THEORETIC AND EXPERIMENTAL CONTRIBUTION CONCERNING THE MEASUREMENT OF THE FUNCTIONAL PARAMETERS OF THE FLUIDIC MILLS WITH SPIRAL JETS

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Abstract. This writing analyses the theoretic bases necessary for the optimisation of this type of mills and presents the results of the experimental researches, which permits the elaboration of a mathematical model able to describe correctly the flow of the compressed air and of the particles inside the mill. It is also presented the experimental apparatus and the mode to determine the speeds in different points of the flow section and the apparatus used for the acquirement of the data and their interpretation and visualization.

Keywords: fluidic mill, spiral jets, micronization, speed of the fluid jet

1. Introduction

The request for ultra fine powders, with granulometry between 1 and 30 µm developed enormous in the last three decades of the past century, as consequence of the impulse gave by the chemical and pharmaceutical industries, and also as consequence of the news agglomeration technologies of the metallic and ceramic powders. 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 metallo-ceramic 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, by the experimental visualization of the fluxes and of the jets with hydraulic models with coloured inks, establishing the fact that in the milling room exist two principal areas:

- The milling area from the periphery of the room to a diameter few greater that the diameter of the circle tangent to the jets direction;
- The classification area, concentrically with the milling area, bounded in exterior with it, until the central orifice for the evacuation of the fluid.

The hydrodynamic models proved that in the milling zone exists especially complex flow, the jets being deviated by the circular transversal flow.

It is concluded that the jet has the behavior of a semisolid cylinder, in which interior the main flux and the transported particles can not penetrate.

It is proved too the existence of fluxes deviated to the plane walls, superior and inferior, that delimited the cylindrical milling room, as well as the presence of some very turbulent areas behind the incident jet and on it opposite side toward the flow direction of the main flux.

For these reasons it results as evident the importances of the turbulent flow's studies from the limit layer that by-pass and are associated with the milling jets.

The experimental model considered in principle a milling room with a lens form - the ideal section for the uniformization of the flux speeds being a parabolic profile. In order to simplify the construction, we preferred to choose the profile of a frustum of cone.

2. Considerations concerning the measurement of the pressures and of the speeds

The first determinations used the constructive characteristics of the experimental models, especially for the measurement of the distributions of the pressures and speeds from the milling room.

The standard version of the Pitot tube is based on the principle of the distribution of the static pressure along a tube with thin walls, curbed at 90^0 and oriented in the direction of the fluid flux. That distribution was described by Ower and Pankhurst [1].

Measuring the value of the static pressure at the end of the Pitot tube it is observed a very rapid variation along it, variation that becomes negative in the area proximate posterior to the measurement tube.

These preliminary determinations was effectuated with two transparent models, in Plexiglas corresponding to some mills with spiral jets from the first generation of APTM, with the diameter of the milling room between 15", respectively 4".

The excessive consuming of compressed air, the very limited resistance of the models and the practical application of the evolutes concept of the theoretic model for proves imposed almost immediately their replacement with prototypes instantly made, presented down.

The main experimental researches where made with transparent mills with spiral jets, manufactured conformal to the next figure.

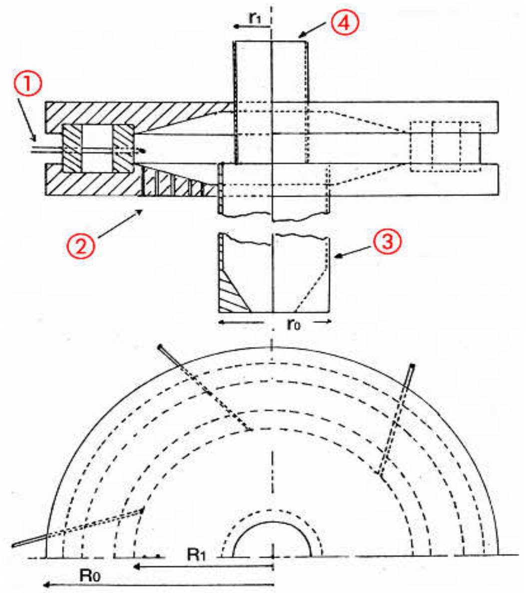

Figure 1. Transparent model used for the experimental researches

1 - nozzles' ring; 2 - different based of the milling room, perfectly symmetrical with the lid; 3 - set of tubes for the classification of the particles (with variable interior profile, conformal to the case); 4 - set of tubes for the evacuation (with variable diameters, conformal with the total pressure measured in the milling room)

NB!: Venturi alimentation system is not shown in the figure; - diameters of the milling rooms: 4”- 8”- 12”; the height of the room: variable: - 6 “- 8”; - diameters of the nozzles: 1/32” - 3/16”; Venturi diameters: - 1/8” - 1/4”

It is to emphasize the fact that, for the availability of the coefficients from the literature and for the correspondence with that the values determined anterior, all the measurements where repeated on similar models at 8” and respectively 12” diameter with perfect cylindrical section of the milling room, similar to these existing in the literature.

