TRIESKOVÉ A BEZTRIESKOVÉ OBRÁBANIE DREVA, 8(1): 49–55, 2012
Zvolen, Technická univerzita vo Zvolene, ISBN 978-80-228-2385-2

VELOCITY FIELD ANALYSIS OF THE FLOWING PARTICLES IN THE FIELD OF WOOD INDUSTRY WITH A NEW MEASUREMENT METHOD

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Abstract

Dust and particle extraction of the wood industry is an unsolved problem. The dust and chip transportation for the scene of machining is either unnecessary intensive, or inadequate. We performed the first experiments with a laser measuring device to determine the velocity field. The system is quite complicated because of the setting of the parameters, so the first experiments were performed with a simple flow. We only used one type of particle size (0.8-1 mm in diameter) and measured the free fall and the velocity field of the artificial flow. Based on our experiments we can conclude that the measuring system works exactly in case of high speeds. This means that the CNC router machine with dust particles in it's flow field can be well analyzed with the laser measuring system. Our goal is to get an accurate picture of wood industry in the field of the production of the images of suction head flows.

Keywords: *floating velocity, Kármán method, flow field, PIV (Particle Image Velocimetry) resistance factor, laser measurement system, dust and chip particles*

INTRODUCTION

The problem of dust-extraction in the field of wood industry is still isn't solved at all. The dust and chip transportation from the scene of machining is either unnecessarily intensive or inadequate. This seriously affects the power balance of producing companies. We want to analyze the velocity fields at the routers, suction heads, cutting types in a new way with a laser measurement system won in a tender. All this means that we have the possibility that for the machine manufacturers of the future we advise more effective suction heads.

MATERIAL AND METHODS

The suction heads in the wood industry play an important roles because of shape-enmureousness of themselves they ensure the extraction of dust and chips on the milling machines. The tool rotations-speed is much higher than in the metal industry, so that the particles are much easier get much higher speed and pulse. The dust and chips can get two ways into the extraction head:

- by using the exhaust air fans
- through peripheral speed of the tools

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Peripheral speeds of the tools are not always preferential, such as at the CNC machining centers, where the particle receives horizontal velocity, but the exhaust would be vertical. This means that the particle flight direction has to be changed by 90 degrees, and this needs large amount of exhaust air, or a special device that changes the flight direction and introduce into the extraction head. Between these two situations, today the large air volume is the solution, but it is an unfavorable solution considering the energy balance.

As already mentioned before, machining centers require a vast amount of exhaust air (an average of 800 m^3/h per extraction), because of the dust and particle concentration is very low (μ = 0.05 to 0.2 kg / kg). In this case we speak lightflow transport.

The principle of pneumatic transportation of particles is the aerodynamic force. The aerodynamic forces on the pushed side consist of the congestion pressure and the particles friction force. This value can be determined by the following equation:

$$W = c_w F \frac{\rho}{2} v^2 \qquad (1)$$

where:

c_w – resistance design factor; F – cross-section on the pushed side;

ρ – destiny oft he material; v – speed difference between the air and particle

The air resistance coefficients of geometric shapes (balls, cylinders, disks) are already technically defined, and depicted on Fig 1. on a logarithmic scale in the function of the Reynolds-number. For Laminar flows can be described according to the the Stoke-law:

$c_w = \frac{24}{Re}$ and $Re = \frac{v \cdot d}{\upsilon}$,

and in the turbulent range, the air resistance coefficient can be considered constant. In the transition range (2 <Re <1000) various empirical correlations can be applied, or can read the values from graphs.

The geometric shapes of dust and chips particles are not symmetrical, so the c_w value depends on your current location. The particle surface roughness seriously affected by the resistance factor.

