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STUDIES CONCERNING THE PARTICLE CONGLOMERATION IN THE FLUIDIC MILLS

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Abstract: *In this paper a documentary study about the problems of the researches oriented in the domain of particles size reduction is presented. The presented mills used for processing represent the most important type used in the powder metallurgy. The paper presents conclusions about the research directions to be considered in the future. Also the problems and the experimental researches for the particles conglomeration are presented. The considerations made in this paper are intended for future research of a serious and complete study of the conglomeration phenomena.*

Key words: *fluidic mill, spiral jets, micronization, conglomeration, particle flux, fluid jet speed.*

1. INTRODUCTION

The request for ultra fine powders, with granulometry between 1 and 30 μm developed extensively in the last three decades of the past century, as consequence of the impulse given by the chemical and pharmaceutical industries, and also of the news agglomeration technologies of the metallic and ceramic powders [6]. Marking the fact that the single installations able to realize these ultra-fine technologies in acceptable economical conditions are the fluidic mills, it is analyzed the working of the fluidic mills with spiral jets, the most modern equipments for the fabrication of the hard plates and special magnetic alloys, as cermets powders necessary to the fabrication of the hard plates and the milling of the diamonds, used for tools with special hardness, or for liquids with abrasive particles very fine. The fluidic mills have been studied along many years [4, 5], by experimental visualization of the fluxes and jets with hydraulic models with coloured inks, establishing the fact that in the milling room there are two principal areas described in the next sections.

2. PARTICLES' CONGLOMERATION PHENOMENON

2.1. Factors that determine the conglomeration tendency

Conglomeration phenomenon of the mill charge is defined as the tendency of the particles transported by the transversal flux to inspissations, form an area with a relatively big density, instead to be distributed in a regular way along the periphery of the milling room.

This phenomenon, very frequent in the mills used in manufacturing, was reproduced in the case of the experimental researches, still remaining a subject not enough treated.

Rogerson presented an empirical diagram, indicating the maximum alimentation pressures of the supersonic jets, depending on the gravimetric debit of the charge, in order to avoid the conglomeration phenomenon at granulometries about 4 mm [1, 3].

From the experiments made for the elaboration of the doctoral thesis, it was emphasized the fact that the Rogerson previsions was very optimistic and, especially the affirmation stating that the conglomeration phenomenon disappears at granulometries under 1 mm is false.

Experiences made by the authors established that the particle conglomeration tendency decreases depending on the:

- growth of the gravimetric charge in an absolute sense and, especially in the case in which the micronization process is started by instant introducing of the charge;
- growth of the alimentation pressure of the supersonic nozzles;
- growth of the particle granulometric dimension;
- running time of the fluidic mill; in a continuous service, the conglomeration can appear after long enough intervals of time.

2.2. The conglomeration associated to a sonorous low pulsating frequency

It was observed, in the case of the mills that are in service without interruption (24 hours a day), the random appearance and disappearance of the conglomeration phenomenon, accompanied by a sound with very low tone, about 0.5−2 Hz.

This phenomenon can be empirically explained by the fact that the collisions between particles generate waves in a sonorous area, that are interfering each other, and in the case of the particle conglomeration, the resulted wave corresponds to the resonance frequency of the acoustic room constituted by the milling room.

2.3. The ratio between the conglomeration and the particle granulometry

Despite some affirmations from the literature, it was observed in practice and confirmed (in the case of the

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mills used in manufacturing) that the conglomeration phenomenon is not decreasing with the reduction of the particle granulometry and do not disappear under 1 mm, (according to Rogerson's hypothesis).

This phenomenon continues to reveal itself in an random way, at mills with any dimension and for charges much more reduced, even in the field 40−1 000 μm.

Note: It is the case of the sulfamethoxazol that conglomerates after 25−30 minutes of service of the mill, therefore the solution is to limit charges at 15 minutes with periodic cleaning.

