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THE EFFECT OF RANDOM GEOMETRICAL AND MECHANICAL PARAMETERS IN IMPACT EXPERIMENTS

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***Abstract*—**The impact with friction between a free falling ball and a rotating disk around a vertical axis was studied in a series of previous papers under the assumption that the ball-disk dynamic system is a plane one, but the contradictory results obtained lead to leaving this hypothesis. Considering the impact between the same ball and the tilted immovable disk, the dynamical and kinematical parameters of the system result with appreciable errors. The elastic characteristic and the micro topography of the contact regions can be found only statistically and therefore finding the kinematical and dynamical parameters of the system should by obtained via statistical methods.

***Keywords*—**dry friction, planar impact, system dynamics, statistical methods

I. INTRODUCTION

THERE are notable works upon the impact with friction [1]-[3]. In the present paper, the collision between a steel disk in uniform rotational motion and a metallic ball is considered. The main aim of the research is finding the effect of tangential percussions occurring during the impact between the free falling ball and the frontal cylinder face.

The effect of tangential percussions can be evidenced by the parabolic trajectory and angular velocity of ball's centre. The ball centre trajectory is an issue relatively simple to control but finding the angular velocity of the ball proved to be a very difficult task, because it was impossible to set a mark on the ball surface, as the region could become contact region and the mark affects the characteristics. Therefore, it was chosen to find this parameter by calculus.

II. THEORETICAL REMARKS

It was accepted that after impact the ball describes a parabolic trajectory in a vertical plane normal on the impact point radius and that ball's motion subsequent to impact is a plane motion (it was *a priori* supposed that the ball's angular velocity after impact is normal to the trajectory's plane), Fig.1. With these hypotheses the horizontal $\mathbf{P_h = P_x}$ and normal $\mathbf{P_n = P_y}$ components of the percussion can be found, respectively.

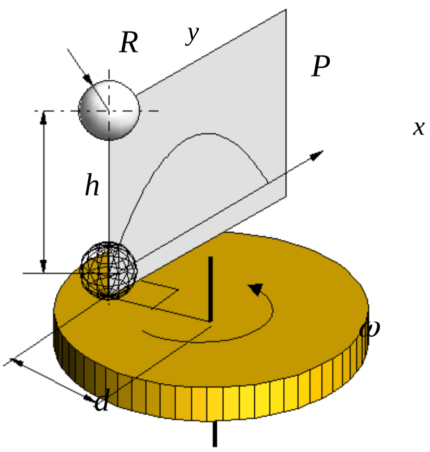

Fig. 1. Scheme of proposed test-rig

For the case of plane collision, the theorems of rigid body dynamics are written, for the moments of impact initiation and impact end [4].

Theorem of linear momentum:

$$\mathbf{m(v''_x\, i + v''_y\, j) - m(-v'_y\, j) = P_x i + P_y j} \qquad (1)$$

Theorem of angular momentum about ball's centre:

$$\mathbf{J_z \omega''_b\, k} = \begin{vmatrix} \bar{\mathbf{i}} & \bar{\mathbf{j}} & \bar{\mathbf{k}} \\ \mathbf{0} & \mathbf{-R} & \mathbf{0} \\ \mathbf{P_x} & \mathbf{P_y} & \mathbf{0} \end{vmatrix} = \mathbf{P_x R \bar{k}} \qquad (2)$$

where $\mathbf{v'_y, v''_x, v''_y}$ are components of ball centre velocities before and after impact, respectively; $\boldsymbol{\omega''_b}$ is the ball's angular velocity after impact; $\mathbf{R}$ is the ball radius; $\mathbf{J_z}$ is the momentum of inertia of the ball; $\mathbf{P_x, P_y}$ are the components of percussion. The above two equations lead to the scalar system:

$$\begin{aligned} & mv''_x = P_x \\ & mv''_y + mv'_y = P_y \\ & J_z \omega''_b = P_x R \end{aligned} \tag{3}$$

After resulting the angular velocity, the kinetic energy theorem can be applied to find the work of internal forces (work of internal friction) assuming that the internal work is caused only by normal the components, using the Lankarani-Nikravesh model [5], improved by Flores [6].

It was observed that the energy balance equation is very well validated for certain values of disk's angular velocity and ball launching height while for some other values of angular velocity and launching height there is a quite rough error. Thus the test-rig was restored, Fig. 2., by redesigning the launching system to ensure constant position for impact point and null angular velocity of launched ball [7]. Using the new device, a series of experimental launchings were performed and the impact traces made by the ball impact on the rig table 1 were registered (the ball 2 was first colliding the disk 3).

