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INVESTIGATION OF PARTICLE-WALL COLLISION

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Abstract. Interaction of the particles of different shapes, sizes and materials with the plane surface was studied experimentally, using a special Laser Doppler Anemometer (LDA) and the corresponding measuring technique. Coefficients of normal restitution and of dynamical friction, obtained for different collision angles, were compared with the results of other works carried out in the recent years.

Key words: particle-wall collision, LDA, normal restitution coefficient, coefficient of dynamical friction.

1. INTRODUCTION

At the present time quite a number of studies are devoted to the particle-wall interaction. What is the reason that forces investigators to turn to this problem again and again? Probably the fact that a number of additional factors is superposed on the main process and their influence may become considerable under certain conditions. Among these factors we can list: particle and wall material; particle shape and roughness of the wall with their variation during the collision process; influence of the accompanying air and rebounded particles on the collided particles; electrical forces; different collision regimes (with or without sliding); etc. Besides, different investigators study the collision process within the bounds of some other main problem: several of them describe the flow in the channel, some others the process of erosion. Different main tasks predetermine different research methods and are often limited by a respectively narrow range of parameter variations. It may lead to the overestimation of some factors, which do not reflect physics of the collision process compared with others. So, results of experimental studies made under the same conditions, even in the recent years ([1], [2]), differ not only in quantity, but also in quality.

We try to study the process of collision itself using unique methods in the maximum possible range of parameters and, as far as possible, strive to exclude the influence of additional factors (first of all – accompanying air). The main task of the present work is to check up the reliability of our investigation methods by the comparison of our data with the data of other authors.

2. EXPERIMENTAL EQUIPMENT

A centrifugal four-channel device is used to accelerate the particles. It is mounted on the base of a coordinate device and can be moved relative to the measuring volume of the LDA. The cover of the centrifugal device has a rectangular opening, where the receiving unit – a truncated triangle prism – is mounted. On the top of the prism there is a regulating receiving hole and in the bottom a cover with outlet aperture to form a narrow bundle of particles. The aperture diameter is from 1 to 3 mm. The plate to be investigated is fixed at a corresponding angle onto the bracket of the cover. The velocity of particles may exceed 100 m/s.

3. MEASURING SYSTEM

The peculiarity of the investigated object is in the fact that the rebound direction of particles is not known beforehand and the rebound cone may be rather wide (especially for particles of irregular shape). This is the reason for elaborating a special LDA characterized by the possibility of operative changing of the direction of the sensitivity vector, i.e., the direction of the measured projection of the particle velocity vector. Furthermore, the offered scheme permits to adjust the LDA during the experiment to the particles of definite size. Changing the sensitivity of the receiving part permits to readjust the system within a size range chosen by adjusting the optical scheme.

The signal from the photo receiver of the LDA is transferred to the counter which analyses its quality and transfers the obtained velocity of the particles crossing measuring volume to the computer. The software is specific for the LDA measurements and consists of subroutines for data collection and analysis. The mean velocity, standard deviation and data rate are calculated. The last one is proportional to the amount of particles crossing measuring volume and permits to determine particles concentration..

4. MEASURING METHOD

The rebound direction was determined as the direction of velocity vector at the point of the maximum particles concentration (Fig. 1). This point was found by linear scanning along the *X* axis at some distance from the plate in the most probable rebound region. Then, the direction and value of the velocity vector were found at this point by the angular scanning of the LDA sensitivity vector. The concentration was determined by the number of Doppler signals registered by the system in one time unit. This number depends not only on the amount of particles crossing the measuring volume, but also on the measuring velocity component, on the adjustment of the system and on the receiving conditions. We can see it well if we compare the distribution of concentration *1* (vertical velocity component) and 2 (horizontal one) in Fig. 2 (both obtained by linear scanning at the same distance of 4 mm from the plate).

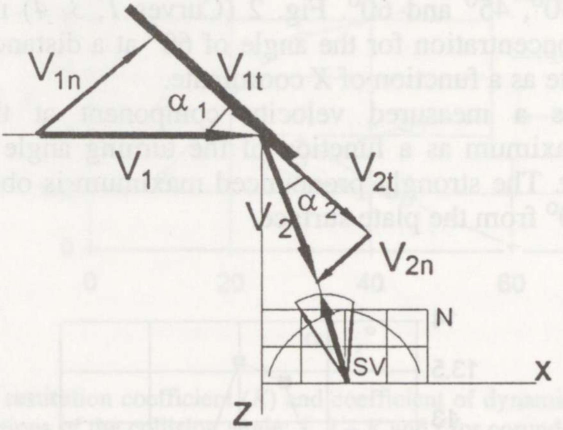

Fig. 1. Determination of the value and direction of particle velocity; *SV* – sensitivity vector, *N* – number of particles crossing measuring volume per unit of time and registered by LDA.