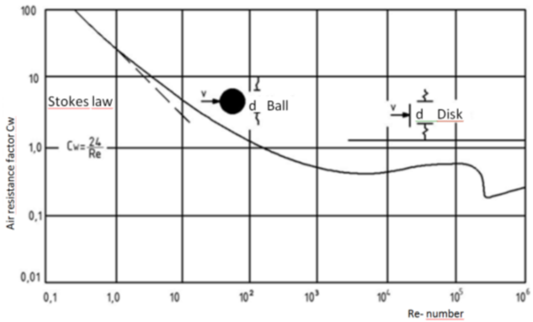

Fig.1. The air resistance factor in the function of the the Reynolds-number

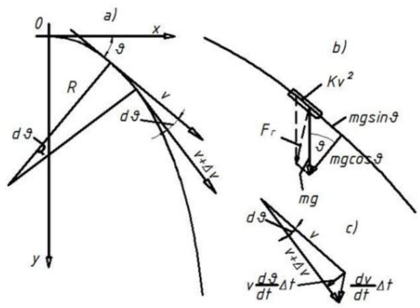

Fig 2. Motion of the particles (a), force vectors (b), acceleration vectors (c)

When increasing the velocity of the air the force acting on particles increases the square of the speed. When the aerodynamic force reaches the level of the weight force acting on the particle, it starts to float. The corresponding velocity is called floating speed. The floating speed for the sphere shape is the following:

$$W = c_w F \frac{\gamma}{2g} v^2 = G \text{ and } G = \frac{d^3\pi}{6} \cdot \gamma_a$$

$W = mg\frac{v^2}{v_{kr}^2}$ from which: $v_{kr} = \sqrt{\frac{4d\gamma_a g}{3c_w \cdot \gamma}}$ (2)

where:

γ_a – specific gravity of particle; d – particle diameter;
c_w – air resistance factor; F – particle cross-section;
γ – specific gravity of air; v – speed of air
v_{kr} – critical speed (floating speed)

We can see clearly (2) the smaller the particle is, the smaller the floating speed as well.

Condition of the pneumatic transport is satisfied if the speed of flow exceeds the floating speed. In practice, this is a little different because, much higher speeds to be used as the material not only has to float but also to move, and this requires a greater speed.

The movement of the particles worth considering to be examined how it effects occur according to the weight force and the aerodynamic resistance. The gravity is represents the vertical direction by the the function of $m \cdot g$, the air resistance against the movement, and the speed depends on the square of speed $(k \cdot v^2)$. Newton's law of motion yields the equation. It is very important however, that the strength, speed, and acceleration vectors to be examined more closely (Fig 2, Kármán-method).

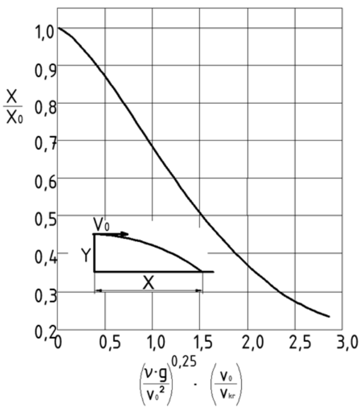

Fig 3. The x throwing dimension-less distance of the dust particle directly to the critical speed and the function of the air resistance coefficient.

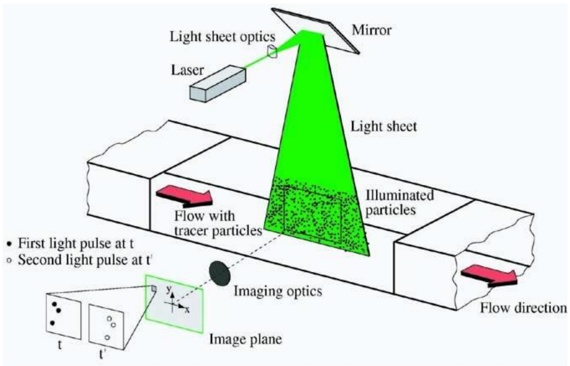

Fig .4. Structure of the flow field measurement system

The motion equation is obtained that the mass and the acceleration multiplied together, then we equate the corresponding force vector.

$m\frac{dv}{dt} = mg\sin\vartheta - kv^2$ (3.a.) $m\frac{d\vartheta}{dt} = mg\cos\vartheta$ (3.b.)

