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DUSTINESS IN HIGH-SPEED MILLING

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ABSTRACT

The paper deals with problems of dustiness and possible methods of its evaluation. After the analysis of a testing and evaluation system the proposal is described of the method of evaluation of the specific emission of dustiness. Results are given in diagrams of a granulometric analysis and the stochastic analysis of the occurrence of particles. Conclusions of this part of research will be applied in the design of an exhaust and filtering/ventilation system for the high-speed milling of wood.

KEY WORDS: high-speed machining, wood dust, granulometric analysis, dustiness emissions

INTRODUCTION

In recent years, effects of wood dust on man are very intensively studied and dealt with by the professional public and literature. Problems of the origin of wood dust during machining are rather often discussed (Dzurenda 2005), (Kos and Lučič 2002), (Očkajová and Beljaková 2004). Its health harmfulness and rather easy explosibility are generally known. Biological effects of wood dust are complex consisting of mechanical, physical and chemical effects. These impacts can be primarily irritable, ie they manifest themselves in the irritation of the mucous membrane of upper air passages and eyes, further allergic, ie manifesting themselves in various skin diseases and not least, they can induce serious diseases, e.g. asthma, nose or larynx cancer.

Dust is generally created by fine particles of solid matter. It originates due to friction, crushing and machining the material (Javorek and Oswald 2001). It can get to the atmosphere due to the relative movement of air particles, particularly during the rotation of tools and exhaust processes. Dust in the atmosphere is always polydispersive, ie it contains particles of various dimensions. Determination of the dispersion of dust is a serious task because the knowledge of particle distribution according to its size is very important from technical aspects. It is critical for the choice and dimensioning dust separators, for the choice of exhaust and transport speeds, for the construction of suction adapters and covers and for the dispersion of dust in the surrounding atmosphere.

In the process of cutting operation and wood machining, chips and dust originate the shape and amount of which are dependent on technological conditions of machining, physical/mechanical properties of wood and the geometrical shape and sharpening of the cutting tool. Chips and dust particles are termed collectively "disintegrated wood material" (Dzurenda 2002).

Our department deals with research into high-speed machining of wood studying also environmental and safety aspects of the operation of machines. We focussed particularly on problems of the working environment quality and dust emissions. For the machine dustiness emissions, it is suitable to prepare a mathematical model, which can enable to evaluate and compare dustiness for similar technological conditions of wood machining (Fischer and Gottlöber 2003), (Gottlöber and Hemmilä 2004), (Kopecký and Rousek 2005). Dustiness emissions are the function of cutting conditions, tool and material machined.

MATERIAL AND METHODS

After careful cleaning and sealing the working space of an experimental milling machine for high-speed milling (Fig. 1), a predefined layer was milled from a workpiece. The exhaust and filtration/ventilation system was set off. During the workpiece passage, the input and output opening of the working space was continually sealed by an elastic packing. Chips and dust were removed from the space manually into polythene bags after sufficiently long time of sedimentation.

Cutting depth was set to a_p = 1 and 2 mm. Feed speeds into cut v_f were set in such way feeds per tooth f_z (0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4 mm) to be kept for selected cutting speeds v_c = 40, 59 and 75 m/s. Cutting speed 75 m/s can be considered to be a speed corresponding to present opinions on high-speed milling of wood. A beech scantling (50×100×1850 mm) of the moisture content of w = 7% was machined.

A six-knife milling head (ϕ125×100×40) of Benmet Ltd. Prague mounted with Pilana HS 19 824 – 18% W (α=25°, β=38°, γ = 27°) knives was used (Fig. 2).

Granulometric analysis

Particles of disintegrated wood obtained in the process of cutting operation show different dimensions and shape (Barcík et al. 2004). Granulometric analysis making possible to find the distribution of particular fractions of chips and dust is a suitable method for the dust grain size determination. It is carried out by sieving when the smallest dimensions of particles are usually determined. Particular particles are during shaking in three axes always set in such a way to pass through the sieve mesh.

From the viewpoint of health risks and explosion hazard dust particles of a dimension smaller than 100 μm are dangerous. These particles rank among the group of so-called inhalable fractions of dust according to the ČSN EN 481 Standard. They differ from other grains of loose materials by very slow sedimentation and long time of persisting in the atmosphere.

