Physical basis of contact mechanics of surfaces

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Abstract. The conditions of contact interaction (pressure, displacement, temperature) of the surfaces of machine parts as the basis for their design and improvement are considered. It is noted that physics is the theoretical basis of the mechanics of interaction of surfaces. A structural hierarchy of interaction types is proposed. The place of mechanical interaction among known to science four types of interaction is defined: strong, weak, electromagnetic and gravitational. A hypothesis has been put forward and justified that in a given range of sizes, mechanical interaction can be considered the fifth interaction between the material objects of the world.

1. Introduction

In technology there is a continuous process of improving the machines and their components. The process of improving machines goes through two main stages. At the first stage, the search and implementation of constructive or technological methods are carried out. At the second stage, a computational and experimental study of the effectiveness of methods for improving machines is carried out. Problems of contact interaction, friction, wear and lubrication are the basic integrating branch of knowledge that ensures the implementation of the process of improving machines.

The conditions of contact interaction (pressure, displacement, temperature) play the role of initial conditions determining the results of the machine's operation [1]. In accordance with these conditions, the machine parts are projected, materials are selected. And also surfaces of machine parts are created, providing the greatest wear resistance, resource and reliability [2]. Physics is the theoretical basis of the mechanics of the interaction of surfaces. However, until now there is no clear idea of the place of the mechanics of interactions with four types of interaction that are well known and recognized in science: strong, weak, electromagnetic and gravitational. In this paper, an attempt is made to show that mechanical interaction is the fifth type of interaction.

2. Analysis of the mechanisms of interaction of elements of matter in nature

In 1687, Isaac Newton explained the motion of celestial bodies and many terrestrial phenomena by the presence of the attraction of all bodies to each other. Since then, they have been trying to explain how two bodies can interact with one another at a distance [3-4].

At present, there is no unified and experimentally confirmed theory of the transfer of forces between the bodies without their contact in physics. Replacement of the problem of interaction by the concept of a field introduced by Faraday and described by Maxwell does not solve the problem. The mechanism of the curvature of space by Einstein does not explain the nature of gravitation.
Among the set of hypotheses about the mechanism of interaction of bodies at a distance, three mechanisms can be distinguished: the screen mechanism; pulsation mechanism; mechanism of the ether flow. The screen mechanism of interaction assumes that the entire world space is filled with minute particles (ether). These particles with high velocities randomly move in all directions. A single particle body is bombarded from all directions equally. Two bodies are screens for particles along the line joining them. There is a difference in pressure on the body from the outside and from the inside, so that the bodies come together. Factually, the bodies come together under the influence of external forces, as in the case of mechanical contact. In the discussion of the variants of the screen model, Lomonosov, Lesage, Thomson V., Maxwell, Poincaré, Jarolimenc, Bock and others took part in the discussion of the variants of the screen model for almost 300 years [5]. Various modifications of the screen interaction mechanism are appearing at the present time (the model of Johann Kern [3]). With the help of assumptions in the work of Kern, the processes of attraction and repulsion of bodies by both electric and gravitational forces are explained.

The pulsation mechanism of Bjerknes was studied and developed by Cook, Guthrie, Gallis, Hicks, Liti, Barton (1909). Pulsating bodies transmit pulsations through the ether. The pulsation from two bodies, forming in space, creates a difference of impulses that act on the body from the outside and from the inside. If the pulses are in the same phase, the bodies repel; if the pulses are in antiphase, the bodies are attracted.

The model of the ether flow originated from observations of the interaction of two moving ships. This observation was conducted by Riemann (1853) and theoretically substantiated by Pierson (1891). In the experiment on the flow mechanism, air was supplied to two hollow spheres with a plurality of small holes. The flow of air from the holes in the balls caused attraction of the balls.

The above three mechanisms or models of the type of interactions presuppose the presence of an ether. Ether in the form of a multitude of tiny particles, uneasily moving in all directions with huge speeds. These models are obvious and popular, because they are understandable.

