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AERODYNAMIC ASSESSMENT OF THE EXTRACTION ATTACHMENT OF CNC PROCESSING MACHINERY

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ABSTRACT

Domestic and international view of exposure to wood dust changed considerably in recent times. Dust originating from beech, oak and other dense hardwoods are classified as carcinogenic materials according to new findings in medical science. Thus, wood dust exposure became an important issue.

CNC processing centres became widespread in the wood industries in the last ten years. The effectiveness of extraction from CNC machines emerged as an important issue to examine, in order to develop a database for the construction of extraction attachments, and, to suggest ways to improve the effectiveness of the extraction based on the data. For this reason we carried out measurements in the vicinity of the attachment and the main spindle of a CNC router.

In the course of our measurements we found that the rotational speed of the cutting tool has a knock-on effect, because it corresponds to the initial speed of wood chips. To divert chips propelled by this initial speed from their original route towards the extraction apparatus, the suction speed, and especially its *z* component needs to be sufficiently large everywhere in this area.

Our measurements indicated that the geometry of the cutting tool is another important factor that influenced both the direction and magnitude of the initial velocity. The effect of the cutting tool was especially significant in the vicinity of the cutter.

KEYWORDS: CNC processing centres, wood dust, particles, extraction effectiveness, initial velocity

INTRODUCTION

Various regulations took effect concerning dust extraction, starting from the mid-1980's, after the Committee for Assessing Hazardous Materials in Germany declared oak and beach wood powder definitely carcinogenic. Workplace air pollution limits were established at 2 mg/m^3 and 5 mg/m^3 for new and used machines, respectively.

Although EU directives pronounce oak and beech powder to be carcinogenic, they allow filtered air recirculation provided that the dust content of the recirculated air is less than 0.2 mg/m^3.

So far, Hungary has no legislation specifically for CNC machinery. On the other hand, in an appendage to Order nr. 25/2000 concerning workplace chemical safety, in effect since January 1, 2001, allowable respirable and total wood dust concentration is established as 1 mg/m^3 and 5 mg/m^3, respectively. The ESzCsM-FMM order nr. 13/2002. (XI. 28.) overruled this, and specified the maximum total concentration value of 5 mg/m^3 only. (Brishing et al. 1991)

Hardwood powder has had a bad reputation in Europe since 1981. Comparative studies conducted in several countries and workplaces established that woodworkers have a very high risk of developing nasal cavity cancer, and this risk is even higher when using dense hardwoods. Subsequent studies have proven the carcinogenic effect of some extractives and materials like varnish, dyes or adhesives, and that cancer development is more likely after irritation caused by wood powder of certain sizes and shapes.

Wood particles get into the lungs carried by the air flow when inhaling, and most of them escape when exhaling or during the self-cleaning process of the lungs. Some particles may get deposited in the lungs, depending on particle size.

According to medical research results, particles in the 0.1 to 5 μm range may get trapped in the alveolar passages (this size range covers respirable dust.) Larger particles are retained in the mucous membrane of the nose, throat, windpipe or bronchial tubes, and the self-cleaning mechanism of the lungs expels them. Particles smaller than 0.1 μm behave as colloids (i.e. show molecular characteristics.) Results of clinical, pathological, anatomical and epidemiology research (animal testing) show that, for most types of dust, specific syndromes are impossible to define, but some disease is usually manifest. (Kiss 2002, Albracht et al. 1989, Heisel 1991, Hirsch et al. 1987)

Practical experience shows that so-called 'inert' dusts present health hazards, too. They have long-term biological effects, without having any fibrogenic, carcinogenic, toxic or allergic effects. Entering the respiratory system in large amounts they overload its protective and cleansing mechanism, thereby causing respiratory disorders.

The health hazard presented by wood powders therefore depends on

- the extent of exposure including dust type, concentration and duration,
- individual factors including the person's physique and fitness (meaning upper airway functions, lung functions and structure, general state of the immune system, special immune reactivity, biochemical reactivity.)