2. ELECTROSTATIC PHENOMENA ASSOCIATED WITH THE CONGLOMERATION

Another unstudied aspect, that was observed during the experiences made for this research is bounded with the appearance of the conglomeration phenomenon associated with the inherent electrostatic charge during the grinding process.

Many searchers put in evidence the presence of some electrostatic charges, without associating it with the conglomeration phenomenon, and tried to remediate the situation using an antistatic construction of the mill or covering the interior walls of the grinding room with special products.

They reported that some antistatic creams could conduct at the improvement of the situation, but they recognized that the observed effects ate limited.

It is also to observe that the tests to "dress" the particles with antistatic products or to desiccate them totally leaded to the total inversion of the performances, with the appearance of some strong static phenomena, at very low alimentation pressures.

Rose described a conglomeration phenomenon in the mills with balls (mechanical non-fluidic mills), the similarity of the conclusions being interesting, because he affirmed that the conglomeration could depend on:

- charge (too little);
- big rotation speed;
- a great friction coefficient between the balls and the particles to be produced.

The last presented factor could be analogous to the use of the antistatic cream, because the antistatic layers function generally through y to mechanisms:

- improvement of the conductivity at the surface, and for this reason the electrostatic load, accumulated locally are dispersed;
- decrease of the friction coefficient, and for that reason the gravimetric debit and the exhausted speed of the charge from the milling room are increased.

The observed inversion of the performances can be attributed to the reduction of the balls charges.

That electrical charge, having the same sign, should conduct to the dispersion of the balls, due to the rejection forces between them.

The friction coefficient can influence the conglomeration appearance after a period, fact that could explain – by the roughness damage of the balls surfaces, Rogerson's observation, limited initially at balls with diameters about 4 mm (their surface could be easily damaged).

At the same time, the absence of the conglomeration of the little balls with diameters about 1 mm (hypothesis considered by Rogerson) was observed.

Generalizing the observation presented above, it is possible to enounce the condition of electric conductivity that do not produces the conglomeration phenomenon, namely:

- smooth and conductive surfaces of the milling room;
- products and particles electric non conductive.

Because these conditions are in fact normal work ones, it will be expected that, according to the above affirmations, the conglomeration phenomenon is minimal.

These elements where presented with the intention to indicate the possible causes and remedies of the appearance of the conglomeration phenomenon in prototypes, in order to avoid the necessary conditions in practical situations in production mills.

The conglomeration is presented as an extraordinary complex phenomenon by aerodynamic, friction and aerostatic nature. Its research is difficult because of the impossibility of reproducing the conditions from a determination to another.

We finish this statement with the practical observation that the micronized products are generally electrical non-conductive and the electrostatic charges that are exhibit at the surface of the micronized particles are generated even by the collision fragmentation.

We consider that this phenomenon is produced along the same fracture lines, that correspond to the declivity planes of the crystals, that bare conglomerate and form the considered particle, knowing that the section along this planes (for example the diamond polishing) is accompanied by the appearance of some strong electric charges, due to the piezoelectric charges at the limit separation layer.

These charges are polarized on the different particle surfaces and, in this manner; the particles are attracted each other, exercising forcible cohesion forces.

The agglomeration of the micronized particles lets much space between particles, which explains the volumetric improvement of the micronized product, in comparison with the same mass of the same product, before the milling.

The great distances between the particles lock any reducing tentative of the electrostatic charge by mechanical means (surface contact with the near walls or sieve, metallic network introduced in the product volume and bound at the earth etc.)

The tentative to reduce electrostatic charges by the ionization of the milling fluid, vibration and included air extraction with aspiration through filtering, did not gave the expected results, conducting to marginal and negligible effects.

The conglomeration of the micronized powders in the milling room and out of it remains an unknown subject that can form the object of further researches and papers, at any scientific level.

3. REZULTS OF THE FLUX VISUALIZATION

3.1. The compressibility effect.

The direction of the nozzle is visualized with a metallic bar (Fig. 1) that permit the measurement of the jet deviation. The comparison between the profile of an inclined jet and the angle of the nozzle proves the fact that the jets under − expanded presents an out angle different of the nozzle angle with $7 - 8^0$.