The milling jets where studied in the area 1/32 - 3/16”, while the alimentation jet of the Venturi system was studied in the area 1/8 - 1/4”.

We can observe the fact that for superior values of the indicated area, the spiral jets become instable in the case of the milling rooms with height about 6 - 8” and for the mills family having 6 micronization nozzles.

During the assays, we discovered that the process becomes stable, without pressure fluctuations in a transversal direction of the flux only in the case in which are used 6 milling nozzles for diameters of the room under 10", while for the bigger diameters that exceed 10 - 18”, the stability condition is realized in the presence of 8 micronization nozzles.

For the study of the particles' transport by the main flux, we used ball made in plastic material (polycarbonate) with dimensions of 1/64, 1/16 and 1/8”. In the case of the mill model with the diameter of 20” partial determinations with balls in polycarbonate with the diameter 3/16” where made.

The form essential spherical of the balls used for the experimental researches is carrying out from the real form very irregular of the particles from the practice, but the approximation do not form the object of this paper, but will be studied in ulterior researches, that have as final purpose the global optimization of the mills working.

3. Experimental researches: the flux' speeds distribution. Determination of the speeds with calibrated Pitot tubes

The Pitot sondes are based (as is shown) on the variation of the static pressure along a Pitot tube.

Measuring the total pressure value at the end of tube, it is observed that the pressure declines rapidly along it, becoming negative and smaller than the static pressure of the fluidic flux.

Because the separation effect of the curved tube in the flux' direction, the static pressure at the tube surface at a given moment begun to increase again along the tube becoming again positive.

The position of this second change of the sign of the static pressure do not depends by the fluid speed, and the Pitot tubes are constructing so that the hole of the static pressure is situated just in this point.

Any other tube that do not respect this standard drawing must be calibrate in function of a standard tube and it is proved that the positioning of the static pressure's hole in any other point as the standard position determines indications having a deviation from the reality is proportional (a constant percent) with the fluid's speed.

The Pitot tubes used for experiments present two pears of holes of the static pressure, fact that imposes their calibration.

3.1. The fluidic mill used for determinations with Pitot tubes.

For the comparing with the existing results from the speciality literature, the experimental researches where made on the described models in Plexiglas with the diameters of the milling rooms 4”, 8” and respectively 12”, presented in figure 2.

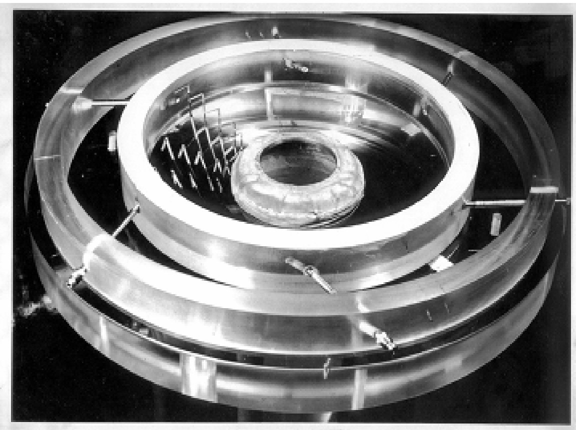

Figure 2. Experimental transparent model of the mill with supersonic jets

The cylindrical section of the milling room was replaced after the first determinations, modifying the internal structure of the mill, adopting a room in the form of the frustum of cone biconcave, that described good enough precisely the ideal form - parabolic of rotation, with the peak of the parabola in the centre of the nozzle of the milling supersonic jet.

We tried different positions and numbers of the milling jets, from 6 to 16 nozzles, oriented tangent at a common imaginary circle, with a radius a few smaller that the third part of the radius of the milling room.