The granulometric analysis was carried out by sieving using a Retsch AS 200 digit apparatus (Fig. 3) with a possibility of the continuous set-up of the vibration sieve amplitude in three axes. The combination of mesh screen of 5 mm, 1 mm, 500 μm, 250 μm and 100 μm was used according to ISO 565 (DIN ISO 3310-1) Standard. The vibration amplitude was set to a value A = 2 mm and the time of sieving to t = 15 min. Throughs were weighed on an digital balance Scaltec SBC 41 accurate to ± 0.001g.

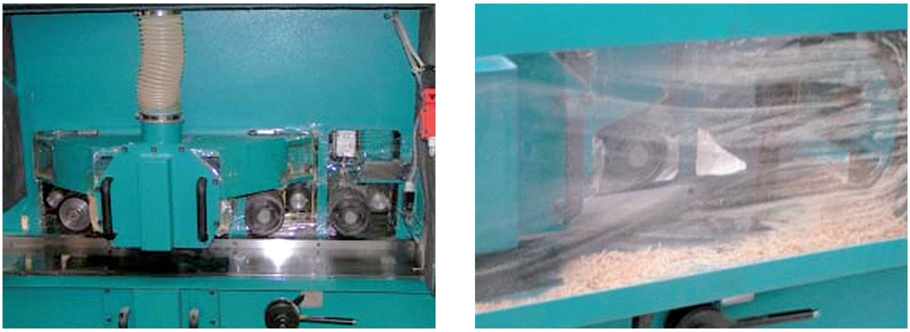

Fig. 1: Sealed working space of the milling machine and chips and dust before collection

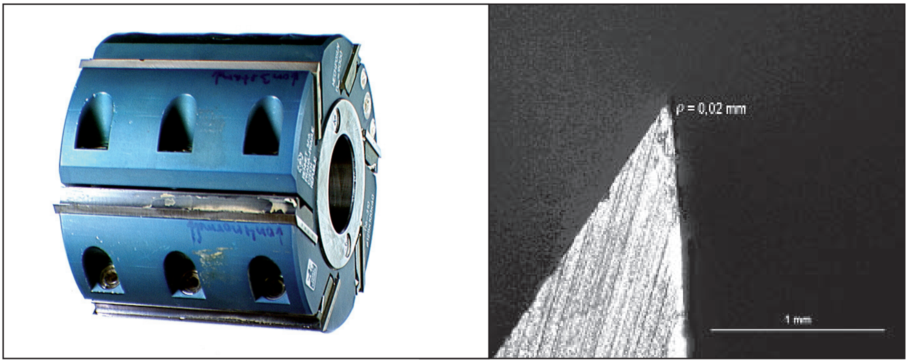

Fig. 2: Milling head of Benmet Ltd. and the condition of knife edge

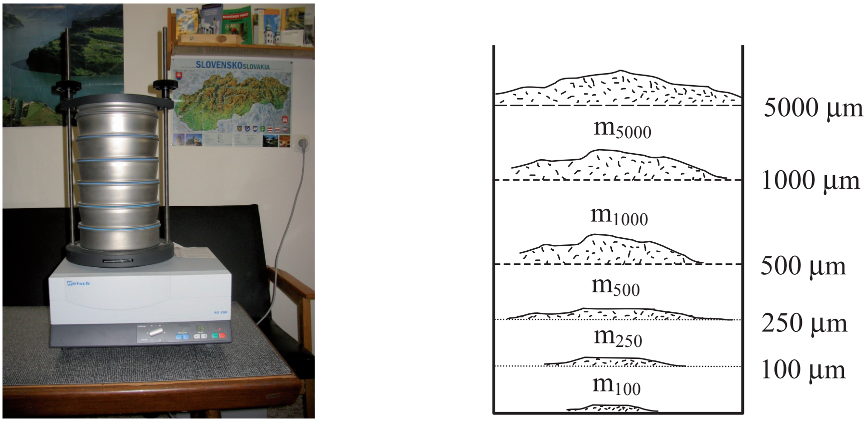

Fig. 3: Retsch AS 200 digit and the scheme of sieving

Image analysis

Samples of inhalable particles < 100 μm were exposed to the computer image analysis by means of a measuring device LUCIA-G 4.0 (Laboratory Universal Computer Analysis) (Fig. 4). The device consists of a Nikon Optiphot-2 microscope with a Nikon 4× objective and the converter of analogue data to the digital form and an efficient computer (processor Intel Pentium 4, RAM 1 GB, HDD 120 GB, operation system Windows 2000).