The supersonic jet, in a transversal flux, with a minimal powder charge presents the series of expansions in the form of a bell (Fig. 2).

It is to observe the deviation of the outer angle and the curving under the flux effect. This effect can be explained by analysing (Fig. 3 and 4) the two limit cases:

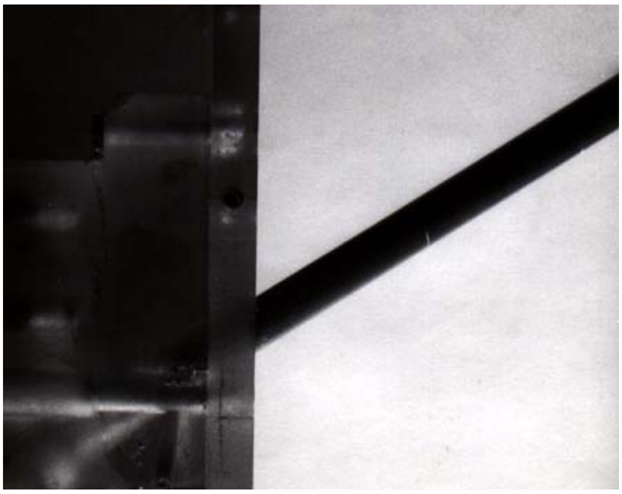

Fig. 1. Nozzle angle visualized by comparison with a bar.

Fig. 2. The supersonic inclined jet, shown with a minimal charge of powder.

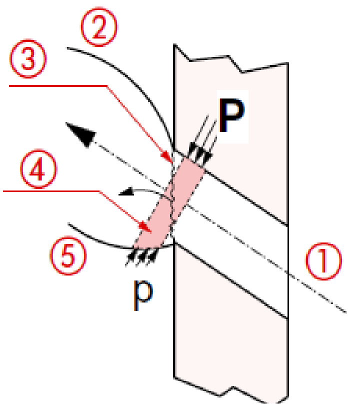

Fig. 3. The sonic line positioned perpendicular on the nozzle's axe. Legend: 1 – nozzle's axe; 2 – the profile of the under-expanded jet; 3 – the sonic line; 4 – the frontal area of the jet, at the nozzle's arrangement; 5 – the inferior limit layer of the jet.

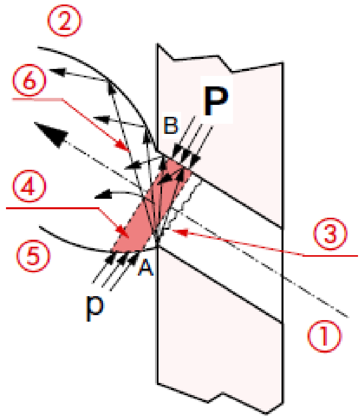

Fig. 4. The sonic line placed in the output plane of the jet. Legend: 1 – 5 as in Fig. 4; 6 – the interfered choke wave, generated by the *A* edge.

- the first, in which the sonic line is situated in the out plane of the jet and;
- the second one, in which the sonic line is positioned perpendicular to the nozzle axis.

The second case is considered as being more close to the reality, because the pressure gradient, in a rectilinear motion, must be null, normal on the direction of the flow.

However, in a non-isentropic flow, the pressure is not the single value that determines the Mach value, but it is probable that the inclined output can induce a non-symmetrical acceleration.

This point should be better studied by the specialists in aerodynamics.

In fact, in this moment it is impossible to find something applicable or similar in the specialty literature.

It appears as probable that the sonic line is positioned perpendicular, but not in it limit layer.

In each of two limit cases, the phenomenon of the under-expandation of the jet can be explained.

In the first case, in the previous figure, in which the sonic line is positioned in the output plane, the limit layer of the fluid is displaced down, having a side at the ambient pressure and the other one at a bigger pressure, and for this reason, it is obliged to rotate to the side with a lower pressure, the ratio of the rotation moment amounting to the pressure difference (in order to simplify, the corner effect with the Prandtl-Meyer expansion is not designed, but it can not interfere in the subsonic flow inside the nozzle).