In these experimental researches, the indicated models' dimensions are different from these of the real ones produced now by APTM, because the laboratory disposes of limited air and nitrogen resources. This deviation do not influences the experimental researches, because it is proved, by comparison with the characteristics of more than 170 mills, reported in the data base of the APTM , that the efficiency, the granulometrical distribution and the stability of the fluidic fluxes are good enough linear and proportional towards the mills in production.

Because we considered that local variations from the vertical position of the supersonic jets of the static pressure can exist, we decided to not use the method Rogerson [2], abandoning the pressure mesh posed on the stop plates and using special calibrated Pitot tubes.

The tubes' diameters where choose good enough little for a reduced influence on the trajectories from the fluidic flux.

There where made many holes - pressure meshes for improving the response speed of the system connected at a piezoelectric mesh very sensible, in parallel with an anemometer with membrane.

3.2. The tube Pitot' positioning in the room of the fluidic mill

These pressure sondes where positioned in families containing 15 parts, that cover all the area between two consecutive jets, for the symmetry of the flow being used 4 stoned families, so, in all 60 sondes, figure 3.

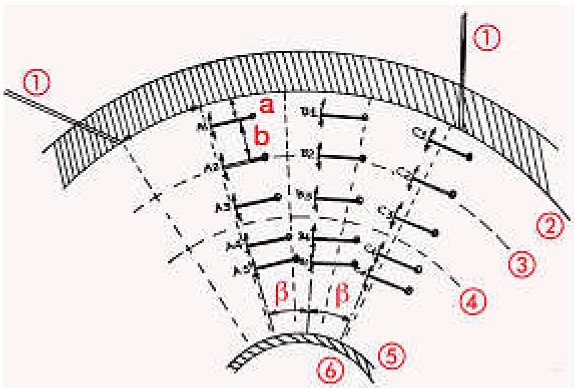

Figure 3. The positioning of the pressure sondes
1- supersonic nozzles; 2 - polar series of the jet's exit; 3 - polar series of the jet's dispersion; 4 - internal polar series; 5 – classificatory; 6 - central exit hole.

In a vertical section the sondes where displaced at different distances from the median axe for each assay determining a measurement family with 5 adjacent positions, the total number of the measurements for each assay being 300 points in space, from that 60 pressure points being contiguous suited by a computerized system of sampling at a cadence of 2 measurements in a second.

3.3. The functional gap for the avoidance of the interference with the supersonic jet

At the first experiences it is observed that the sounds from the extreme positions, placed near the supersonic jets indicates a maximum at a negative inclination from the jet direction, idle when the spondee's extremity is directed to the centre of the mill.

It is discovered in this sense that this behaviour, evidently undesired, is due to an interference in the milling jet, the extremity of the sondes becoming in it high turbulence zone (figure 4).

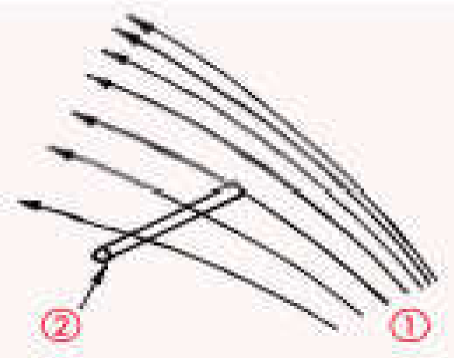

Figure 4. The interference of the sonde with the milling jet

By consequence, these sondes where rotated from the tangential flux's direction in order to avoid the turbulence zones, for these sondes being registered only the total pressure from the sonde's extremity, the static pressure from the prove holes being considered unrealistic.

During the assay, the internal surfaces of the milling room presented the tendency to become opaque by the shot bomb and it was necessary to be bright finished again, trying the treatment of the surface with a transparent hardened surface.

The obtained results do not correspond to the expectation and for this fact the closing plates in Plexiglas where substitutes with plates made in thermal treated glass, manufactured from plates with high thickness (15 mm) Saint-Gobin, and soldered in a package for the obtention of the desired thickness in a specialized factory in Murano, Italia.

The determinations where consequently repeated, obtaining similar results with these of the precedent researches. Especially, is to remark the correspondence of the speed with the three-dimensional model of the fluidic flux described by Kurten [3].

The three-dimensional charts, designed by the computerized system, presented of determination families and commented down demonstrate the existence of the milling zone and separation zone predicted by Rumpf and Kurten [1].

It is to observe that in the separation area the flux is generally one-dimensional, while in the milling room is confirmed the essential three-dimensional characteristics of the fluxes.