After the solution of the differential equation, for the horizontal velocity component, we get the following result:

$$v_x = v_0 f(\vartheta) = v_0 \frac{1}{\sqrt{1+\frac{kv_0^2}{mg}\left(ln\frac{1+sin\vartheta}{cos\vartheta}+\frac{sin\vartheta}{cos^2\vartheta}\right)}} \quad (4)$$

After another integration of the particle path coordinates are obtained as follows

$$x = \int_0^t v_x\,dt = \frac{v_0^2}{g}\int_0^\vartheta \frac{[f(\vartheta)]^2 d\vartheta}{\cos^2\vartheta} \quad (5) \qquad y = \int_0^t v_y\,dt = \frac{v_0^2}{g}\int_0^\vartheta \frac{[f(\vartheta)]^2 \sin\vartheta\, d\vartheta}{\cos^3\vartheta} \quad (6)$$

From (6) can be calculated the ϑ_0 that $\frac{g \cdot y}{v_0}$ dimensionless value of the expression. ϑ_0 is particle impact angle to the surface. The horizontal throwing distance of the particle can be specified using the following formula:

$$x_0 = v_0\sqrt{2Y/g}$$

x_0 – horizontal dropping distance; v_0 – initial speed
Y – throwing height

The Fig 3. shows the x throwing dimensionless distance of the dust particle directly to the critical speed and the function of the air resistance coefficient.

The following experiments are based on two theories, such as the air resistance and floating speed trajectory theory in given flow field.

OPERATION OF THE MEASURING SYSTEM

Ludwig Prandtl was first addressed by examining the flow fields, thus created the ancient PIV system (Particle Image Velocimetry).On our institute we used two-dimensional Particle Image Velocimetry system for measurements with, of which structure is shown in Fig 4.

The light source is a laser beam that is optically converted it to a form of a thin strip of light which illuminates the involving particles. Perpendicular to it stands a CCD camera which is synchronized with the laser frequency flashes and takes the shots. Two laser pulses follow each other, and simultaneously two images is taken. The time difference between the two images can be up to some microsecundum, and which makes it possible is the obturator of the the digital camera. Thanks to this a high-speed particle fields can be investigated. As a result, arbitrarily set within the party a lot of images can be made. With a rather complex mathematical algorithm the program compares the images and then calculates the velocity of the particles. In the two pictures it finds the identical particles, and from the coordinates and time it determines the magnitude and direction of the speed vector.

This measuring system with it's structure and parametterizable possibilities is fully compliant with fast-moving dust and chips particles speed analysis needs of the wood industry

RESULTS

Free fall of the dust and chip particles

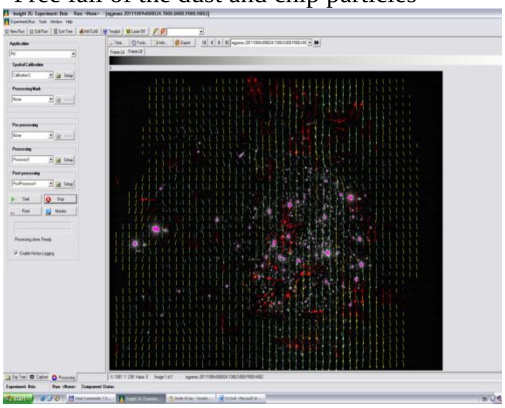

Fig 5. Evaluable free falling particle can be evaluated with each of the vectors

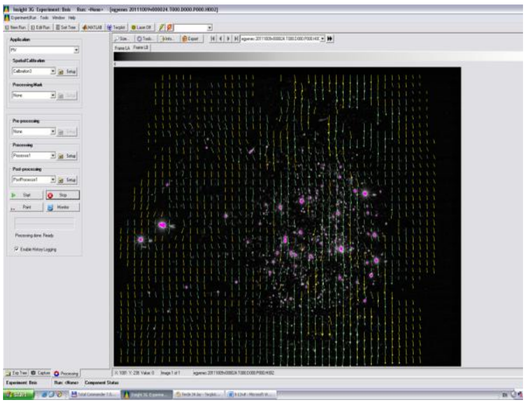

Fig.6. Free falling particle volume after mathematical interpolation, deleted vectors are deleted, incomplete flow field completed with probability computing

In the next series of measurements were made some preparation analysis's, in order to gain practical experience in the field of adjusting parameters. Of course, it was important to check the accuracy of the measurement system.

The dust flow experiments were performed with 0.8-1.0 size fraction of wood dust. The measurement and evaluation has very strict limits, so poor concentration of wood dust can't be evaluated to obtain images. With normal dust concentration we got the corresponding picture. The following images, the particles are free falling and some phases of the mathematical processing can be observed.

