The Phenomenon of Blow During Landing, Support, Grip and Locomotion

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***Abstract*—The physical phenomenon Impact accompanies most of the processes in robotics and mechanics as a whole. In this material, attention will be paid to the processes of landing, support, grip and locomotion and the manifestation of the Impact phenomenon in these processes. Some theoretical statements of this phenomenon will be shown and conditions for the synthesis of some characteristic kinematic chains of these processes will be derived. An interesting fact is the phenomenon of self-centering of the kinematic chains of the mechanisms of these processes.**

Keywords*— landing, support, grip, locomotion, self-centering

I. IINTRODUCTION

In each of the processes – landing, support, grip and locomotion [1], at a given moment there is the phenomenon of Impact [2]. These processes are processes of interaction between two bodies. This phenomenon manifests itself, usually at the initial moment of these processes, that is, at the moment of the first contact between the two bodies. It is usually assumed that the phenomenon of impact is a harmful phenomenon and designers aim to minimize its consequences. The reason for this is the impact force, which acts for a very short time interval, but is of very high values and in most cases leads to destruction or at least to unpredictable deformations [3].

Essentially, the phenomenon of Impact has two physical manifestations. One is when the two bodies have a certain speed towards each other [4] and at a given moment they meet and hit each other.

The other is when the two bodies (in this case the concept of "two bodies" is conditional) are connected to each other and represent a single whole and as a result of some force they break their connection and take their own trajectories.

It is known from mechanics that when a body breaks down into separate parts, the trajectories of these parts are such that the total trajectory of their total mass remains unchanged [5].

When two or more bodies are combined [6], there is an increase in the mass of the combined body and therefore there is a change in the trajectory.

In this material, we will take a brief look at the Theory of Impact and will derive some dependencies in which the impact force from the Impact phenomenon has a positive effect.

A. Theoretical statements from the Theory of Impact.

When two bodies come into contact, the physical phenomenon of impact occurs. Entering the theory of impact, the physical phenomenon of Impact is characterized by an impact in a very small time interval. In this time interval, the so-called impact force acts, which takes on very high values.

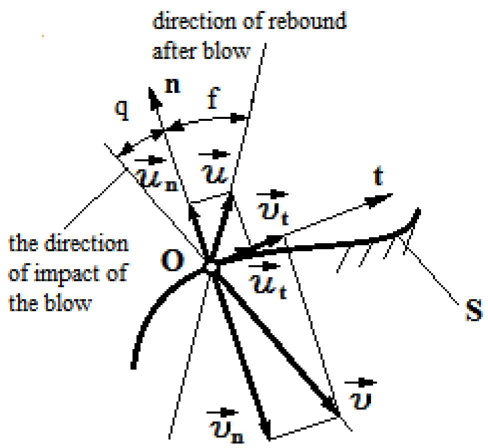

Fig. 1 Schematic diagram of the impact of a material point on a stationary surface.

If we hit a material point with mass m on a stationary surface $\boldsymbol{S(x,y,z,t)=0}$, at an angle ∢q to the normal n (Fig. 1) of the surface *S*, with a speed *v*, then the reaction to the impact will depend on the physic mechanical properties of the matter of the material point and the surface *S*, at the moment of impact. In this material we will limit ourselves only to the shape of the bodies, assuming that the physic mechanical characteristics are uniformly distributed over their surface and volume.

The normal to the surface at the point of impact is given by the expression:

$$\boldsymbol{n} = \boldsymbol{grad\, S}(\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z}, \boldsymbol{t}) = \boldsymbol{0} \qquad (1)$$

At the moment of contact of the material particle with the surface *S* and when leaving the point of contact, regarding the velocity (Fig. 1), the following equality is valid:

$$\boldsymbol{grad\, S.v} + \frac{\boldsymbol{dS}}{\boldsymbol{dt}} \geq \boldsymbol{0} \qquad (2)$$

At the initial moment of impact t_0 the basic equation of the impact theory, projected onto the normal and tangent, takes the form:

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

This system of equations is indeterminate, because the equations are two, and the unknowns are 4, i.e. $\boldsymbol{I_t^m}$, $\boldsymbol{I_n^m}$, $\boldsymbol{u_t}$ и $\boldsymbol{u_n}$. Newton added two additional empirical relationships based on a large number of experiments and observations.