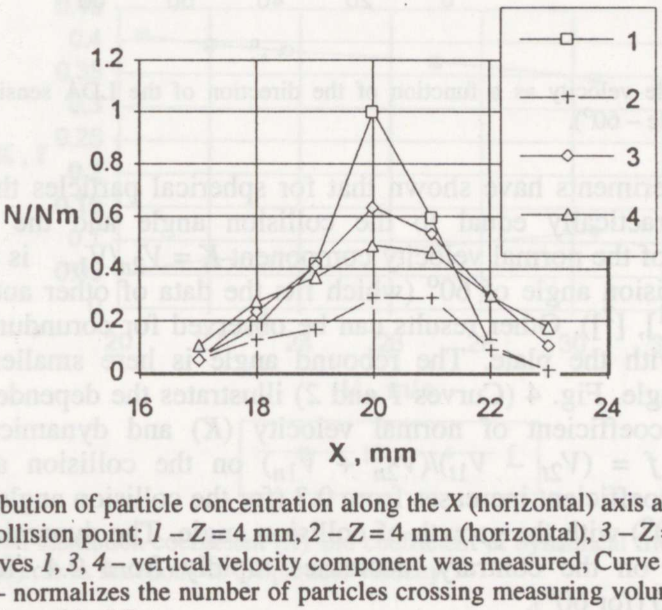

Fig. 2. Distribution of particle concentration along the *X* (horizontal) axis at a distance of *Z* from the collision point; *1* – *Z* = 4 mm, 2 – *Z* = 4 mm (horizontal), *3* – *Z* = 6 mm, *4* – *Z* = 8 mm. Curves *1*, *3*, *4* – vertical velocity component was measured, Curve 2 – horizontal one. N/Nm – normalizes the number of particles crossing measuring volume per unit of time and registered by LDA.

Although these maxima differ value they are located at the same place. Moreover, the regions where particles are revealed, practically coincide. Just these two characteristics are important for finding the rebound angle and thus this method seems to be suitable for determining the concentration in our case.

5. EXPERIMENTAL RESULTS

At the first stage the interaction between non-spherical corundum particles (mean size 120 μm) as well as glass spheres (700 μm) and the hardened steel plate was studied. The considered angles between the plate and flow were 30°, 45° and 60°. Fig. 2 (Curves *1*, *3*, *4*) illustrates the distribution of concentration for the angle of 60° at a distance $z = 4, 6, 8$ mm from the plate as a function of X coordinate.

Fig. 3 shows a measured velocity component at the point of concentration maximum as a function of the turning angle of the LDA sensitivity vector. The strongly pronounced maximum is observed at the angle of about 40° from the plate surface.

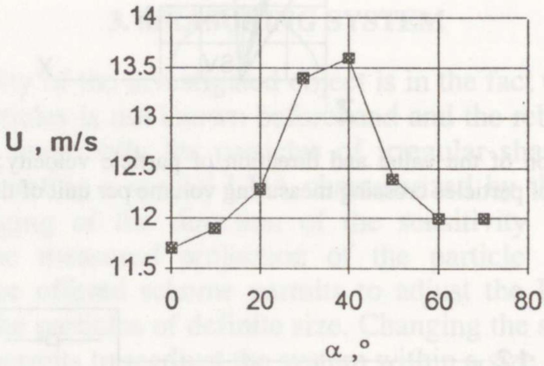

Fig. 3. Particle velocity as a function of the direction of the LDA sensitivity vector (collision angle – 60°).

Our experiments have shown that for spherical particles the rebound angle is practically equal to the collision angle and the restitution coefficient of the normal velocity component $K = V_{2n}/V_{1n}$ is about 0.77 for the collision angle of 60° (which fits the data of other authors quite well, e.g. [1], [2]). Other results can be observed for corundum particles colliding with the plate. The rebound angle is here smaller than the collision angle. Fig. 4 (Curves *1* and *2*) illustrates the dependence of the restitution coefficient of normal velocity (K) and dynamical friction coefficient $f = (V_{2t} - V_{1t})/(V_{2n} + V_{1n})$ on the collision angle. The restitution coefficient increases from 0.3 (for the collision angle of 30°) to 0.45 (for 60°) with the growth of collision angle. The dynamical friction coefficient, on the contrary, decreases rapidly from 0.4 (for 30°) to practically 0 (for 60°).