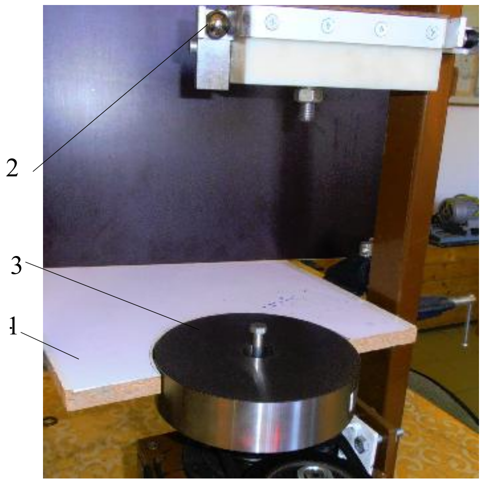

Fig. 2. Actual testing device

The first source considered was the disk's vibration. To reduce the magnitude of the disk's vibrations, the shaft on which the disk was fixed was manufactured for a second time and the disk was replaced by a new one, precisely machined and controlled. The vibrations reduced considerably but the effect upon the dimensions of the print scattering region was practically unnoticeable. In Fig. 3 is presented the spreading region for the collision of a $\phi 19$ ball, free falling from a 0.280mm height on a disk rotating with $260\,\text{rpm}$.

As it can be seen from Fig. 3., a trend of agglomeration of impact mark occurs after an appreciable number of launchings was made.

A second set of tests was obtained considering the chronology of impact traces and noting down them. As is shown in Fig. 4, it cannot be established a rule for points happening. But a systematic phenomenon was observed, referring to placing of impact traces on the same side of the theoretical trajectory plane (the plane normal to the vector radius of the contact point from the disk).

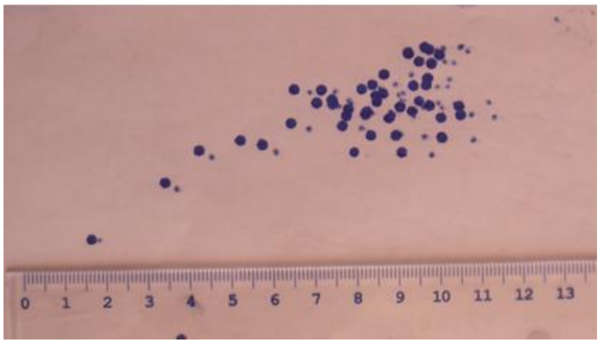

Fig. 3. Traces of the second impact between ball and rig-plate

In a previous work [7] it was proved that the hypothesis that the ball moving after the first collision (with the disk) is a planar one must be abandoned, as the ball angular velocity has more components than the normal one to the parabolic trajectory plane.

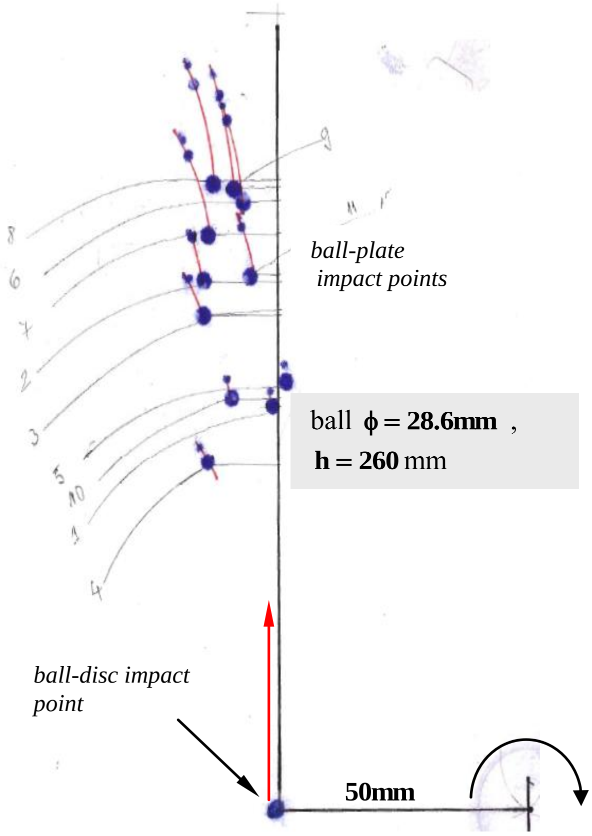

Fig. 4. Marks of ball-table collisions
ball $\phi = 28.6$ mm, $h = 260$ mm

III. Improved Testing Methodology

It was supposed that the main error sources are the disk vibration and the variation of elastic and geometric parameters around the contact points. To eliminate these errors but also maintaining the tangential component of percussion, the two dimensional impact between the ball and immobile tilted disk was studied, Fig. 5., and Fig. 6.