In the second case, in which the sonic line is positioned in the normal plane of the jet, a double expansion at the nozzle wall will occur, because the reflection of the expansion waves.

For these reasons, the considerations will be limited to the situation in which the super pressure in the *A* point is enough (as it results from the experiences) and determines expansion at the nozzle wall, letting the fluid jet under expanded, up to the point *B*. Also, in this case a marginal fluid layer will be given to a pressure difference, that will determine its inclination or the edge effect with the centre in the *A* point will be greater than the effect in the *B* point. In this case, the fluid mass will rotate more in point *A* than in point *B*.

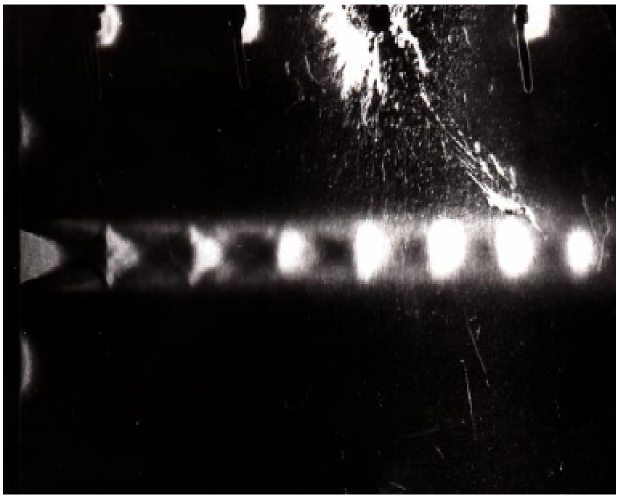

Fig. 5. Supersonic jet, without transversal flux, with expansion in the form of bell.

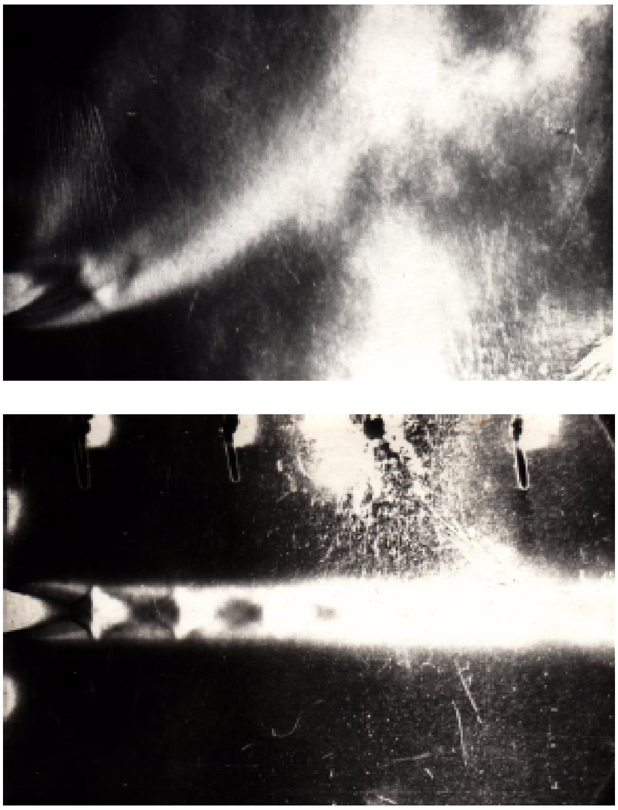

Fig. 6. Supersonic jet without (upper), and with a strong transversal flux (lower), with a total expansion of a choke wave.