Dust and particle velocity field according to forced flow

In the following experiments the free falling particles was blown horizontally by a fan. In different measurement series different horizontal speed measurements were used. The following figures shows the flow fields at the given speeds.

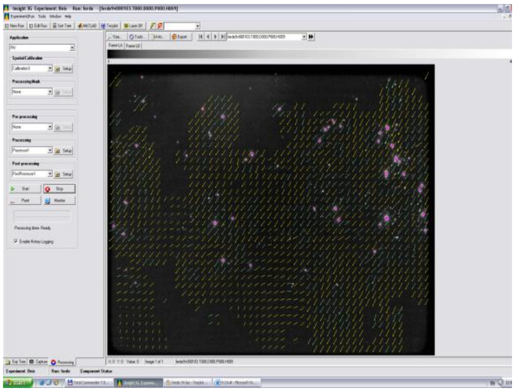

Fig 7. Particles in free fall in forced horizontal flow.

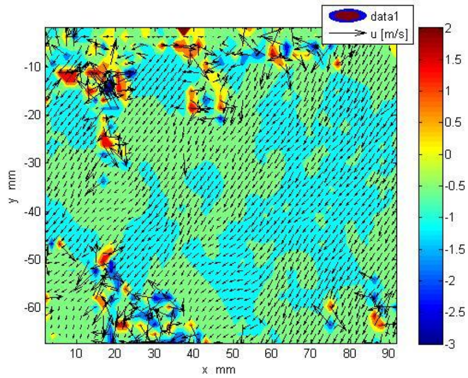

Fig 8. Particles in free fall in forced horizontal flow, post processed by MATLAB

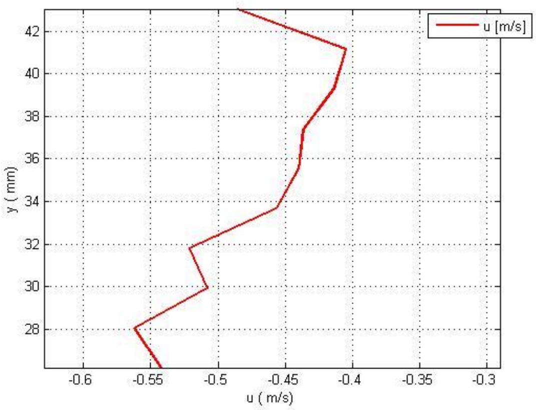

Fig 9. Speed distribution of particles in the selected cross-section at free falling in forced horizontal flow, MATLAB

Velocity field analysis of dust and chip particles in with manual milling machine

In the he following groups of measurements we analyzed the velocity fields of a manual milling machine. On the following figures the effect of the tool air inlet is shown.

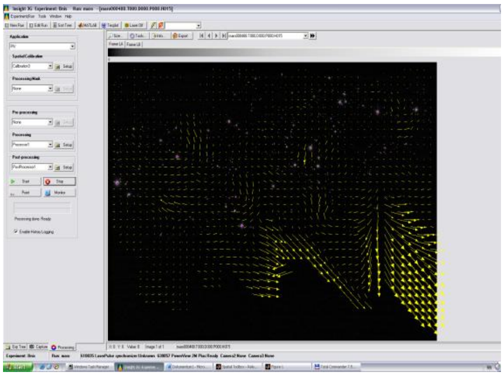

Fig 10. Flow image of a manual milling machine

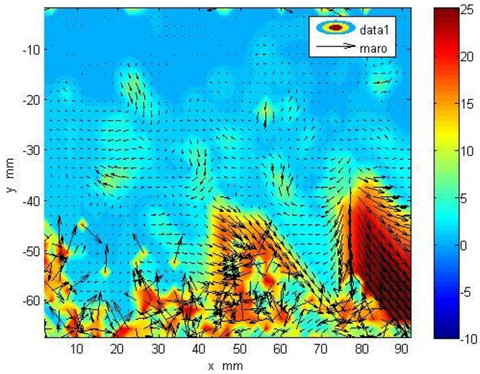

Fig 11. Vector field of a manual milling machine processed by MATLAB

Validation of the system with free falling woodchip

The measurements showed here the velocity field of free falling particles, a forced motion particles and partices generated by a manual milling machine. The measurement results and the subsequent analysis showed that the system is capable of measuring velocity field analysis of flowing wood dust. The second important question is how reliable and accurate the measurements are. In case of 0.8-1.0 mm fraction of dust particles we measured the free falling speed from the height of 1, 1.5, 2 m, and verified by theoretical calculations afterwards. The critical fall rate constants speeds were determined using the following formula: $v_{kr} = \sqrt{\frac{4d\gamma_h g}{3c_w\gamma_l}}$