In modern physics, it is accepted that the mechanism of all kinds of interaction is the mechanism of exchange of particles of interacting bodies. In the electromagnetic interaction between electrons, the effect of one on the other is due to the exchange of photons. These photons are not fixed experimentally, therefore they are called virtual. Essentially, a continuous arrow of one electron is postulated to another. A similar mechanism is assumed for other types of interactions. When the interaction is strong, the quarks exchange gluons, with a weak interaction by z-particles, with graviton interaction by gravitons. Physicists claim that quantum electrodynamics describes this mechanism of electromagnetic interaction well. It is believed that for other interactions this mechanism and theory are valid for weak, strong and gravitational interactions.

It follows from the review that all mechanisms of interaction of bodies at a distance presuppose the presence of a material carrier between bodies. This is either the elastic ether or external streams of particles, or the internal radiation of particles. This proves that mechanical interaction is one of the most grounded and studied fundamental mechanisms of interactions in physics and mechanics.

3. The scale order of matter and interaction in the universe

3.1. The scale order of matter in the universe

In accordance with [6], the minimum size of matter in the universe is determined by the dependence:

\[ l_{\text{min}} = \frac{\hbar G}{c^2} \approx 10^{-18} \text{cm} \]

where \( \hbar \) is the Plank constant; \( G \) is the gravitational constant; \( c \) is the speed of light.

The total size of the universe is estimated at 61 orders = 10^{61} cm. Based on this, the scale center has the order of 61/2 = 30.5, which corresponds to the size of the scale center equal to: \( \lg l = -32.8 + 30.5 = -2.3 \) or \( l = 10^{-2.3} \text{cm} \approx 50 \mu\text{m} \).

This value corresponds to the average size of the biological cell of most living creatures on earth, including humans. The main material objects of the universe are: metagalaxy, galaxy, galactic nuclei,
stars, star nuclei, human, nucleus of a cell, atoms, atomic nuclei, electrons, electron nuclei, photons and maximons. If these objects are arranged in descending order of sizes, then the distance between the dimensions is stable and with an accuracy of 0.5 order are 5 orders (Table 1). In total there are 12 levels, 6 on each side of the large-scale center.

This shows that in the scale hierarchy of the universe there is a strict order - a certain periodicity. The average galaxy is many times larger than the average core of the galaxy, to which the latter is larger than the average star size, and so on.

Table 1. Dimensions of objects and types of interactions in the universe.

| Level | lg l, μm | lg l, cm | Objects of the universe | Interaction |
|-------|----------|---------|-------------------------|-------------|
| +6    | 31       | 27      | metagalaxy              | gravitational |
| +5    | 26       | 22      | galaxies                |
| +4    | 21       | 17      | galactic nuclei         |
| +3    | 16       | 12      | stars                   |
| +2    | 11       | 7       | nucleus of stars        |
| +1    | 6        | 2       | human                   |
| 0     | 1        | -3      | cell nucleus            |
| -1    | -4       | -8      | atoms                   |
| -2    | -8       | -13     | nuclei of atoms, protons |
| -3    | -14      | -18     | electrons               |
| -4    | -19      | -23     | nuclei of electrons     |
| -5    | -24      | -28     | photons                 |
| -6    | -29      | -33     | maximons                |

Given this pattern, the size of a human is defined as the closest class to the size of the nucleus of the cell. That is, the human size (161.5 cm) is $10^5$ times larger than the size of the cell. This fact builds a person into a cosmological object.

3.2. Types of interaction of elements of matter

In physics there are four types of interaction of elements of matter: weak - between elementary particles; strong - inside the core; electromagnetic - between elements carrying electric charges and gravitational - between space objects.

It is suggested that the types of interaction at different levels are localized. In accordance with this, each type of interaction corresponds to its own body size. Between the bodies of large cosmic dimensions (planets, stars, galaxies, $10^7...10^{27}$ cm) act gravitational forces. Between the super small bodies (photons, electrons, $10^{-33}...10^{-7}$ cm) there are forces of weak interaction. Among the bodies commensurate with the atomic nuclei ($10^{-15}...10^{-8}$ cm) there are intra-atomic or nuclear forces, which relate to a strong interaction. The widest range of body sizes ($10^{-13}...10^{-7}$ cm) is under the influence of electromagnetic interaction forces.