In the same figure (Curves *3* and *4*) the results for glass spheres by Petrak ([1]) are also given. The comparison gives us an expected result: the normal restitution coefficient for spheres is bigger, than that for corundum, while the dynamical friction coefficient is smaller. The form of the curves is rather similar.

Fig. 5 gives us *K* and *f* as functions of velocity of the corundum particles for the collision angle 60°. *K* decreases slightly while *f* increases.

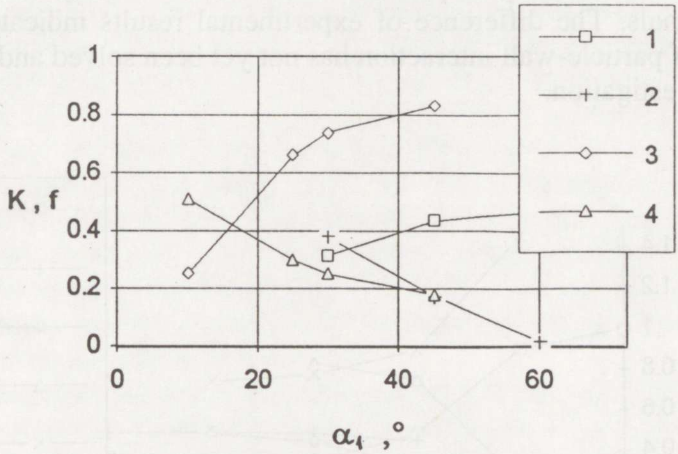

Fig. 4. Normal restitution coefficient (*K*) and coefficient of dynamical friction (*f*) of the particle as functions of the collision angle; *1*, *2* – *K* and *f* for corundum particles, *3*, *4* –*K* and *f* for glass spheres ([1]).

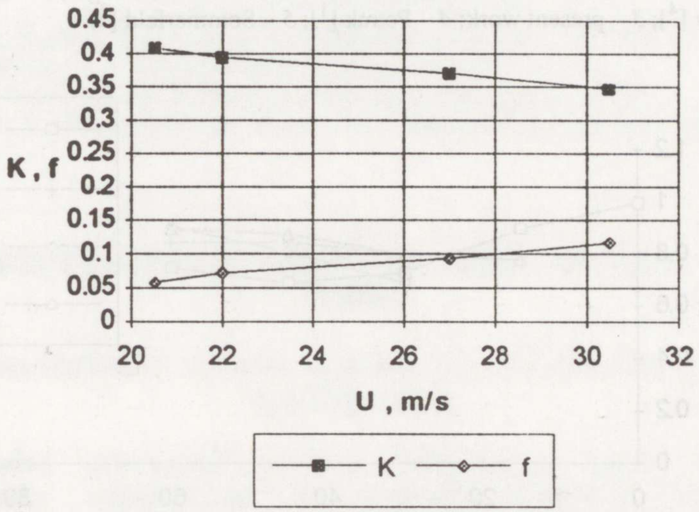

Fig. 5. Normal restitution coefficient (*K*) and coefficient of dynamical friction (*f*) of the corundum particle as functions of the particle velocity.

Figs. 6 and 7 represent the results of the most important experimental studies carried out during the last years by using modern experimental techniques. Nevertheless, in the region of small collision angles (< 30°) the obtained results differ both in quantity and in quality, although Curves *4* and *5* (Fig. 6) describe the results of measurements with practically the only parameter which has an essential influence on the normal restitution coefficient (*K*). This coefficient for non-spherical particles (Curves *1*, *2*, *3*) is about two times smaller than that for spheres (Curves *4*, *5*) and it does not depend considerably on particle size, collision velocity and particle or wall materials. The difference of experimental results indicates that the problem of particle-wall interaction has not yet been solved and it requires further investigation.

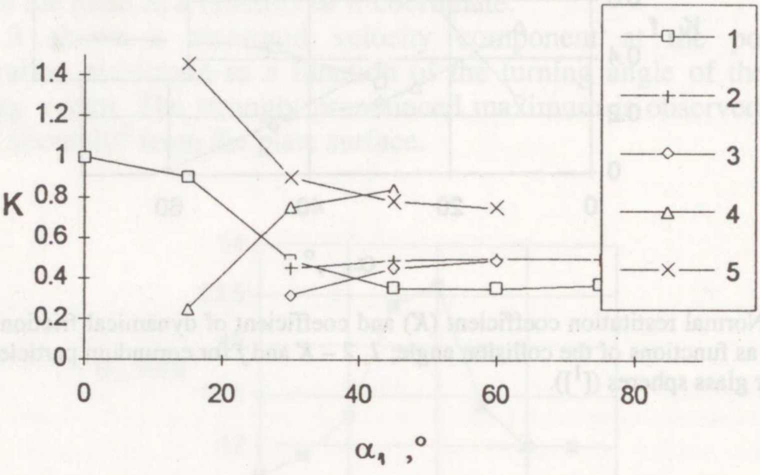

Fig. 6. Normal restitution coefficient as a function of the collision angle; *1* – Tabakoff [3]; *2* – Ushakov [4]; *3* – present work; *4* – Petrak [1]; *5* – Sommerfeld [2].