In the case of sawdust, especially that originating from dense hardwoods

- Reaction type: irritation, immune reaction, cancer,
- Lung disorder: allergic rhinitis, bronchial asthma, nose and nose cavity cancer,
- Observations: skin inflammation. (Brishing et al. 1991)

Due to the above, extraction effectiveness from CNC machines is an important topic to deal with. The factors influencing the effectiveness of extraction from these machines are, as follows:

Efficient extraction attachment construction

The criteria for this are, as follows:

- Striving for good tool coverage and small dust escape openings,
- Attachment to be placed near to where wood chips and powder are generated,
- Exploiting the kinetic energy of the chips to facilitate getting them into the attachment,
- The construction of the attachment is crucial in terms of workplace dust exposure.

Good extraction system

Whatever portion of the dust generated at the workplace does not enter it is lost for the system, and remains at the workplace as a contaminant.

The second important condition of good extraction, in addition to attachment construction, is a sufficient suction speed. This does not necessarily mean high speed, which is important because related extraction and recirculation costs increase production costs.

Cutting tool and cutting parameters

These influence the size distribution of the chips and their initial speed that indirectly affect workplace dust exposure.

Dust and chip extraction from CNC processing centres

Based on much practical experience and over a long time period, effective extraction systems could be constructed and implemented for conventional woodworking machinery. These ensure sufficiently low dust concentrations, as prescribed for workplaces, provided that operating instructions are complied with. The need to enhance throughput and flexibility, however, led to the advent of CNC processing centres. These centres are very flexible in terms of wood processing, but are less suited for extraction.

This is due to the following reasons:

- Wood processing centre constructions were inherited altogether from the metal industries, where there is no possibility of the aerodynamic removal of shavings, because of high material weight, and the amount of shavings is much less, too. (Hoffmeister and Blecken2000, Heisel et al. 2000)
- Wood industries use a number of different tools at high rpm's and speeds. Generated chips – in the case of most cutting heads – exit in the radial direction, propelled and kept on course by centrifugal forces. Because of the requirement of flexibility, tool magazines, and frequent edge moulding operations, favourable (i.e. radially located) attachment situation is impossible to achieve. Extraction airflow is directed vertically, upwards, which requires a 90° change of chip movement direction that gets harder to achieve as particles get bigger, due to their higher moment. These particles, getting trapped by the bristle skirt cover, fall mostly on the table, where they may be removed from only by using high air velocities. Using an auxiliary fan connected to the central network, may improve extraction effectiveness. (Hoffmeister and Blecken2000, Heisel et al. 2000)
- The morphology of the processed material is complex and variable, ranging from softwoods through light and dense hardwoods to chipboard. Accordingly, particle size distribution is much varied, and its extraction and levitation is governed by the Schimple rule.
- Simple early CNC machines, drills and routers, have developed into processing centres employing complex adapters like drill, router, circular saw and sanding units mounted on a single tool frame. These adapter systems complicate the task of effective dust and chip removal because they scatter chips, shavings and dust in completely different directions and with varying intensity. (Knorr et al. 2002, Heisel et al. 2000)

The degrees of freedom provided by CNC machines, especially those working with solid wood, should also be considered. The main processing unit may have a maximum of three translation and three rotation degrees of freedom. Good extraction systems should provide acceptable dust concentration values without restricting the machines' functionality. The purpose of our research is to find solutions to this problem. Covering the processing heads with large extraction casing, the usual solution used today, should be regarded as a transient measure. Large attachment cross sections, coupled with the need for high suction speed, requires a large air throughput, which is energetically unfavourable.

Despite the significant investments into extraction systems, this problem is not satisfactorily solved for processing centres. Workplace dust exposure limits are very low, and related energy costs call for a better solution. Because of the need for increased throughput, demanding quality requirements, ever-increasing cutting speeds (in order to achieve better surface quality) and, last but not least, to achieve reliability, chip and dust extraction effectiveness needs to be drastically improved.