In mechanics, the experimental fact is the transfer of effort from one body to another by direct contact. This mechanical contact interaction can be considered the fifth fundamental type of interaction. Mechanical contact interaction is visually realized in a relatively narrow range of sizes ($10^{-3}...10^{3}$ cm). This range includes all living things (from a cell to a human) and all machines created by human. Thus, both the human and the results of his work are in one narrow range of sizes.
For this range the forces of mechanical interaction are fundamental and the motion is transmitted with a direct touch.

The mechanics of contact interaction is the basic section of the mechanics of a rigid deformed body. In this section of mechanics, the basis for calculating the contact interaction of machine parts and mechanisms is created. Understanding the need for greater efforts to find a common nature of the interaction between elements in the material world, we propose the following hypothesis. Without touching the strong interaction, we assume that the weak, electromagnetic and gravitational interactions differ from each other only in the amount of matter in the interaction process. That is, the electromagnetic and gravitational interaction is the sum of the interactions of electrons and atoms with each other or the sum of weak interaction effects in different amounts of matter.

3.3. Internal and External Interaction
Two concepts are introduced: internal interaction and external interaction (impact). Internal interaction occurs under the influence of internal forces in the absence of external influence on these bodies. Examples of internal interaction at macrolevels are: attraction or repulsion of magnets; adhesion or attraction of bodies with direct contact. External interaction or the impact of one body on another occurs in the presence of external forces applied to interacting elements. If the external forces act on the attracting magnets, then the external component of the interaction forces is added to the internal component of the interaction forces. General forces in the interaction are equal to the sum of the forces exerted by the internal and external interaction:

\[ F = F_i + F_e \]  

In the equilibrium state, in the absence of external forces, a purely internal interaction takes place. In the overwhelming majority of cases, there is a complete interaction in the presence of external influences. When in physics the types of interaction are considered, they mean only internal connections between the elements of the system without direct contact. The external effect of one element on another is accomplished by changing the distance between the elements and the law of the change in the force from the distance. Mechanical interaction takes place in the presence of external forces. Let’s consider the contact of two bodies and the transfer of force from one body to another under equilibrium conditions. In this case, internal forces can be divided into two components: \( F_{\text{ad}} \) - adhesion, causing attraction of bodies, and \( F_{\text{re}} \) - component, causing repulsion of bodies:

\[ F = F_{\text{ad}} + F_{\text{re}} \]  

With allowance for (1) and (2), the sum of the interactions can be written as:

\[ F = F_{\text{ad}} + F_{\text{re}} + F_{\text{int}} \]  

With mechanical contact, the forces of external interaction are counterbalanced by internal repulsive forces:

\[ F_e = F_{\text{int}} \]  

In the case \( F_{\text{ad}} = 0 \) the following relation holds:

\[ F_i = F_e \]  

That is, the forces of external interaction are balanced by the forces of internal interaction. This fact explains the relationship between the mechanical and weak interactions between atoms.

4. Scale levels and types of interactions in contact mechanics
The system of machines ensures the conversion of energy into motion with specified parameters. The transfer of movement from one element of the machine to another is carried out by means of their
mechanical contact. Mechanical contact is the main way of transferring traffic in the machines. At the same time in classical physics there is no mechanical contact as a kind of interaction between bodies. In physics, only four types of interactions are recognized: strong, weak, electromagnetic and gravitational.

4.1. Scale levels of contact interaction
Contact interaction can be divided into five levels: 1 - macro level; 2 - micro level; 3 - meso level; 4 - contact of crystals; 5 - contact at the level of atoms and molecules. A total of 12 basic levels are set. Systematization of levels is shown in Table 2. Let’s consider each of these levels more detailed.