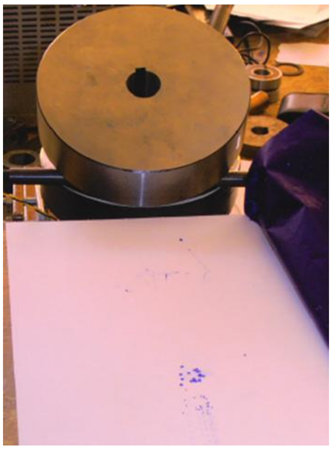

Fig. 5. Impact marks between the ball and tilted motionless disk

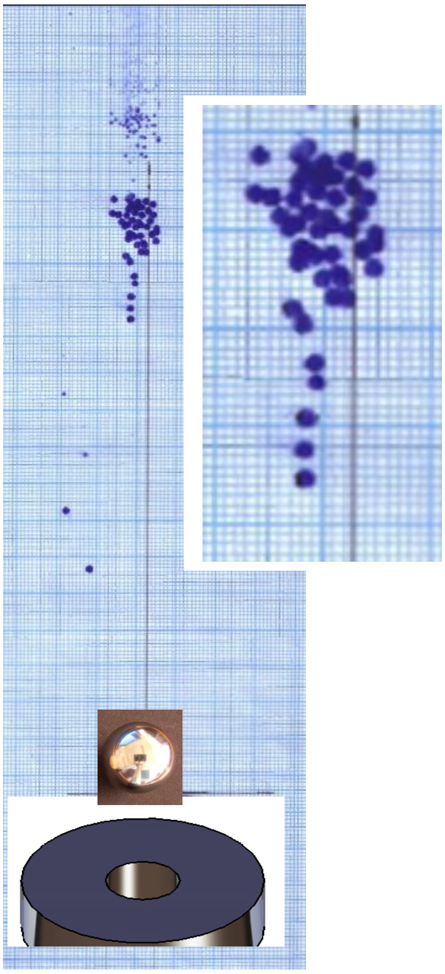

Fig. 6. Marks set for falling ball from the same experiment conditions

Analyzing the impact test marks from Fig. 6., it is observed that the scattering region elongates along the projection on the table of theoretical trajectory plane. There were completed a sufficient number of experiments and therefore a tendency of marks disposition was noticed. As it can be observed from Fig. 6., although the disk is motionless and all the parameters are maintained, the impact traces don't set on a straight line, as the symmetry requires. The only explanation for this deviation consists of local asymmetry of micro topography and strong variation of elastic parameters in the contact vicinity. With this hypothesis, three experimental impact sets were made using a steel ball, a mouse ball and a wood ball respectively, the results being presented in Fig. 7.

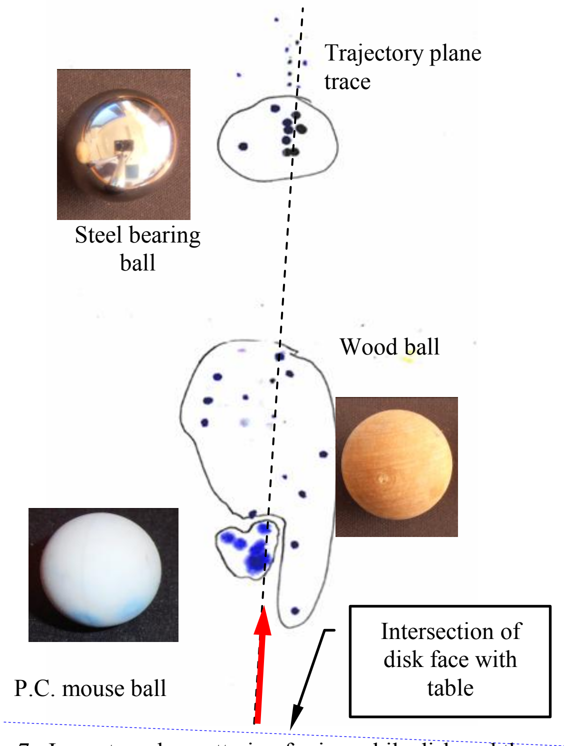

Fig. 7. Impact marks scattering for immobile disk and three balls of different materials

It is noticed that the mouse ball traces are the most agglomerated. These marks also present the largest dimension and it is assumed that thus, the mechanical and micro topography un-uniformities are averaged. The largest scattering tendency was observed for the wooden ball which is known to be an inhomogeneous and anisotropic material.

Fig. 7 reveals another interesting aspect, namely, for the steel ball launched in identical conditions, the marks align along a straight line, only a few remaining isolated.