An image from the microscope is scanned by a chip television CCD camera Hitachi HV C20 (RGB 752 × 582 pixels) with horizontal resolution 700 TV scan lines. This device makes possible to identify particular dust particles and to quantify their basic morphometric characteristics, ie mean width, length, circularity, perimeter, circumference, particle area etc.

For the faster evaluation of the characteristics a special Makro program was prepared substantially accelerating the procedure (Kopecký and Mazal 2005).

The procedure of an image/analytical processing can be briefly expressed as follows:

1. Making a microscopic picture (depicted area circa 2.76 × 2.00 mm)
2. Storing the picture in a special format *.lim making possible to store real dimensions of objects
3. Image/analytical processing: opening the picture, starting the measuring macro (adjustment of contrasts and other parameters, automatic distinguishing the particle images from the background, their morphological separation and actual measurement).
4. Through the procedure mentioned above 9 various characteristics were measured (see Tab. 1)
5. The transfer of measured data to a spreadsheet program MS Excel 2000 and their storage in the form of a data file *.xls. (see Tab. 1)

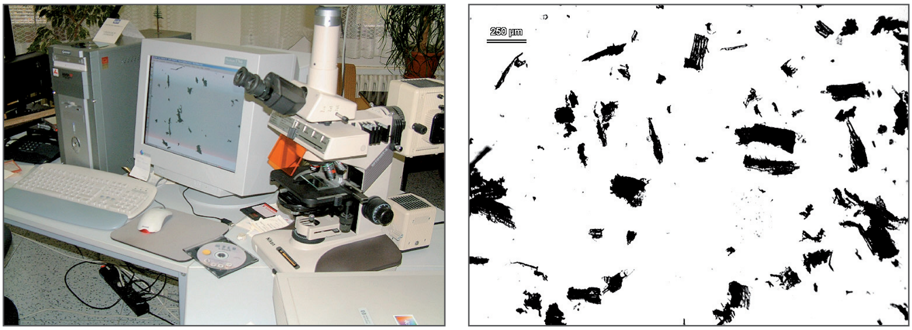

Fig. 4: Laboratory Universal Computer Analysis and an analysis of the image of particles smaller than 100 μm

Tab. 1: Measured dimensions of dust particles (v_c = 75 m/s, f_z = 0.2 mm, w = 7%)

26.5.2005								
beech sample 3								
sampling 08.02.05								
Area	VolumeEq Sphere	Perimeter	Length	Width	MaxFeret	MinFeret	Circularity	Elongation
7972.37	535482	423.692	162.908	48.9377	172.345	70.503	0.558079	2.44451
3380.18	147834	230.61	82.7111	40.8673	82.7111	58.7155	0.798714	1.40868
11446.8	921279	530.104	210.733	54.3191	198.708	97.9712	0.511885	2.02823
5090.47	273212	463.259	207.043	24.5865	164.632	65.8509	0.298071	2.50008
915.745	20846.2	120.822	50.0843	18.2841	50.0843	24.8433	0.788297	2.01601
16119.8	1.54E+06	943.461	434.643	37.0875	401.722	96.7522	0.227573	4.15207
6464.09	390953	334.779	106.948	60.4412	120.285	86.6641	0.724771	1.38794
16254.5	1.56E+06	692.471	290.23	56.0056	228.978	140.759	0.425971	1.62674
5265.54	287427	360.079	143.293	36.7466	155.715	55.6744	0.510336	2.79689

RESULTS AND DISCUSSION

Results of the granulometric analysis confirmed a hypothesis that the change in cutting conditions did not substantially affect the amount of wood particles > 1 mm. It is also evident from curves of throughs for samples of dust with feed per tooth f_z = 0.2 mm, Fig. 5.