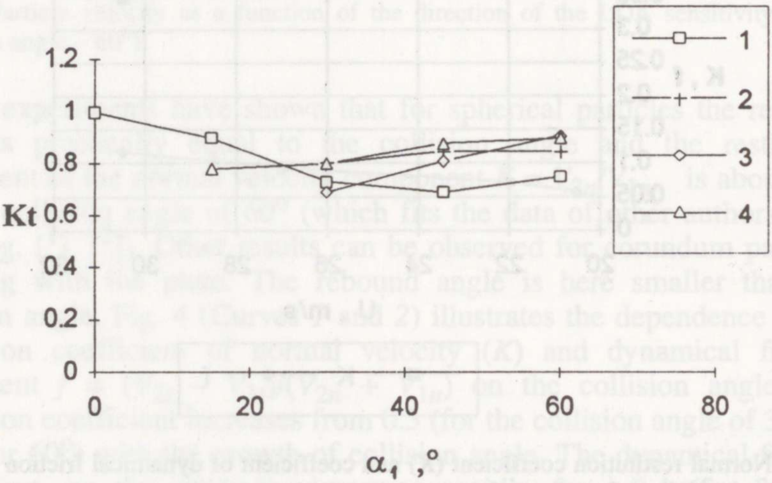

Fig. 7. Tangential restitution coefficient as a function of the collision angle; *1* – Tabakoff [3]; *2* – Ushakov [4]; *3* – present work; *4* – Petrak [1].

Fig. 7 demonstrates that the values of tangential restitution coefficient $K_t = V_{2t}/V_{1t}$ obtained by different authors for different parameters also lie in a respectively narrow range for the angles of 30^o–60^o. It is convenient to improve our experimental methods in this region by comparing our results (Curve *3* in Fig. 6 and Fig. 7) with the results of other authors.

6. CONCLUSIONS

a) The rebound angle and normal restitution coefficient K for non-spherical particles are considerably smaller than those for spherical ones. For non-spherical particles the normal and tangential restitution coefficients (K and K_t) do not depend essentially on the mean size of particles while for spherical ones this dependence is more considerable.

b) The range of the collision angles 0^o–30^o is the region of the most essential differences (even contradictions) between the data of different experimental works. For the angles 30^o–60^o most investigators get $K = 0.7 - 0.8$ for spherical particles and $K = 0.35 - 0.5$ for the particles of irregular shape. In this range (30^o–60^o) we have got K and K_t that fit the results of other authors quite well.

c) Our experiments have confirmed that each following investigation in the narrow range of parameters may give justification for some particular point of view, but need not lead to a common understanding of the process. All the contradictions may be eliminated only by systematical investigation in a wide range of parameters with the same equipment and measuring techniques.

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TAHKETE OSAKESTE PÕRKEPROTSESSID METALLPLAADI PINNAL

Feliks FRIŠMAN, Igor HALJASMAA, Toivo PAPPEL, Ülo RUDI, Igor ŠTŠEGLOV

Kasutades spetsiaalselt osakeste kiirusvektori suuna ja suuruse määramiseks väljatöötatud laser-doppleranemomeetrit on uuritud ebakorrapärase kujuga korundosakeste ja sfääriliste klaasosakeste põrkumist karastatud metallplaadil. Erilist tähelepanu on pööratud põrkenurkade määramisele diapasoonis, mille puhul erinevate autorite

seisukohtade lahknemine on kõige suurem, ning analüüsitud lahknemise võimalikke põhjusi.

ИССЛЕДОВАНИЕ СОУДАРЕНИЯ ЧАСТИЦ С ТВЕРДОЙ ПОВЕРХНОСТЬЮ

Феликс ФРИШМАН, Игорь ХАЛЬЯСМАА, Тойво ПАППЕЛЬ, Юло РУДИ, Игорь ЩЕГЛОВ

Исследовано соударение несферических частиц корунда и стеклянных сфер со стальной закаленной пластиной. Для измерения величины и направления вектора скорости используется специально разработанный для этой цели доплеровский анемометр. Определен диапазон изменения углов соударения, где данные различных исследователей существенно расходятся. Обсуждаются возможные причины этих расхождений и направления дальнейших исследований.