- *The ratio of the absolute values of the normal projections of the relative velocities before and after contact is a constant value and depends only on the physicomechanical properties of the matter.*

$$\frac{\boldsymbol{u_n}}{\boldsymbol{v_n}} = \boldsymbol{h} \qquad (4)$$

This coefficient is called *the coefficient of recovery*. It varies in the range between 0 and 1, i.e. $0 < h < 1$. At h = 0 there is a completely plastic impact, that is, all the energy of the impact is spent on plastic deformation. At h = 1 there is a completely elastic impact, that is, there is a complete recovery of the motion after the impact, albeit in a different direction.

- *The ratio of the absolute values of the normal projections of the relative velocities before and after contact is a constant quantity and depends only on the physicomechanical properties of the matter.*

$$\frac{u_t}{v_t} = 1 - c \qquad (5)$$

Where: c *is called the coefficient of instantaneous friction.*

The two empirical relationships introduced by Newton make it possible to solve equations [3] and find the velocities and impulses during the impact.

As is evident from the above considerations, the impact theory is not an exact theory built on the basis of exact physical quantities and their specific change depending on the change in the surrounding conditions. This is an approximate theory, but it is still based on numerous experiments and the results, which have been confirmed by practice with satisfactory accuracy.

The relationship between the angle of attack q and the angle of reflection after the impact f is as follows.

$$\mathbf{tan\, q} = \frac{\mathbf{v_t}}{\mathbf{v_n}}\, , \mathbf{tan\, f} = \frac{\mathbf{u_t}}{\mathbf{u_n}} \qquad (6)$$

Or

$$\frac{\tan f}{\tan q} = \frac{1-c}{h} \qquad (7)$$

The magnitude of the shock impulse is found by the formula

$$I^m = \sqrt{(1+h)^2 cos^2 q + c^2 sin^2 f} \qquad (8)$$

1. *Kinetic energy.*

The momentum of the system after transformation takes the form:

$$\boldsymbol{mu} - \boldsymbol{mv} = \boldsymbol{I^m} \qquad (9)$$

From which we obtain

$$\frac{\boldsymbol{mu^2}}{\boldsymbol{2}} - \frac{\boldsymbol{mv^2}}{\boldsymbol{2}} = \frac{\boldsymbol{1}}{\boldsymbol{2}}\boldsymbol{I^m}.(\boldsymbol{v}+\boldsymbol{u}) \qquad (10)$$

An equality is obtained, which shows that the change in kinetic energy when a material point hits a surface is equal to the product of the momentum of the impact force and half the sum of the attack velocity and the reflected velocity.

The kinetic energy lost as a result of this phenomenon is

$$\Delta \boldsymbol{T} = -\frac{\boldsymbol{1}}{\boldsymbol{2}}\boldsymbol{m}(\boldsymbol{v}-\boldsymbol{u})^{\boldsymbol{2}} \qquad (11)$$

Carnot's theorem expresses the loss of kinetic energy using the coefficient of restitution

$$\Delta \boldsymbol{T} = -\frac{\boldsymbol{1}}{\boldsymbol{2}}\boldsymbol{m}\frac{\boldsymbol{1-h}}{\boldsymbol{1+h}}(\boldsymbol{v}-\boldsymbol{u})^{\boldsymbol{2}} \qquad (12)$$

At h = 1 there is a completely elastic impact and ΔT = 0, that is, there is no loss of kinetic energy. At h = 0 there is practically no second phase of the impact and all kinetic energy is lost.

When the kinetic energy changes in a mechanical system, Carnot's theorem takes the form

$$\Delta \boldsymbol{T} = -\frac{\boldsymbol{1-h}}{\boldsymbol{1+h}}\sum_{i=1}^{n}\frac{\boldsymbol{1}}{\boldsymbol{2}}\boldsymbol{m_i}(\boldsymbol{v_i}-\boldsymbol{u_i})^{\boldsymbol{2}} \qquad (13)$$

where i is the number of participating material objects in the mechanical system.

