INTERMITTENT MOTION OF CHALK ON A SOLID SURFACE

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1. Introduction

When the chalk is moving on a board you can observe an interesting phenomenon when the chalk begins to hop and leave a dotted line. Although it is easily reproduced in any part of the world [1], such movement still has no exhaustive explanation. Suggested theoretical models are rather difficult, require numerical resolution and do not give a clear picture of the phenomenon [2]. The study of dry friction collides with paradoxes, which are discussed in scientific articles in our time [3]. The paper proposed a simple theoretical model of the phenomenon and exact solutions are obtained, which are confirmed experimentally with good accuracy.

2. Theory

In our model, the chalk is modeled by a rod, along which the force is in the direction of the board. When the chalk is touching the board on condition of jamming and we try to move it and save some angle of inclination, through the chalk deviation, due to the tension of the muscles, the moment of force M arises. It increases with increasing angle of deviation α from the equilibrium position,after that in some moment the chalk jumps out.

$$M = -k\alpha, \qquad (1)$$

where $k > 0$ - the constant, which takes into account the biomechanical properties of the hand with the rod.

When the chalk is in flight, there is no friction and a moment of muscle strength turning rod, accelerates it. That rod, by inertia, passes the equilibrium position and deviates in the opposite direction. Simultaneously, when the chalk is in flight, we continue to apply force to it, trying to press it against the board, so that it returns to the surface again.

The equation of the dynamics of rotational motion acquired in our model as equations of oscillation.

For flight: $I_0\ddot{\alpha} = -k\alpha$, where I_0- the moment of inertia relative to the center of mass. To touch the surface $I\ddot{\alpha} = -k\alpha$ $(I = I_0 + mr^2)$.

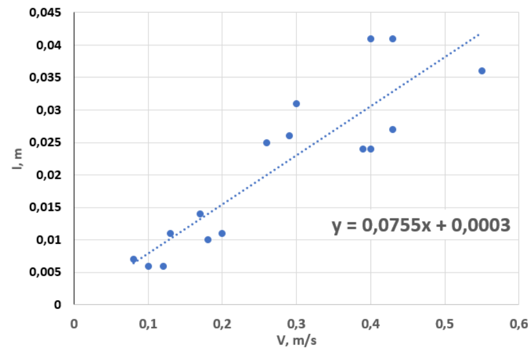
For typical modes of movement of each of the two phases takes place half-period. Then we get a simple dependency relations *time of contact* to *time of flight*:

$$\frac{t_S}{t_F} = \sqrt{\frac{I}{I_0}}, \qquad (2)$$

where: t_S – the time of turning, t_F – flight time.

3. Experiment

The experimental studies have confirmed a good ratio of touching time to the time of flight. It was also investigated the dependence of the linear velocity of the rod from the length of the "step" and force pressure on the chalk. The plot gives experimental data on the dependence of the length of the "step" on speed along with the averaged line that almost passes through the



Pic. 1. Experimental data

origin. The angular coefficient of 0.0755 has a physical meaning of a period of movement. It turns out that the period does not change with increasing pressure force and average speed. That means that the coefficient *k* in the moment of force (1), which characterizes the elasticity of the system when it deviates from the equilibrium position, remaining unchanged.

The measurements were carried out on different surfaces (movable and immovable) using high-speed shooting and electronic dynamometer from a set MultiLab.

4. Conclusion

The proposed theoretical model, whereby on the body act proportional to the deviation of force and moment of force, got a pretty good experimental confirmation. In particular, it was found that the ratio of times of two types of motion for a homogeneous rod is 2 ($t_S = 2t_F$), and The distance between the tracks of the chalk on the board is proportional to the speed of the movement. The explanation of the chalk movement is physically simple. The almost complete absence of slippage associated with the occurrence of jamming.

5. References

[1] R.I.Leine, Periodic motion and bifurcations induced by the Painlev_e paradox. European Journal of Mechanics A / Solids, 21: 869-896, 2002.
[2] Painlevé paradox // From wikipedia. URL: https://en.wikipedia.org/wiki/Painlevé_paradox (Date of appeal: 18/03/2018).
[3] His Hand Does not Even Move// From Youtube. URL:https://www.youtube.com/watch?v=l789l6np-qA (Date of appeal: 18/03/2018).