I. Macro level. Level 1. Contact on the nominal contact area. The nominal contact area is outlined by the apparent dimensions of the contacting bodies. The dimensions of the nominal area are within \( A = 1 \times 10^{-2} \) mm\(^2\). The nominal contact pressure \( \sigma \) at the load \( Q \) is determined from the ratio:

\[
\sigma = \frac{Q}{A} \tag{6}
\]

II. Microlevel. Level 2. Contact wavy surfaces on the contour area of contact.
The contour area of interaction is formed as a result of compression of a wavy nominal surface. On the contour area the actual contact areas are also located. The value depends on the geometry of the surface and on the load. The dimensions of the site are estimated \( A = (1 \times 10^{-3}) \) mm. The contour contact pressure \( \sigma \) is determined from the relationship:

\[
\sigma = \frac{Q}{A} \tag{7}
\]

Level 3. The actual (physical) contact area \( A \) is the sum of the actual contact areas of the bodies when surfaces are rough. The size of the actual area is determined by the value of \( A = 1 \times 10^{-3} \) mm. The actual contact pressure is determined by the ratio:

\[
\sigma = \frac{Q}{A} \tag{8}
\]

The actual contact pressures can exceed the nominal pressures by two orders of magnitude. At high loads, actual pressures cause plastic deformation [7] and can be equal to hardness (according to Brinell):

\[
\sigma \approx HB \tag{9}
\]

Level 4. Micro roughnesses are also not absolutely smooth, but are covered by submicroroughnesses. Their dimensions are an order of magnitude smaller than the microroughnesses. The size of these areas is measured by several nanometers. There is no generally accepted theory of contact on submicroroughnesses. It can be assumed that this level is transitional between mechanical and physical contact.

III. Meso level. In addition to the size, the contact level is characterized by the material-science structure of the contacting elements [8]. In this case mesocontact takes place. Mesomechanics is the science of transient processes in the mechanics of a deformed body between contact mechanics and contact physics.

Level 5. Within the general meso level, it is also possible to identify large-scale sublevels. If the contact is at the level of structural grains, the area size \( A_{\text{nc}} \) is estimated at several micrometers: \( A_{\text{nc}} = (10^{-4} \ldots 10^{-3}) \) mm.
Table 2. Levels of contact interaction.

| Level | Element | Contact Type | Contact Characteristic | Form of Contact |
|-------|---------|--------------|------------------------|-----------------|
| I     | macro level | 1 | $10^{-1}$ | Contact by nominal area |
| II    | micro-level | 2 | $10^{-1}$ | Contact by contour square |
|       |           | 3 | $10^{-3}$ | Contact by real area |
|       |           | 4 | $10^{-5}$ | Contact of submicroroughness |
| III   | mezo-level | 5 | $10^{-3}$ | Contact surface of texture grains |
|       |           | 6 | $10^{-4}$ | Contact of elements of structure grains |
|       |           | 7 | $10^{-2}$ | Contact of secondary structures |
| IV    | crystals  | 8 | $10^{-5}$ | Contact of population crystals |
|       |           | 9 | $10^{-6}$ | Contact of individual crystals |
| V     | Molecules and atoms | 10 | $10^{-5}$ | Contact of molecules |
|       |           | 11 | $4 \times 10^{-6}$ | Contact of atoms |
|       |           | 12 | $4 \times 10^{-9}$ | Contact of atomic nuclei |
Level 6. Contact on the elements of structural grains has an order of magnitude smaller than contact on grains (from ten microns to a micron).

Level 7. To the structural meso level can be attributed contact on secondary structures that cover the primary structures. The size (thickness) of these secondary structures is in the range of up to one micrometer.

IV. Crystals. Level 8. Structural grains of materials consist of a conglomerate of crystals or a crystal structure of grains. Each crystal consists of atoms. Contact of crystals occurs at sizes of contacting bodies of the order of 0.1...0.01 \( \mu \text{m} \).

Level 9. The crystals in the grain lie in one plane. Crystals have microroughnesses the size of one crystal. This is already the beginning of the nanoscale with dimensions of 1 ... 0.1 nm.

V. Molecules and atoms. Level 10. In the case of secondary structures, alloys or polymers, the surface is coated with molecules or clusters of molecules consisting of atoms with dimensions of \( 10^{-5} \ldots 10^{-7} \) mm.

Level 11. The main physical level of contact is the contact of atoms separated by electrons or an electron gas. The size of a single contact object is \( 3 \times 10^{-6} \ldots 4 \times 10^{-6} \) mm.