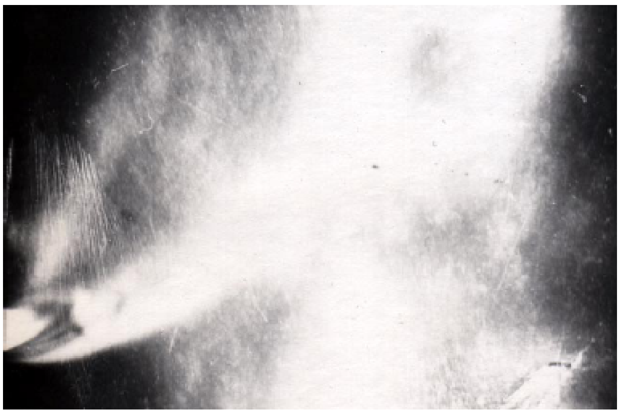

Fig. 7. The supersonic jet shown with a strong transversal flux.

The jet without a transversal flux presents the expansion series in a bell form (Fig. 5).

A close examination of the inclined jet indicates a difference between the expansion forces of the jets in form of bell on the two sides that could not happen in the first described case, strengthening the argument of a sonic line perpendicular to the axis jet and an inclination corresponding to the choke waves (Fig. 6).

It is interesting to observe that as in the case of an incompressible fluid, an inclined jet would behave apparently in this way due to the pressure variation along the wall caused by friction.

It is to underline the determination of the fact that the size if the jet inclination varies with the increase of the alimentation pressure and inclination angle of the nozzle.

This effect is considered as one of the most important demonstration of this paper, because it influences the mills performances in an unusual mode, unpredictable and negative one in some cases.

The distribution of the choke waves in a perpendicular jet, without a transversal jet (free jet), was determined entirely by other papers, when for the inclined jets the particular asymmetry must be considered, the generated choke waves being inclined and sometime presenting oscillating effects, until the stabilization.

The supersonic jet, without transversal flux presents expansion series in form of bell and the development of the choke wave in the characteristic form of pear, when the jet with a strong transversal flux do not present this series of bell expansions.

It is observed the deviation and the bending of the jet under the influence of the transversal flux.

At the supersonic jet with a strong transversal flux, without expansions in the form of bells, it can be observed the great turbulence in the posterior area of the particle collisions (Fig. 7). In the case of inclined jet emitted in a strong transversal flux, the choke wave distribution is disturbed much more rapidly than in the case of the free jet. This fact is due to a stronger mixing process, associated to the transversal flux, in comparison with the static medium in the case of the free jet (Fig. 7).

The fact that the jet is very visible on a good distance from the output of the nozzle represents an indication concerning the persistence of a significant difference of temperatures.

3.2. Supersonic jet with a strong transversal flux without expansions in form of bell.

It is observed (Fig. 8) that the tourbillions from the lateral-posterior area that entrain particles at high speeds in the collision area succeeded by the tertiary fluxes extremely turbulent, and because posterior tourbillions are very visible, indicate the fact that:

- tourbillions consist of a significant extension of the cold fluid jet and,
- intensity of the tourbillion effect determines the improvement of the speeds that exceed the speed of the transversal flux.

3.3. The supersonic jet with transversal flux

It is easy to observe (Fig. 9) distinctly the tourbillions from the lateral-posterior area, the collision area and the tertiary fluxes, extremely turbulent. Tipping [2, 3] indi-

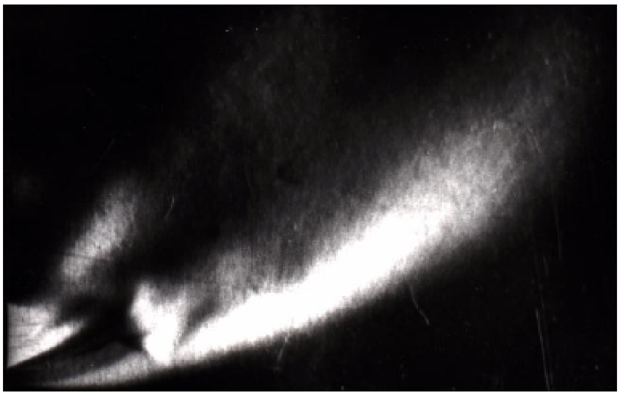

Fig. 8. The supersonic jet shown with a transversal flux; it can be see the entrainment tourbillions.