The pressure peaks of the prove sondes on the A front are almost similar with a symmetric curve of the errors distribution, of Gauss type, profile that is typical for the flow jets.

These pressure maxima are reducing in intensity between the ranges A, B and C, fact also typical for the flow jets.

It is evident the fact that exists very few indications concerning the effect of the limit area in which are creating reverse radial fluxes near the closing plates; the increasing of the speeds near the inferior plate, in the classification area, is arrogate probably more to the approach of the exit hole, that determine a local acceleration of the flux.

4. Precision, reproducibility and the safety of the attempts

4.1. Determinations with Pitot tubes

The safety of the measurements with Pitot tubes is considered good enough limited.

From the presented ideas it results an unsafely factor between 0% and +40%, available for each speed value due in principal to the influence of the turbulence (the influence if the compressibility is not considered).

We can precise that by that method we measured maximal speeds about 100 m/s.

Verifications at the calibration unit proved that the manometer system can be reproduced with a precision of ±10%, in the pressure games ±3 barg, for an inclination of the measure sonde about the maximum value of 30%.

The main cause of the law reproducibility in areas with pronounced fluid transfer is due almost sure to the positioning precision of the sonde that where aligned visually, in function of indications marked at t5he base, with a precision of ± 0,1mm.

The value of the main angle of the transversal flux and, by consequence, the sonde alignment must carefully considered, because the flux direction was theoretically determinate, while in the areas proximate to the supersonic jet a interference is produced by turbulences generate by that, turbulences that deviate the direction of the flux vector.

We must note the aspect proved anterior of the jet curvature, visual confirmed and theoretical approximated in some publications from the literature.

That jet curvature lead on to the impossibility of the exact determination of the point in space in which the prove sonde must be positioned.

All some the limitations, the presented results must be read in relation with their purposes, precisely the presentation of a speed distribution, informal and quantitative, of the macro phenomena of the fluidic flux, from where we can obtain important conclusions that are not generally based on absolute values, but only on the relative variation of the speed's gradient, in order of magnitude determined by the precision of this kind of measurement.

4.2. The probable error of the absolute speeds' gradient

We mention that the standard statistic deviation of the absolute speeds is much greater as the standard deviation theoretically predictable including the fact this factor is to take in consideration as e exponential square function the misrepresentative points being amplified exaggerated, and for these reasons it is to expect that the measurements are generally greater as the real mean value.

Much more, because the uncontestable and inevitable differences between a measurement and another one, due to the variation of the mill charge ant to this package up, the traced values concerning the speeds' distribution from the fluidic flux present limits.

In thwart of the fact that the computerized measurement system has a high safety and provable of the determination in free supersonic jets (underlined by the NASA publications), it is to say that that methodology act an immense data volume to be analyzed.

It is informally indicated the fact that the methodology generates over 1.500.000 measurements at a scanning speed around 50 zone/sec, so, families of instant values around 7 - 10 billions data in a second.

The system was connected at a net PC-Cluster, composed from 7 nodes, with a theoretical capacity at 2.7 Gflops/sec (2.7 billions operations/sec), utilized by APTM for the interpolation of the optimization data from the production mills.

5. The results' interpretation.

5.1. Experiments with Pitot tubes

The speeds, measured with that method must be considered as super estimated, as is shown up.

In thwart of that imprecision, the relative values obtained are important and to be retained considering that, if the measured values in to proximal points differ one to another with a greater value that is attribute to the turbulences, the difference itself becomes significant.

That idea leads on at the conclusion that the three-dimensional distributions of the flux direction presented up make evident very great gradients, the predominant characteristic being:

- The very accentuated profile of the speeds from the flux front A - the most proximate from the flux - reduces considerably the speed from the next sections (namely the fronts B and C);
- In the central area, the flow is essentially two dimensional, acknowledging this hypothesis, described in the literature for the final zone of the spiral of the micronized particles' trajectory.

5.2. The analysis of the repeatability the speeds' measurements

About the general repeatability of the results for many functioning conditions families, is reasonable to consider that the level of the turbulences in a certain point from the milling room will have the same amount order, independent of these conditions, and that the difference from a family to another one describes in fact the real difference of the speed.

In a large sense, this reasoning confirms the expectations conformal to, the speeds in the milling room, in any point improve with the improvement of the alimentation pressure of the supersonic jets and, in parallel, with the reduction of the loading charge of the mill with particles.