The elements of the extraction system attached to processing centres often provide unsatisfactory extraction of dust and chips. Non-extracted particles remain on the workpiece, on the machine or in its vicinity, affect the operation and manufacturing speed adversely, and necessitate manual cleaning, which is costly.

The amount of dust particles issued into the workplace environment (flying dust) usually exceeds allowable workplace concentration. For the extraction of dust and chip particles, much higher airflow speeds are needed than that needed for their transportation. The extraction fan is found at the end of a collection passage, and it requires much energy, because it needs to provide the appropriate air velocity over a long tube section. It would be much better to employ individual extraction (fan) in the vicinity of the cutting head, that would require much less energy and provide higher air velocity. Thus, chips could be extracted effectively, after which a smaller airflow would be sufficient for their transportation. Accordingly, particles would be taken out of the airflow right after extraction, and transported in traditional (e.g. pneumatic or mechanical) ways.

The purpose of more effective extraction is always improved capturing of the particles at the extraction area. This basically necessitates increased suction speeds at this location. Compared to traditional processing machinery, processing centre extraction attachments are much more complex, because these machines may have as many as three to five degrees of freedom of movement, while the workpiece is stationary. Tool spindles are usually vertical or may be tilted, and the cutter heads are mounted on a bridge or overhang. This configuration is especially awkward in terms of extraction. The extraction attachment has to move along with the tool, to be present where chips are generated. The extraction apparatus must work effectively in all locations. Its effectiveness depends on initial extraction airflow asymmetry and the cutting process that usually produces an oriented chip stream. The ejection vector of chips during cutting is not defined because of the arbitrary movement of the tool spindle and also because of the varied tool types being used. Flying, non-extracted particles remain on the transport equipment, on the workpiece, on the machine or in the air, and may be removed using high air velocities or mechanical cleaning (brushes) only.

One way to achieve effective extraction is to modify the trajectory of dust and chips immediately as they are generated. This possibility is very useful for profiling machines where material is being moulded using small diameter tools as it passes through the machine, and, consequently, the initial speed of the particles is low. In these types of machines, the slow-speed material flow of the chips may be easily modified by the extraction airflow. Exiting chips usually leave in the tangential direction, remaining usually in the rotational plane of the tool, and the chip stream does not widen much. Ventilation caused by the tool does plays an important role in terms of chip trajectory. If extraction is upwards in the vertical direction, particles should first be slowed down and averted from their horizontal flow. This would, however, require sufficiently high air velocities in a direction across the particle flow, which leads to high energy consumption.

MATERIAL AND METHODS

The purpose of the investigation

According to chapter 1.1, we considered the aerodynamic investigation of the environment (and interior) of the extraction attachment of CNC machines important, in order to implement effective extraction for machines with varying degrees of freedom.

The purpose of the measurements described below was to establish the resultant air velocity (magnitude and direction) in the vicinity of the tool and the extraction attachment, i.e. under the bristle skirt, when using standard operation rpm's and modern, contemporary cutting tools (a 16mm dia. spiral-edged router tool, a 60mm dia. straight-edged router tool, and a 125 mm dia. lightweight metal router tool with 12 cutting edges arranged in a clockwise spiral.) The examination of various tools is necessary because tool geometry may help or hinder increased extraction efficiency. This may help us in developing not only cutting tools but innovative extraction appliances, too. (Varga et al. 2003a,b)

The CNC machine

The basis of our examinations was a bridge-mount CNC processing centre with "2.5 D" degrees of freedom that was at our disposal. The machine is connected to a local extraction apparatus, i.e. air gets recirculated into the workplace atmosphere. Two extraction attachments are located above the main tool spindle (Fig. 1.)