where:

d - particle diameter; c_w - 0.44 air resistance factor

$\gamma_h -$ 500 kg/m^3 specific gravity of wood; $\gamma_l -$ 1.24 kg/m^3 specific gravity of air

According to (2) were determined times of fall depending on the distance shown in Figure 12.

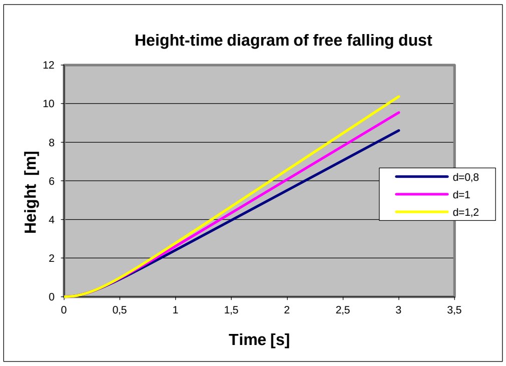

Fig 12. Time-height of fall according to the partice diameter of 0.8, 1, 1.2 mm (oak)

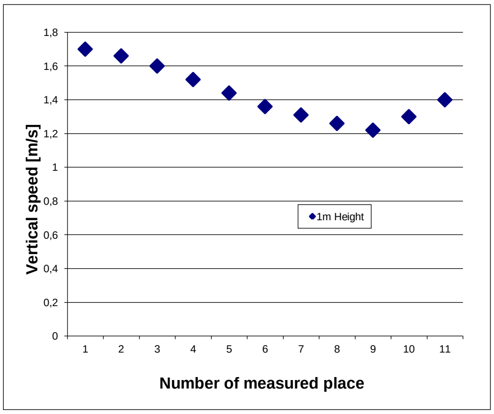

Fig 13. Free falling wood dust particles' speed profile, diameter is 1 mm, throw-height 1m, oak

The following figures show free falling speed profiles of particles measured by the PIV system.

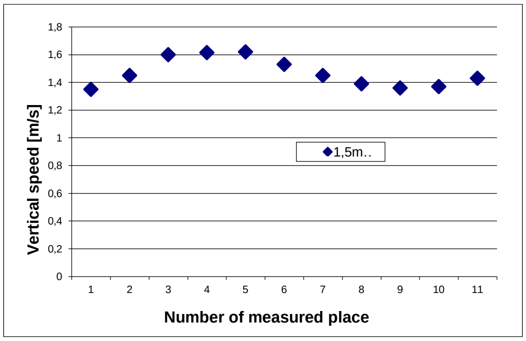

Fig 14. Free falling wood dust particles' speed profile, diameter is 1 mm, throw-height 1.5 m, oak

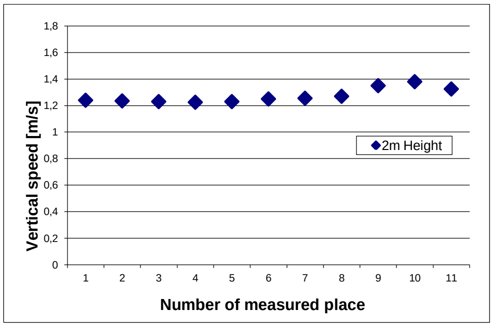

Fig 15. Free falling wood dust particles' speed profile, diameter is 1 mm, throw-height 2.0 m, oak

CONCLUSION

From the measurements it can be seen that the measured speed values is only loosely correspond to those of the theoretical calculations. The problem is that the air resistance coefficients of the particles are highly variable, while in theory we calculated approximate ball shape. The particles are not symmetrical in shape, and their surfaces are rough. The scatter is also due to the dust particles rotating during falling so that the air resistance coefficient is always changing.

The validation process has proven that the measuring system is working well, however, in order to verify the accuracy, additional measurements should be made with the air resistance.

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