Level 12. With the free movement of electrons between atoms of metals, atomic pairs enter into contact, located in the crystals. At levels 8 to 12 there is no mechanical contact, there is a physical contact of the atoms.

4.2. Types and Relationships of Interactions in Contact
In the system of contact interaction of two elements, three zones can be distinguished:

I - zone of action of mechanical forces: micro-, macro- and mesomechanics;
II - zone of contact at the atomic level: the contact of molecules, atoms and nuclei of atoms, the zone of action of electro-magnetic forces;
III - transition zone, in which the form of interaction cannot be determined strictly, this is the meso level and the level of crystals.

In most cases, new models are proposed in science based on facts and known models. This is done on the basis of assumptions and principles of logical (theoretical) consistency, and not new facts. Given that the type of interaction is associated with the scale, the following hypothesis is advanced: each type of interaction in objects of a higher level (large scale) can be considered as the effect of the sum of interactions at the objects of a lower level (of a smaller scale). In accordance with this hypothesis, the electromagnetic interaction is the result of the summation of weak and strong interactions in the sizes of objects of electromagnetic interaction. In this case, the place is not a linear summation, but summation with the transition of quantity to quality (one type of interaction in the other). There is something similar to the phase transformations of one type of interaction into another. Gravitational interaction is the summation of electromagnetic interaction on a cosmic scale. Mechanical interaction is the sum of electromagnetic interactions in the scales of objects of contact mechanics. The mechanical contact interaction is the result of summation over the entire area of the actual contact of the electromagnetic interaction at the level of atoms and electrons. Thus, the main criterion or condition of the type of interaction is the size of the material object. In the above sense, mechanical interaction can be considered the fifth type of interaction of elements of matter.

5. Conclusions

- According to the principle of a telescope and a microscope, a human is at the center of the world not only as an object of supervision. Human acts as an object equally remote both from the edge of the universe, and from the depth of the microcosm. The size of a human (more precisely, its cells) is 50 \( \mu \text{m} \) in 10 30.5 times smaller than a metagalaxy. And 10-30.5 times bigger than the smallest by modern ideas in physics. That is, a human with the same intensity knows both the macrocosm and the microcosm.
- In physics four types of interactions are known: weak, strong, electromagnetic and gravitational. And there is no mechanical interaction. At the same time for a human as a large
center of knowledge of the world, mechanical interaction is the main one. In this paper, a hypothesis is advanced that a mechanical interaction can be considered the fifth interaction between the material objects of the world.

- An objection may be that the mechanical interaction is not fundamental, but is the sum of known electromagnetic interactions. However, in physics there is no direct evidence that all known interactions are independent of each other. On the contrary, the main efforts of physicists are aimed at finding a unified interaction, the unified nature of the forces of interaction. If we accept that the unified nature of interactions exists, then it is logical to have a mechanism for summing up interactions of a smaller scale into larger scale interactions. For example, we can assume that the electromagnetic interaction is the result of summing up the forces of weak interaction. And gravity is the result of summing up the forces of electromagnetic interaction. If this is allowed, then it is logical to assume that the mechanical interaction is the fifth type of interaction in physics.

- The term "interaction" reflects the presence of mutual attraction or repulsion between objects without a material carrier of interaction. This material carrier for the transfer of interactions in all fields is absent. With mechanical contact, there is no need to represent interaction as an interaction between fields. Here there is a direct contact of the surfaces of objects. This gives a clearer understanding of the nature of the interaction.

- The force of mechanical interaction on the actual contact area is equal to the sum of the forces of electromagnetic interactions between atoms in crystals or molecules. In this case, the transition from one type of interaction to another is not linear and simple. The transition from electromagnetic interaction between atoms in the contact zone leads to the formation of a new type of interaction - mechanical, which has its own objects and laws. This transition can be regarded as a phase transition in the process of realizing interactions. The laws of mechanical interaction are studied in the mechanics of a deformable body called contact mechanics. Thus, contact mechanics studies the regularities of the fifth type of interaction in physics and mechanical interaction.

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