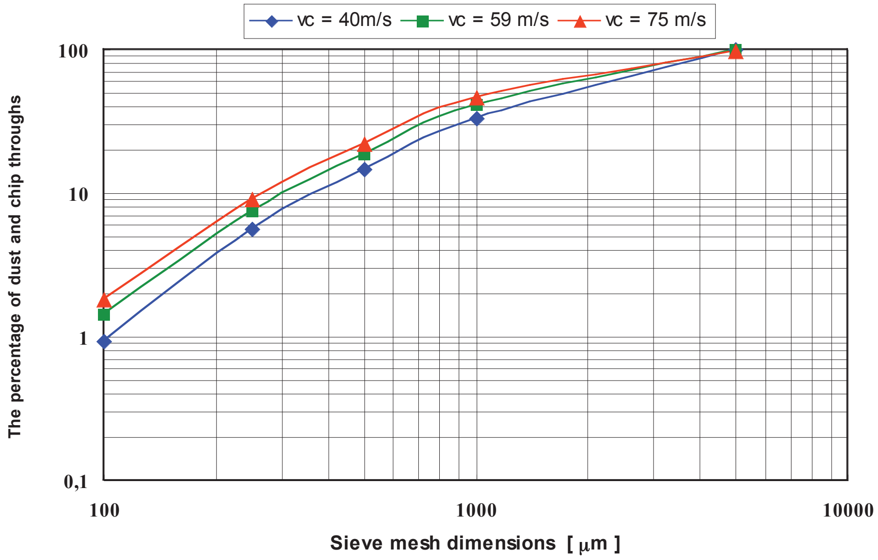

Fig. 5: Curves of throughs

The amount of dust fractions up to 100 µm resulted in substantial increase in high-speed machining. It is caused by a fact that the contact of a cutting tool and a workpiece lasts a shorter time and, thus, a smaller chip originates, see the course of cutting conditions in Fig. 6.

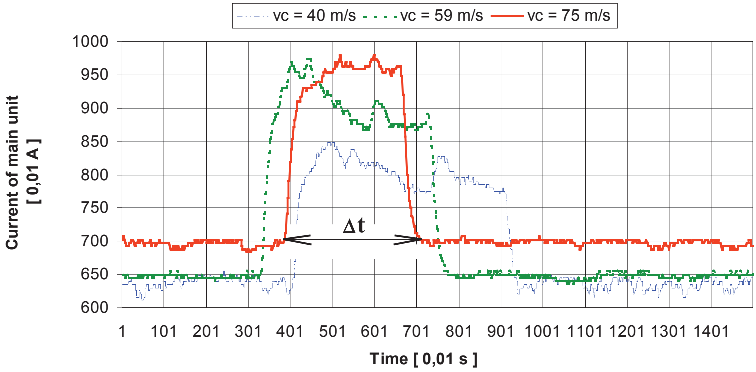

Fig. 6: The course of cutting conditions

Diagram in Fig. 7 depicts the dependence of a percentage of the amount of fine dust up to 100 µm on cutting conditions. The amount of fine dust substantially increases with decreasing feed per tooth f_z. The fact is also corroborated by a theory because with higher feed per tooth the length of chips increases (see Fig. 8 and relation (1)) being more compact and thus the proportion of course dust fractions and chips increases.

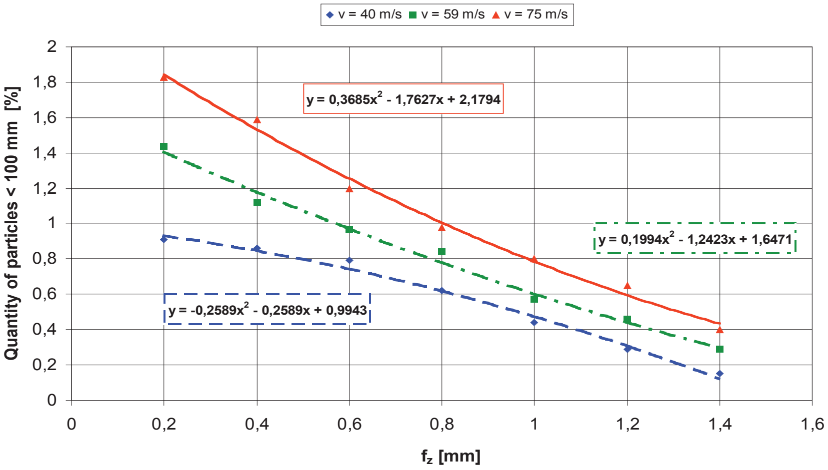

Fig. 7: The percentage of the amount of fine dust depending on cutting conditions