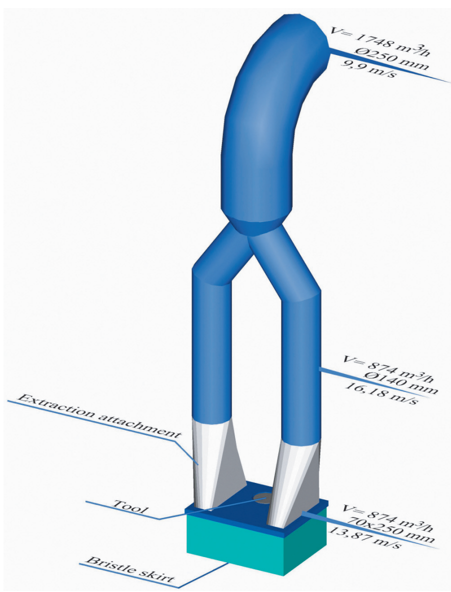

Fig. 1: the extraction attachment of the CNC processing centre and main extraction parameters

Measurement parameters

To accurately assess the velocity profile in the vicinity of the extraction attachment, inside the bristle skirt, 12 measurement points were designated in each of three measurement planes. A highly accurate, diamond-bearing, aluminium propeller AHLBORN FV A915 S240 type anemometer with a measurement range of 0.5 to 40 m/s was used to measure the *x*, *y* and *z* components of the air velocity. For the exact definition of measurement location and to keep settings constant, we used a measurement stand that may be rotated and adjusted in *x*, *y* and *z* directions to suit needs. Anemometer-measured speeds were read directly from an attached digital instrument. The anemometer was unable to provide velocity components. These were determined at all locations with the help of an aerodynamically suitable "wind vane" that pointed in the airflow direction.

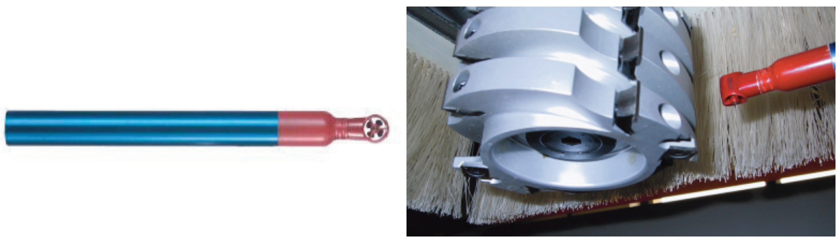

Fig. 2: Propeller anemometer in action

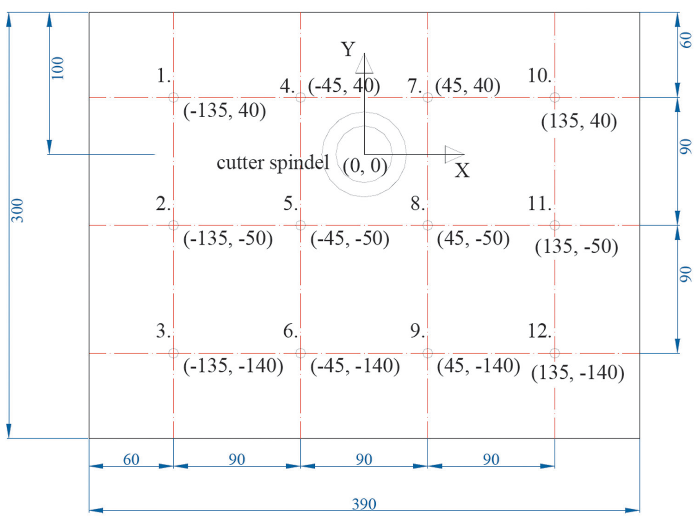

Fig. 3: x and y co-ordinates of the measurement points in each of the three planes, relative to the cutter spindle – plan view.

Planes nr. I, II and III were located at 5 mm, 65 mm and 125 mm above the bottom of the bristle skirt, respectively. Resultant speed and the angles between the resultant vector and the planes can be calculated from the measured *x*, *y* and *z* components.