Fig. 9. The supersonic jet with a transversal flux, presenting a collision area.

cated that the posterior tourbillions are made especially from the transversal flux, suggesting that this explanation is probably more correct.

However, the fact that the tourbillions are less distinctive as the jet itself indicates the availability of the first explanation.

It is impossible to conclude which of the two effects is more veridical; probably both effects are produced and superposed.

An interesting observation is the fact that, in the case of the perpendicular jet, an important deviation of the jet up to the area of the Mach disc is not produced. In case of the inclined jets, this deviation is more reduced, having the possibility to considerate, with an enough precision, that the jet was not deviated in the area of the maximum concentration of the particles.

4. CONCLUSIONS

The stagnation area behind the jet is not really stagnating, that is it is crossed by certain fluid currents. There are not doubts about the fact that this area is produced by an "inverse turbulent flux", generated by the friction of the transversal fluid with the walls of the limit layer of the supersonic jet.

These tourbillions can be observed very well at the base of a solid cylinder (Fig. 10), protuberant from a wall, but their existence in an inverse sense, associate to a supersonic jet, is of course surprising. They can be considered generated by the variation, in the limit layer, of the stagnation pressure, that is present on an area far from the wall.

When the flow of the fluid stops, the resulting gradient of the pressure produces a secondary flow to the wall that generates the tourbillion.

Another explanation of this phenomenon (Fig. 11) can be given considering the superposition of the tourbillions from the limit layer that forms finally a single tourbillion.

The stagnation from the front of an oblique cylinder is only partial, so that the intensity of the tourbillion is reduced (Fig. 12).

Bradbury and Wood observed that the "dead area" decreases with the improvement of the jet intensity, and that observation is according to the presented mechanism (that explains the fact that the tourbillion generated at the wall level becomes an integral part of the supersonic jet itself).

This frontal tourbillion presents an evident importance in the study of the milling studies.

The vortexes existing in the posterior part of the jet (Fig. 13) was not shown by others researchers. This absence can be explained probably in two ways:

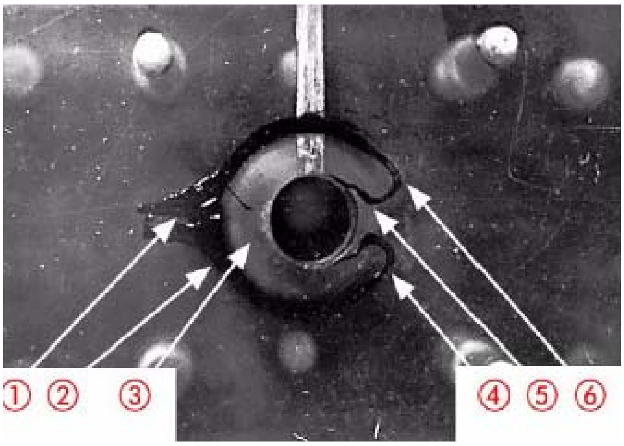

Fig. 10. Visualization of the tourbillions in the stagnation area.

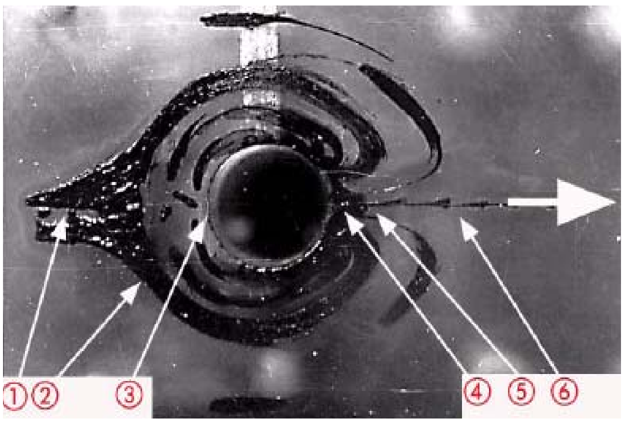

Fig. 11. Definition of the peripheral turbulence area of the supersonic jet.