New experimental tests were completed for two different launching heights, for the same steel ball in the same launching conditions, noting the chronology of the marks. In Fig. 8, the phenomenon revealed above, is clear for both cases, and the earlier marks are more close to the disk, remote from the main bunch which are agglomerated in an asymptotic manner. The possible explanation of the phenomenon is the following: with increasing running number of collision, the asperities from the contact region on the disk – which is strictly the same, due to special design of the launcher, are successively plastically deformed, and thus, after a significantly collision number, the geometry of the impact region is stable. After this stabilisation, only the geometry and the mechanical characteristic from contact point vicinity from the ball remain as perturbing factors.

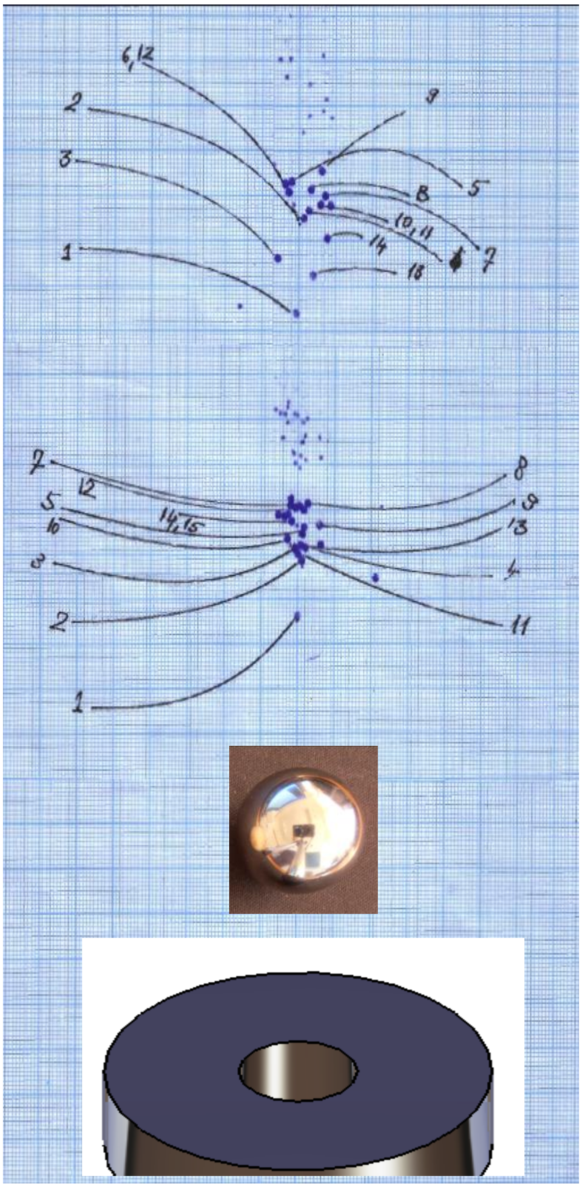

Fig. 8. Mark sets for two launching height of the same ball

The final conclusion arising is that in the case of rotating disk tests, the scattering of ball marks is due to the variation of mechanical characteristics and micro geometry of regions in the contact point vicinity from disk and ball. These parameters variations cannot be neither eliminated nor precisely modelled. The aleatory character of these parameters variation also influences the impact test results. Consequently, it is required a large number of experimental data and a statistical approach [8] for results processing.

REFERENCES

[1] R. M. Brach, *Mechanical Impact Dynamics, Rigid Body Collision,* John Willey and Sons, 1991.

[2] W. J. Stronge, *Impact Mechanics,* Cambridge University Press, Cambridge, 2000.

[3] Y. Wang, M. T. Mason, "Two-dimensional Rigid-body Collisions with Friction", *Journal pf Applied Mechanics,* vol 59, September 1992, pp. 635-642.

[4] R. N. Jazar, *Advanced Dynamics: Rigid Body, Multibody, and Aerospace Applications,* Wiley, 2011.

[5] H. M. Lankarani, P.E. Nikravesh, "A contact force model with hysteresis damping for impact analysis of multibody systems", *J. Mech. Des.* 112, 1990, pp. 369-376.

[6] P. Flores, M. Machado, M.T. Silva, J.M. Martins, "On the continuous contact force models for soft materials in multibody dynamics", *Multibody System Dynamics,* vol. 25, 2011, pp. 357-375.

[7] S. Alaci, F-C. Ciornei, I. Românu, D-V. Amarandei, "Can the collision between a free falling ball and a rotating disk be regarded as a plane impact?", *Proceedings of 16th International Conference on EHD Lubrication and Traction, VAREHD 16,* Suceava, October 25 -27, 2012.

[8] W. Navidi, *Statistics for Engineers and Scientists*, 3rd edition, McGrawHill. New York, 2011.