For the theoretical length of a chip it follows:

$$l_m = \sqrt{a_p \cdot D} = \frac{f_z \cdot a_p}{h_m} \tag{1}$$

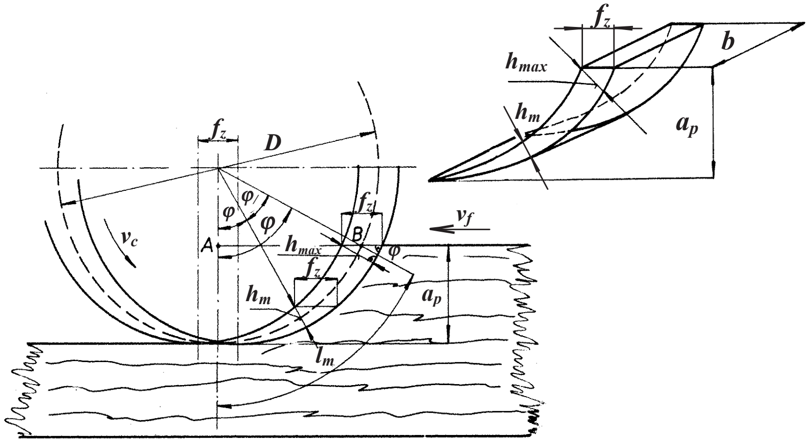

Fig. 8: Kinematic conditions at plane milling

Comparison of dustiness can be carried out by means of the model of the machine dustiness emissions. For similar technological conditions of machining (e.g., for plane milling) it is possible to compile a mathematical similarity model which is the function of cutting conditions, a tool used and machined material. Results of a granulometric analysis are input data for the model. Moreover, it is necessary to start from theoretical relations for the determination of the chip mean thickness and kinematic conditions representing tool- workpiece interactions (Fig. 8).

Dustiness emission E is defined as a ratio of the weight of dust (Δm) and time of machining (Δt) (Fischer and Gottlöber 2003), (Gottlöber andHemmilä 2004).

$$E = \frac{\Delta m}{\Delta t} \qquad [\text{ g/s }] \tag{2}$$

For the weight emission of dustiness E, it is also possible to express a relation

$$E = \frac{\Delta m}{\Delta V} \cdot \frac{\Delta V}{\Delta t} = e \cdot Q \qquad [\text{ g/s }] \tag{3}$$

where e … specific weight emission of dust [g/m^3]
Q… volume flow of dust [m^3/s]

It is advantageous to introduce the specific weight emission of dustiness referred to as e, ie dustiness emission related to the volume flow of dust.

$$e = \frac{E}{Q} \qquad [\text{g/ m}^3] \tag{4}$$

Considering also the material machined, particularly its density we get the specific emission of dustiness ε which is expressed as a dimensionless similarity number (Kopecký and Rousek 2005). A value of the specific emission of dustiness is an indicator for relative comparisons of the origin of wood dust at machining various species, for concretely set cutting conditions and tools used.

$$\varepsilon = \frac{E}{Q \cdot \rho} = \frac{E}{b \cdot a_p \cdot v_f \cdot \rho} = \frac{E}{b \cdot a_p \cdot f_z \cdot n \cdot z \cdot \rho} = \frac{E \cdot \pi D}{b \cdot a_p \cdot f_z \cdot v_c \cdot z \cdot \rho} \tag{5}$$

After substitution into the equation (5)

for feed per tooth $$f_z = h_m \cdot \sqrt{\frac{D}{a_p}} \quad [\text{ mm}] \tag{6}$$

we get the specific emission of dustiness as a function of the mean thickness of a chip h_m and cutting speed v_c.

$$\varepsilon_{\%} = \frac{E \cdot \pi \cdot \sqrt{D}}{b \cdot h_m \cdot \sqrt{a_p} \cdot v_c \cdot z \cdot \rho} \cdot 100 \quad [\,\%\,] \tag{7}$$

The specific emission of dustiness of particles up to 100 μm as a function of cutting speed v_c and chip thickness h_m is depicted in Fig. 9. A substantial increase of the dustiness emission occurs at a high cutting speed $v_c = 75$ *m/s* when the speed of a milling head reaches a value $n = 11\,400$ *min*$^{-1}$ (*rpm 11 400).* High-speed milling can cause even threefold increase in the specific emission of dustiness as compared with the standard speed of milling $v_c = 40$ *m/s (n = 6000 min*$^{-1}$*).* In practice, however, this extreme situation should not occur because it is necessary to choose a recommended feed per tooth the mean chip thickness to be always greater than the radius of the tool blunting. For example, with the radius of the edge blunting $\rho = 0.02$ *mm* (Fig. 2) the actual value of feed per tooth should not decrease below $f_z < 0.3$ *mm*. Otherwise, the chip thickness is equal or even smaller than the radius of edge blunting and the tool stops to cut the material. Due to the increased crushing of machined material dustiness rapidly increases.