The speeds' charts, presented for different particles' granulometry, in constant conditions of pressure and charge, do not present significant differences, the main variable that influence the speeds' distribution resulting to be even the

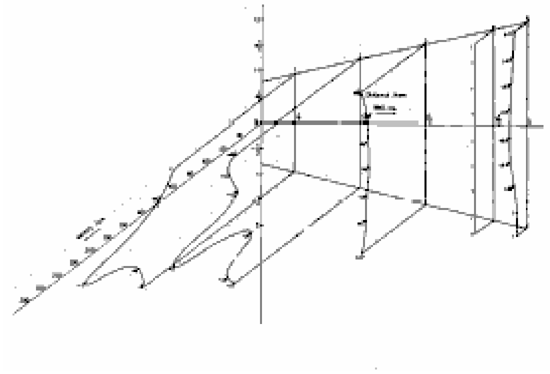

Figure 5. Variables of the assay: powder charge 0 grams; alimentation pressure 2 bar

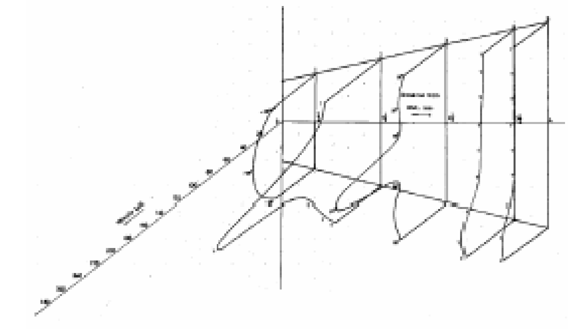

Figure 7. Variables of the assay: powder charge 150 grams; alimentation pressure 2 bar

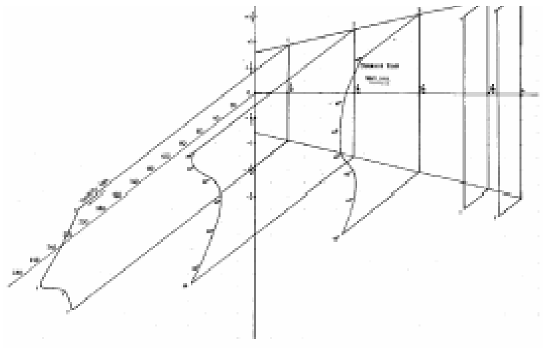

Figure 6. Variables of the assay: powder charge 0 grams; alimentation pressure 5 bar

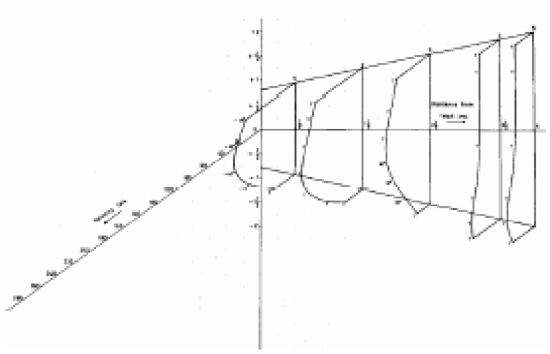

Figure 8. Variables of the assay: powder charge 150 grams; alimentation pressure 5 bar

alimentation pressure of the supersonic jets and the weight of the charge, the particles' granulometry having a secondary influence.

5.3. The comparation with qualitative observations

The quantitative evidence of that qualitative considerations (that where determined) confirms the jet's deviation by the tangential flux.

This fact is proved by comparing the distribution in the case without charge with the one obtained in the case of running with charge with the show down in particular, of the fronts.

The distribution from the 3 position, without charge make evident a very little influence, almost inexistent of the supersonic jet, while the determinations with charge prove a very important distribution of the speeds in this position.

That fact is due to the reduction of the size order of the transversal flux under charge that determines a layer deviation of the jet and a significant penetration in the 3 position.

A similar behavior is underlined in the position 1 (figures 5, 6, 7, 8), the distribution presenting a important profile of the jet in the front A in the case without charge, while with charge this profile is very reduced, fact that indicates that the supersonic jet's trajectory was radial displaced, to the center, by the tangent flux.

6. Conclusions

The made researches where very numerous and offered clear and significant results, proving the viability and the reliability of the adopted and manufactured measuring system, admitting in this way to the authors works and major progresses, original, in the suitable sense of that research, precisely the optimization of the function of the fluidic mills with spiral jets.

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