The cutting tools that were examined:

- a 16 mm dia. spiral-edged router tool
- a 60 mm dia. carbide tipped router tool with two straight edges
- a 125 mm dia. lightweight metal router tool with 12 cutting edges arranged in a clockwise spiral (measurement points 4 and 5 had to be shifted in the x direction by -10 mm, while points 7 and 8 by +10 mm, due to the large diameter of the tool.)

Fig. 4: 16 mm, 60 mm and 125 mm diameter router tools

RESULTS AND DISCUSSION

The first step in our investigations was the examination of extraction without operating the cutting tool. In this case, cutter-induced ventilation did not influence the direction and magnitude of velocity measured in the designated locations.

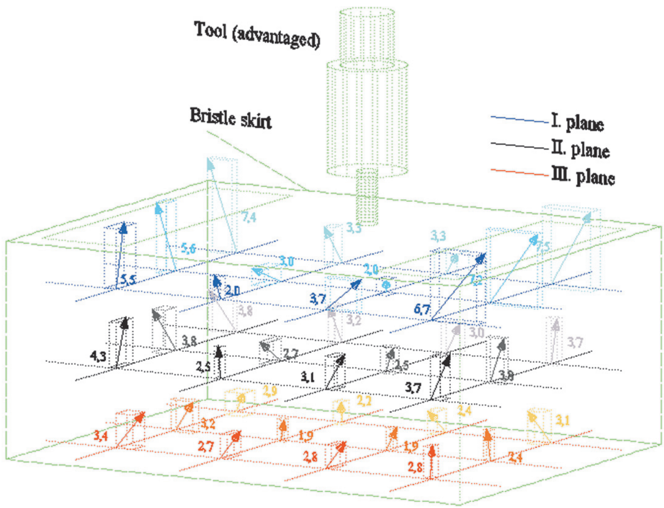

Fig. 5: 3D representation of the resultant velocity vectors operating the extraction system only (values are in m/s)

After this, all three tools were operated at standard rpm's to examine the interaction of extraction and cutter rotation. Based on the results and observations from these measurements along with those of the previous one, we can make conclusions concerning the ventilation induced by the various tools and their effects, as well as concerning speed and airflow direction changes in the various locations. (Varga et al. 2003a,b)

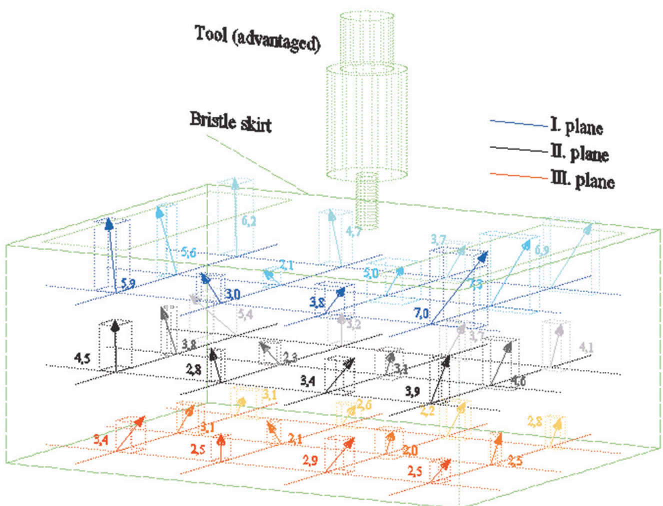

Fig. 6: 3D representation of the resultant velocity vectors when operating the 16 mm dia. cutting tool (values are in m/s)