2. *Oblique impact of two bodies*

The impact of two bodies is called oblique if the absolute velocities of their centers of gravity are not directed along the line connecting them.

$$\boldsymbol{m_1.u_1} + \boldsymbol{m_2.u_2} = \boldsymbol{m_1.v_1} + \boldsymbol{m_2.v_2} \qquad (14)$$

After projecting this equality onto the normal and tangent at the point of contact, we obtain.

$$|m_1.u_{1n} + m_2.u_{2n} = m_1.v_{1n} + m_2.v_{2n} \qquad (15)$$

$$|m_1.u_{1t} + m_2.u_{2t} = m_1.v_{1t} + m_2.v_{2t}$$

To this system of determination, we add the two empirical dependencies *from Newton's theorem for the coefficients of restoration and the momentary friction.*

$$\boldsymbol{h} = -\frac{u_{1n}-u_{2n}}{v_{1n}-v_{2n}}\ ;\ \boldsymbol{c} = -\frac{u_{1t}-u_{2t}}{v_{1t}-v_{2t}} \qquad (16)$$

II. CHARACTERISTICS OF LANDING STRIKE, SUPPORT, GRIP AND LOKOMOTION

A. Landing blow

Landing is a complex process that takes into account parameters and circumstances from different disciplines of engineering sciences. Landing can be a controlled or uncontrolled process, it can be under the influence of an external force or due to the opposite direction of the movement of the two bodies, etc. *That is, landing is a process in which two bodies approach each other, in which at least one of them controls its movement parameters*.

At the first moment of contact of the two bodies, the phenomenon of Impact occurs for a short time, which affects both bodies.

From d'Alembert's principle for Impact it follows:

$$\boldsymbol{I^m} + (\boldsymbol{m.v} - \boldsymbol{m.u}) = \boldsymbol{0} \text{ or } \boldsymbol{I^m} + [-\boldsymbol{J}(\boldsymbol{m.v})] = \boldsymbol{0} \quad (17)$$

This expression shows the relationship of the Impact phenomenon with the inertial characteristics of the impacting bodies and is called *the inertial impact impulse*.

The conclusion that can be made *is that the smaller the inertial characteristics during landing, the weaker the impact will be.*

The effect of self-centering is manifested in all the listed processes, but it is most noticeable during landing. If the landing gear is multi-point, then the probability that all contact points will simultaneously make contact with the second body tends to zero. The first point that establishes contact with the second body triggers the Impact phenomenon, as a result of the impact force and the excited friction force, a moment is generated at the point of impact, which tends to rotate the first body around the point of contact towards the center of mass of the first body.

B. Impact on support

In essence, the support is a point, line, plane, surface or volume (in the case of a fixed support) between two bodies that are pressed against each other by an external attractive force acting on both bodies.

Impact at landing and impact at support are analogous. The difference between these two processes is that in impact at landing it is between two bodies that have no connection with each other before the start of the Impact phenomenon. In Impact at support there is a preliminary connection between the two bodies.

In this case, d'Alembert's principle takes the form:

$$\boldsymbol{I_a^m} + \boldsymbol{I_k^m} + [-\boldsymbol{J}(\boldsymbol{m.v})] = \boldsymbol{0} \qquad (18)$$

Where:

$\boldsymbol{I_a^m}$ – is the impact impulse of the active forces of the system;

$\boldsymbol{I_k^m}$ – is the impact impulse of the forces of the connections.

The expression can be summarized as follows: The impact impulses of the active forces and the forces of the connections on the one hand and the inertial impact impulse on the other hand are balanced. This leads to an analogous conclusion on the control of the Impact phenomenon, as in the landing process.

As an example, the structure of the human foot and its function in the control of the impact phenomenon are shown.

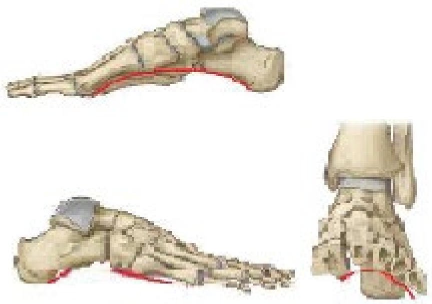

Fig.2. The human foot has three arches – Medial, Lateral and Transverse

The function of these arches (Fig.2.) is to absorb the impact force that occurs when the foot contacts the road (like springs). They sequentially straighten and release their energy, as a motive force to move the body forward.