To assess the behaviour of dust from various aspects, e.g. its potential to separate in various types of separators, its health effects, possibilities of sedimentation, possibilities of explosion, it is necessary to know not only its granulometric composition but also its probable occurrence in the given dustiness emission.

The probable occurrence of fine dust < 100 μm can be described by the 2-parameter Weibull stochastic model which fits the majority of cases of the occurrence of a random quantity. Parameters of the Weibull model, viz. the parameter of form (***b***) and the parameter of a scale (***a***) are movable, ie dependent on the statistical distribution of particles. The Weibull model can change into e.g., Gaussian, log-normal, exponential and other stochastic models.

Input data for the Weibull model calculation were obtained from the computer-based image analysis. Unknown parameters of the Weibull model were determined by the least squares method from the course of the statistic probability of the occurrence of dust particles.

The mean width of a particle was chosen as a random variable. Density of the particle occurrence probability of a given dimension x is defined by a relation

$$\mathbf{f(x) = \frac{b}{a^b} \cdot x^{b-1} \cdot exp\left[-\left(\frac{x}{a}\right)^b\right]} \tag{8}$$

where a ... parameter of a scale (dimension of a random quantity)
b ... parameter of form (dimensionless)

As an example, stochastic distribution of particles is presented for cutting conditions corresponding to feed per tooth $f_z = 0.2\ mm$ (Fig. 10). Density of the probability of the occurrence of fine dust particles with the parameter of form b = 1.26 to 1.33 ranges between the exponential and log-normal distribution of a random quantity.

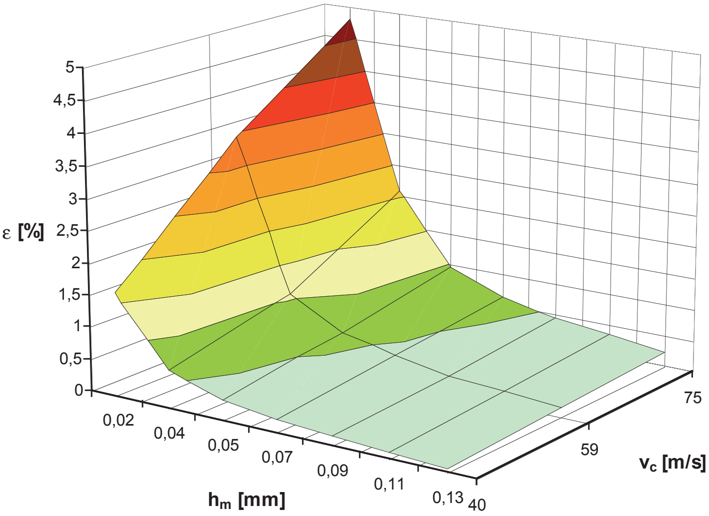

Fig. 9: Specific emission of the machine dustiness for particles smaller than 100 μm

