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COLLISION OF A ROTATING SPHERICAL PARTICLE WITH FLAT WALL IN LIQUID

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Abstract. *The collision of the rotating spherical particle with a flat wall in liquid was studied experimentally. The glass and steel balls rotating in water and silicon oil were used. The ball motion was recorded by a high-speed video system. It was shown that the restitution coefficient depends not only on the Stokes number but also on the particle angular velocity; the restitution coefficient decreases with increasing of the rotational Reynolds number.*

Key words: ***restitution coefficient, spherical particle, particle rotation, liquid viscosity.***

The modeling of particle-particle or particle-wall collisions requires a detailed understanding of the mechanics of impact and rebound. The energy dissipation due to an inelastic contact is usually characterized by a coefficient of restitution, defined as the ratio of the rebound velocity to the impact velocity, $e = | v_r / v_i |$. In a fully elastic collision coefficient of restitution $e = 1$, whereas for a perfectly plastic collision $e = 0$. Most of the studies deal with so called dry collisions, i.e. collisions in vacuum or gas. Only a few works take into account effect of fluid viscosity on the collision process, but we have not found any study dealing with the effect of particle rotation. Davis et all. (1986) declared, that the pertinent number for the collision is not the Reynolds number, but the particle Stokes number which compares the particle inertia to the fluid viscous forces $St = (1/9)(\rho_p / \rho_f)Re$, where $Re = d\, U\, \rho_f / \mu$ is a Reynolds number, ρ_p and ρ_f is a particle and fluid density, respectively, d is a particle diameter, μ is fluid dynamic viscosity, and U is the particle impact velocity.

Let us suppose that the particle shape is spherical, it moves in a liquid and collides with a plane wall. The rebound of the particle after collision depends on the material of particle and the wall, on impact velocity and the restitution coefficient, which is a function of the particle Stokes number (Gondret et all., 2002). For $St < St_c$, where $St_c \approx 10$ is a critical Stokes number, the restitution coefficient is equal zero, and no rebound occurs. The restitution coefficient increases with increase of the Stokes number, and reaches the maximum value when the Stokes number is about 2000 – 3000, where it is close to the value of restitution coefficient determined for a collision in gas, where the fluid resistance is negligible.

The goal of the present work is examine experimentally the effect of liquid viscosity and of particle rotation on the restitution coefficient of the spherical particle rebounding from a plane wall in liquid. Water and silicon oil were used as a liquid, smooth glass and steel spherical particles of diameter d = 14, 16, and 19 mm, and a sheet of glass of thickness 21 mm was used as impact surface. The particle was rotated about a horizontal axis with an initial angular velocity ω_0 in a special spinning device, which ensured the required ball rotation. Translational velocity of the ball was reached by free fall. Immediately before the collision the angular velocity becomes 1.5 – 2 times less than ω_0. After the collision with the wall, the ball rebounded and the combined translational and rotational motions were recorded with a frequency of 1000 frames per second by the digital video camera MotionPro X High-Speed CMOS Digital Camera.

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Particle trajectories and velocity components are illustrated in Fig. 1 for glass particle of d = 16 mm rotating in clockwise direction with an initial angular velocity ω_0 = 5 800 rpm in water. The angular velocity just before the 1st impact was significantly less, only ω_1 = 3 288 rpm, and further ω_2 = 1 846 rpm, and ω_3 = 895 rpm just before the 2nd and 3rd impact, respectively. The particle trajectory is displayed in upper part of Fig. 1, interesting is effect of the particle rotation on change in x-direction during the first impact. The height of the jump gradually decreased in successive jumps.

The instantaneous particle velocity components in vertical (normal) and horizontal (tangential) directions were computed as the time derivative of the co-ordinate increment between two successive images, and the corresponding velocity components v_y and v_x were plotted as function of time, see Fig. 1 bottom. The normal velocity reached the maximum just before the first collision, decreased nonlinearly with time.

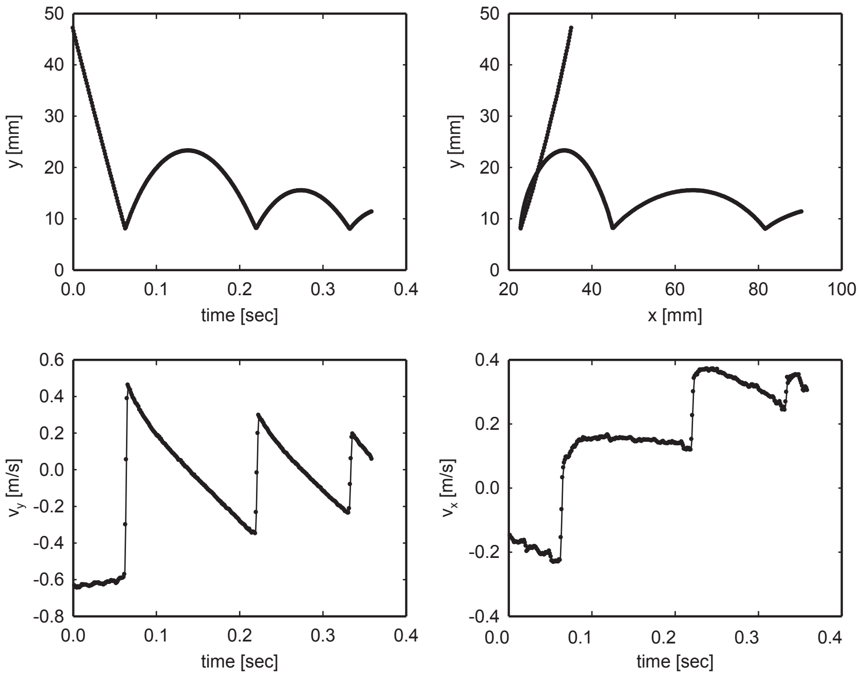

Fig. 1: Trajectories and velocity components of rotating glass spherical particle falling in water (diameter d = 16 mm, initial angular velocity ω_0 = 5 800 rpm).

The characteristics of the golf ball motion before and after the collision for three different initial angular velocity ω_0 (ω_0 = 0; 4500; and 5200 rpm) are given in Table 1. The maximum value of the restitution coefficient *e* is reached when the particle does not rotate. The larger angular velocity before the collision corresponds to the smaller restitution coefficient.

Table 1: The characteristics of the ball motion before and after the collision.

No.	ω_0 [rpm]	$v_{i.n}$ [m/s]	$v_{r,n}$ [m/s]	e	St	ω_i [rpm]	$Re_{\omega,r}$
1	0	-0.39	0.27	0.70	1 850	0	0
2	4 500	-0.51	0.31	0.60	2 420	2 005	95 300
3	5 200	-0.75	0.35	0.46	3 570	3 065	145 500

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