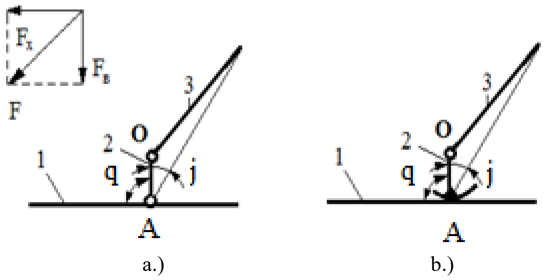

Fig.3 Bounce-back impact during gait

The contact point A is of essential importance for the foot. The contact is usually with a discontinuous second derivative of the law of motion, that is, there is an impact.

In human gait, the so-called bounce-back impact is used (Fig. 3, a). By means of a suitably selected kinematic design of the foot and the values of the angles q and j, the horizontal component of the force Fx continues to act after the contact is established, as a driving force. The contact point A of the foot is formed as a curve, that is, a cam mechanism (Fig.3,b.), increasing the step so that the horizontal force is driving for the system. In space, this heel is formed by a suitable volume with a shape corresponding to the action of the driving force and its components.

C. *Impact during gripping*

In point 2.2. for the support process it was mentioned that for this process to exist, it is necessary to have an external force that presses the two bodies against each other. If this external pressing force is zeroed or becomes negative, the support phenomenon cannot be realized, in this case, it is necessary to synthesize a grip. *During gripping, external forces and moments can acquire different values, without limitation, whether they are positive, negative or zeroed.*

The gripping process is a process in which more attention is paid to the forces of the connections between the two bodies. This process emphasizes the control of the size of the connections between the bodies, in order to realize the gripping phenomenon.

In practice, the grip is synthesized as a support to which additional mechanisms are synthesized that grip the other body, providing clamping forces between the gripping mechanism and the second body.

There are many examples of gripping mechanisms in biomechanics.

D. *Impact during locomotion*

Locomotion is a periodic process of the phenomena of support or grip. In practice, we can speak of a body that changes its shape and the position of the center of gravity in the presence of locomotion. *Considered in depth, this phenomenon occurs between two bodies that, without breaking the connections between them, perform relative motion.* The periodic nature of locomotion suggests that the impact process is also periodic. Therefore, the impact force during locomotion will represent a periodic discontinuous function in time, with periodic peaks of amplitude.

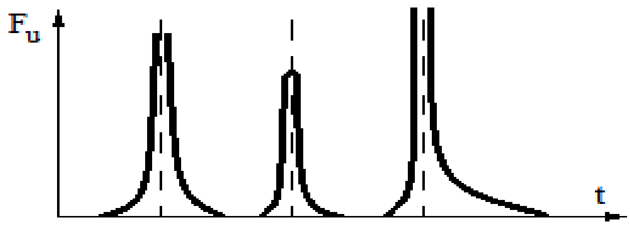

Fig. 4. Sample graph of impact force during locomotion.

From Fig.4. the periodic nature of the impact force during locomotion is noticeable. The first amplitude is almost symmetrical, which shows that the impact force arises and is extinguished without using its resource. The second amplitude shows that the kinematic system has an option to limit the amplitude of the impact force. The third amplitude shows that the kinematic system uses the energy resource of the impact force. The periods between impacts are not equal, since they are set by the kinematic system itself depending on the locomotion process.

III. CONCLUSION

Not always a physical phenomenon, which is usually considered negative, has only negative results in practice.

1. As is evident from the material presented, the physical phenomenon Impact also has positive sides. The quantities involved in this phenomenon have applications in landing, synthesis of supports and grips, as well as in locomotion.
2. An important phenomenon of the Impact phenomenon is the self-centering effect that it generates on the actions of the kinematic chains of the mechanisms of the listed processes.

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