-point vertex (Steward's Platform). without loss of possible movements. The three-point vertex is not a limitation on the possibilities of the presented approach for synthesis of a contact mechanism.

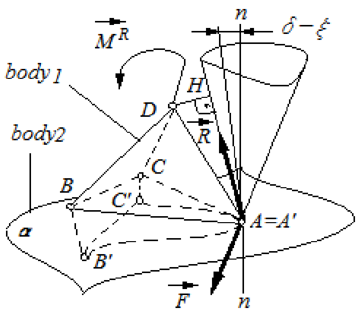
The possibility of synthesis of solid-state contact technology and a mechanism for its implementation opens up new opportunities for designers of long kinematic chains operating both on Earth and in space for the development of the space industry.

6 SELF-CENTERING

In every contact between two bodies. the physical phenomenon of Self-Centering is observed. The theoretical statement that contact between two bodies can occur at a single point is approximate and idealized. Usually. contact occurs in a spot. line. area. or volume.

Figure 7

Force diagram of self-centering effect at three-point support



In Fig. 4. the body 1 is presented. which establishes contact with the body 2. The goal of the task is for the three support points *A*. *B* and *C* of body 1 to coincide with their locations *A'B'* and *C'* of body 2. In practice. the triangle *ABC* does not exist in reality. At this stage of the task. it is assumed that there are only three support points methodologically connected in one triangle. From the diagram in "Fig. 4." it is evident that the surface of body 2 in the contact zone is not a plane. but a random surface. This shows that if the triangle *ABC* is real. then a three-point contact could not occur.

In practice. it is almost impossible for the two triangles *ABC* and *A'B'C'* to establish contact at all three points simultaneously. *There is always one point that first establishes contact and then. thanks to the self-centering effect. contact is also obtained at the other points of the support.* This first point may be random. but it can be set in advance during the synthesis of the contact technology between the two bodies.

The approach of the two bodies to each other can be realized by changing their position along the six degrees of freedom in space. In this way. the contact of the first point (point A) between the bodies will realize an oblique impact with all the consequences arising from this physical phenomenon. A direct impact between the contacting bodies is a special case of the oblique impact and is usually set in advance in the technology.

The normal n – n at the point of impact and the central axis of a conical surface passing through the point of contact *A* = *A'* determines the difference of the angle of reflection and the angle of attack d-x. *DH* is the distance from the center of mass of the first body *D* (in the case when point *D* is the center of mass of body 1) to the directrix of the reaction of the support $\vec{R}$. As a result of the reflected force $\vec{R}$ and the excited friction force (the friction force is not shown in the diagram. its directrix is along the tangent at the point of impact *A=A'*. and perpendicular to the normal n – n) a moment M^R is generated at the mass center *D*. The normal reaction $\vec{R}$ is short-term and of very high value. since it is generated by the impact force at the contact of the two bodies at point A. In this way. the resulting moment M^R tends to rotate the first body so that contacts are established with the other support points *B* and *C* with the second body. Due to the high values of $\vec{R}$. the momentM^R also has high values for a short time. which is practically an instantaneous impulse. This momentary impulse breaks the contact at point A and rotates the contact mechanism around point D. In this way. the contact mechanism makes contact with one of the other support points *B* or *C* where the entire contact procedure is repeated. The movement of the two bodies towards each other increases the kinematic characteristics (the support reaction $\vec{R}$. but at the expense of this some geometric characteristics (the distance *DH*) are reduced.

The self-centering effect is a repeating decaying process over time. It is considered as a source of oscillatory movements of mechanical systems. With increasing clearances in mechanical systems. excitation of vibrations and the production of unpleasant sounds are observed. This is due to the excitation of oscillatory movements by the self-centering effect.

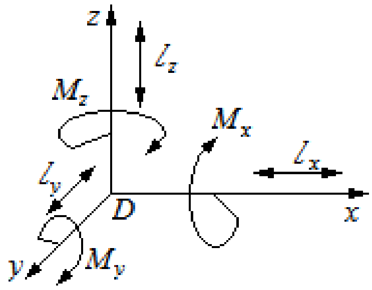
7 DESIGN OF THE KINEMATIC MECHANISM

From a kinematic point of view. point *D* is an important kinematic center that regulates the geometric position of the support points according to the geography of the contact point with the second body (Fig. 4.). The contact mechanism is a module of the kinematic system of the first body. which is connected to the second body and in some supports and in all grips. this module becomes an integral part of the second body. If there is any relative movement between the two bodies. then this movement. in most cases. is carried out through the kinematic connections around point *D*.

Usually. the kinematic point *D* has three mutually perpendicular rotational degrees of freedom along the three coordinate axes. but in some cases it is possible that it has all six degrees of freedom.

Figure 8

The six basic movements in an orthogonal coordinate system.



The approach to designing a contact mechanism goes through several stages:

- During the first stage. it is established how many degrees of freedom are necessary for the mobility of point *D*. This shows that the proposed approach has a wider comprehensiveness in the synthesis of kinematic connections. The degrees of freedom can be a maximum of six;
- Determining the structure of the kinematic scheme with respect to point *D*. Will it be real or unreal.. Here we are talking about the kinematic scheme of the contact mechanism. where it must be specified what type it will be. Will it be of an open type. or of a closed type. or of an open-closed type. When the type of the kinematic scheme of the contact mechanism and its functionality are specified. the position of point *D* is determined. At this stage. the position and behavior of point *D* during the entire cycle of the technological action of the contact mechanism is already visible;
- It is determined how many points the structure implementing the movements around point *D* will have. The behavior of the contact mechanism in contact with different types of surfaces for which it is intended is checked and an assessment is made whether it is necessary to add new contact points or another different technological solution;

- During the fourth period. the activities of the kinematic units are distributed according to the technological requirements of the contact mechanism. If the contact mechanism is of a hybrid type and in its kinematic scheme there are separate sections that activate the support action. others that activate the gripping action. then at this stage the loads are distributed for the purpose of sizing;
- During the fifth period. the contact mechanism is sized according to kinematic and dynamic indicators.

8 CONCLUSION

Finding a correct and specific schematic solution of a contact mechanism is of utmost importance for synthesizing an accurate and working technological scheme of the contact between solid bodies. The contact mechanism. in principle. is part of a long kinematic chain and for this reason. special importance is paid to point *D*. as their connection.

The main conclusion that can be drawn from the above is that the synthesis of any long kinematic chain (technological. locomotion or manipulation) begins with the synthesis of the contact mechanisms with which this kinematic system will connect with the surrounding world. This conclusion is also confirmed by the surrounding nature. The birth of a new life. whether from flora or fauna. first develops contact and sensor mechanisms as a priority. and then additionally develops biokinematics.

Creating an accurate and specific technological scheme of the contact is a basic prerequisite for the synthesis of a specific schematic solution of a contact mechanism.

The specific technological scheme of the contact provides the first conditions for the synthesis of the contact mechanism and in particular of point *D*. This point is the first step towards the synthesis of the specific long kinematic chain.

The two mathematical methods shown for finding point D unambiguously indicate the type of contact mechanism. its geometry and force pattern. depending on its method of operation.

The contact of two bodies is the basis of mechanics. giving rise to a series of different secondary physical phenomena with different consequences.

Self-centering is one of these physical phenomena and occurs at every contact of two solid bodies. This physical phenomenon has a periodically damped character. which can excite self-oscillating movements of the structure. if not taken into account when dimensioning it.

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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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