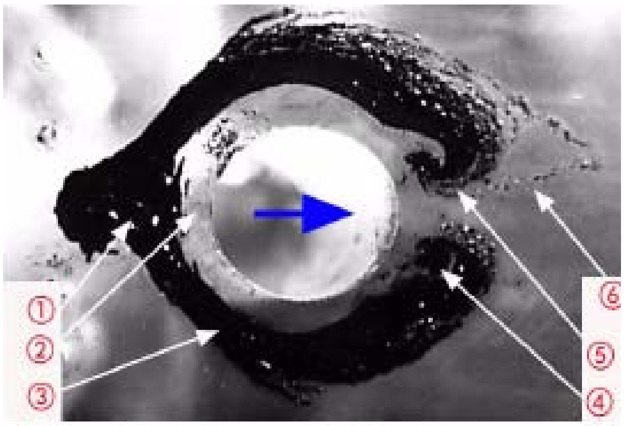

Fig. 12. Stagnation area in front of the Venturi's orifice.

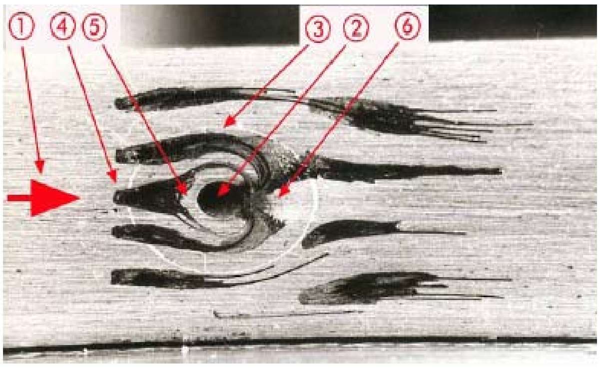

Fig. 13. Anterior and posterior turbulence areas of the supersonic jets.

- In the first instance, the absolute intensity of the posterior tourbillions depends on the absolute speed of the transversal flux, and because this paper includes determinations at speeds about 150 m/sec, these are a few times greater than the speed used by other researchers in the case of the perpendicular jets. This can be a first explanation of the absence of indications in this field in literature;
- In the second instance, this paper has shown that these tourbillions are not very evident at perpendicular jets, apparently because of the predominance of the stagnation area, according to figure.

The publications in the literature are limited at the case of the perpendicular areas and the authors made the hypothesis that, even in the case in which the jet was strong enough to produce evident posterior tourbillions, the frontal tourbillion could be also strong and, as a consequence, the resulted "dead area" could mask the posterior tourbillions.

Probably, the most important it is the determination of the fact that the frontal tourbillion appears at the wall and has an opposite direction to the posterior tourbillions.

Another important point that must be remembered is the fact that these posterior tourbillions carry along themselves a part of the transversal flux.

These tourbillions are considered as being of the greatest importance for the milling effect in the spiral jetmills.

The wake behind the jet consists of a third dimension to the wall, and the fluid derives from the jet, at a certain distance from the jet, or it is the jet itself. This phenomenon can be explained as follows:

- If this effect is not produced, in the presence of an enough aspiration able to detain the separation from the transversal flux at all levels, a stagnation point would be produced behind and at a certain distance from the jet
- The pressure in this posterior stagnation point would be bigger at the exterior of the limit layer than in its interior, because the speed distribution and a flow to the wall could arise. That phenomenon is similar to the previous presented case.

The visualization of the photographic tracing is very conclusive for the turbulences existing in the anterior and posterior area of the jet shown in photos.

The posterior area is considered similar to the anterior tourbillions produced by the viscous friction of the jet near the wall and it is supposed that the tourbillions that appear near the wall are included in the primary jet or allied to the posterior related tourbillions that have the same rotation sense.

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