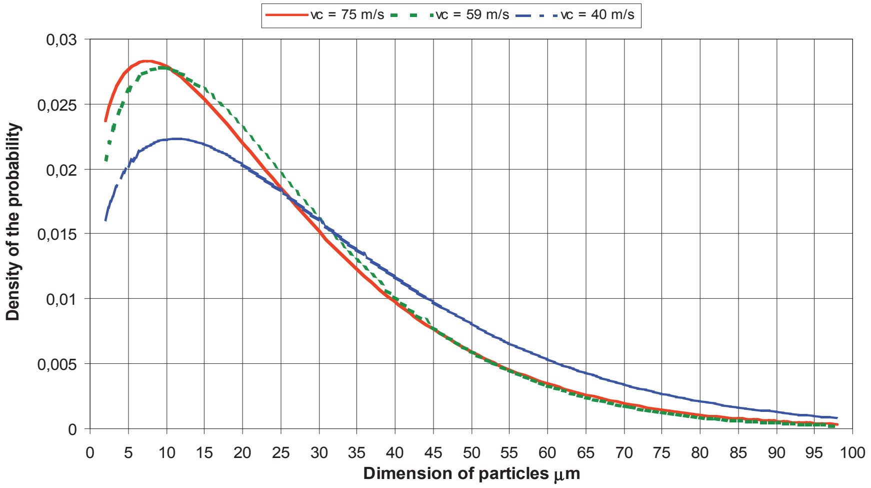

Fig. 10: Stochastic distribution of particles for feed per tooth f_z = 0.2 mm

Fig. 10 shows that at high-speed milling, there is the highest occurrence of dust particles with the average width about 7 µm. Further evaluation of the results confirmed a hypothesis that with increasing feed per tooth f_z the dimension increases up to a double value at feed per tooth $f_z = 0.8\ mm$.

CONCLUSION

Measured and modelled courses of the dustiness for standard conditions of milling are consistent with similar studies carried out abroad (Fischer and Gottlöber 2003) confirming a theoretical hypothesis that the amount of dust particles decreases with increasing the average thickness of chips and related feed per tooth.

Dustiness at high-speed milling can increase up to a threefold value as compared with standard conditions of milling. It is caused particularly by the shorter time of the tool/workpiece interaction and at smaller feed per tooth a_p, synergetic effects (dustiness is multiplied) of the shorter length of chips occur.

Generally, particles with dimensions smaller than *10* µ*m* can get to the bronchial system and depending on their size to various parts of the tract (tracheobronchial, broncho-alveolar). Therefore, the knowledge of the stochastic occurrence of fine dust particles ranks among valuable data. On the basis of this knowledge it is necessary to propose such measures in a machine (particularly the optimum form of the sucking cover and exhaust nozzles) excessive amounts of these fine dust particles not to get to the working zone of an operator and, thus, the allowable concentration of dust not to be exceeded in the workplace.

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REFERENCES

1. Barcík, Š, et al., 2004: Vplyv vybraných fyzikálno-mechanicko-technologických vlastností juvenilného borovicového dreva na granulometrické zloženie triesky pri rovinnom frézování. In: Trieskové a beztrieskové obrábanie dreva ´04. Starý Smokovec-Tatry, Pp. 23-29
2. Dzurenda, L., 2002: Vzduchotechnická doprava a separácia dezintegrovanej drevnej hmoty. Zvolen, Pp. 14-23
3. Dzurenda, L., Orlowski, K., Wasilewski, R., 2005: Granulometric analysis and separation options of dry sawdust exhausted from narrow-kerf frame sawing machines. In: Drvna industria 2/05, Pp. 55-60. Zagreb
4. Fischer, R., Gottlöber, Ch., 2003: Basic in optimisation of wood cutting on the example of peripheral milling. In: 16th International Wood Machining Seminar. Matsue, Japan
5. Gottlöber, Ch., Hemmilä, P., 2004: Analysis and Modelling of Human and Enviromental Aspects on The Example of Peripheral Planing. In: 16th International Wood Machining Seminar. Matsue, Japan
6. Javorek, L., Oswald, J. 2001: Feed force during milling. In: Wood research - 46(2), Pp. 29-36, Bratislava
7. Kos, A., Lučić, R.B., Horvat, D., Šega, K., Bešlić, I., 2002: Influential factors on indoor air dustiness in woodworking companies. In: Drvna industria 3/02, Pp. 131-140. Zagreb
8. Kopecký Z., Mazal P., 2005: Microscopic and stochastic analysis of wood dust. In: Forestry and Wood Technology. Annals of Warsaw Agricultural University - SGGW, sv. 56, Pp. 354-357
9. Kopecký, Z., Rousek, M., 2005: Granulometric Analysis and Dust Emissions in High-Speed Milling. In: Forestry and Wood Technology. Annals of Warsaw Agricultural University - SGGW, sv. 56, Pp. 349-353
10. Očkajová, A., Beljaková, A., 2004: Dimensional analysis of wood dust particles. In: Trieskové a beztrieskové obrábanie dreva ´04. Starý Smokovec-Tatry, Pp. 163 – 168

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