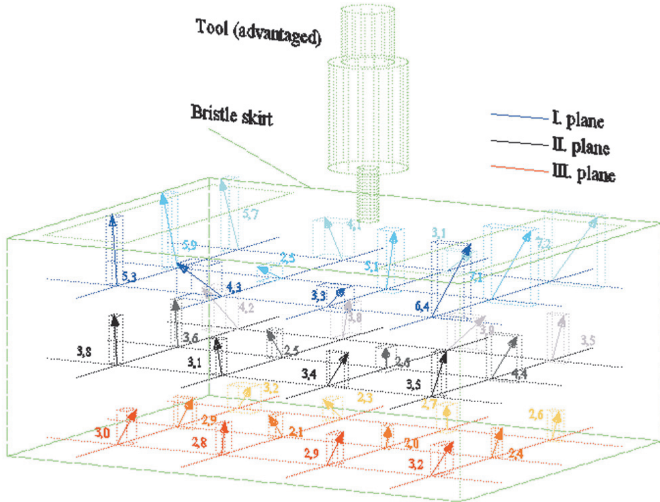

Fig. 7: 3D representation of the resultant velocity vectors when using the 60 mm dia. cutting tool (values are in m/s)

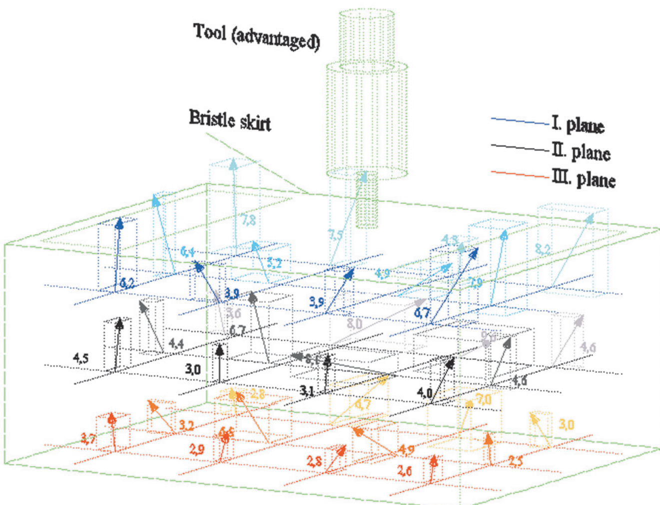

Fig. 8: 3D representation of the resultant velocity vectors when using the 125 mm dia. cutting tool (values are in m/s)

CONCLUSIONS

The size distribution of dust and chips generated by woodworking operations is extremely variable, ranging from 0.1 micron to mm and even cm magnitudes. In addition, species, moisture content and cutting direction, all of which influence the size and aerodynamic characteristics of the generated dust and chips, are also varied (Varga et al. 2003a). Cutting tool speed is another important factor, since it corresponds to the initial velocity of the chips and dust. The suction speed, and especially its *z* component, needs to be sufficiently large at every point to divert particles propelled by this initial speed from their original course, and extract them.

Fig. 8 shows that in the vicinity of the 125 mm dia. cutter, velocity components increased significantly, which is due to the ventilation arising from the particular tool's geometric arrangement. Our measurements showed that, in addition to rotational speed, cutter geometry influenced both the magnitude and orientation of the resultant velocities. This change was more pronounced at measurement points close to the cutter. The diagrams demonstrate that the turbulence is sufficient to turn the original, idle velocity vectors in the opposite direction (see plane nr. III. on Fig. 5 and 8.)

Constructing adequate extraction systems is obviously not only a technical issue, but also a question of economics.

Based on the above we consider the following our most important tasks:

- Based on a sufficient amount of measurement results, we need to determine the most important processing tools and equipment to be dealt with.
- The conditions in which dust and chips are generated, their particle size distribution and factors influencing it, machine construction, the most effective extraction attachment constructions and the possibility of complete machine covering, need to be examined.
- Measurements need to be extended to machines with different degrees of freedom, different cutting tools, rpm's, and, most importantly, different cutter types, because the measurements conducted so far already indicated that cutter type and rpm significantly influences air velocity direction and magnitude at the examined measurement points.
- A general goal is to facilitate the construction of modern, sufficiently effective and relatively economic extraction systems. A possible solution is using variable frequency extractor fans so that airflow intensity could be adjusted to be appropriate for the utilised cutting tool and rpm. This could lead to significant cost savings, because power uptake would change according to tools and rpm, and unduly high amounts of air would not be extracted when there is no need.

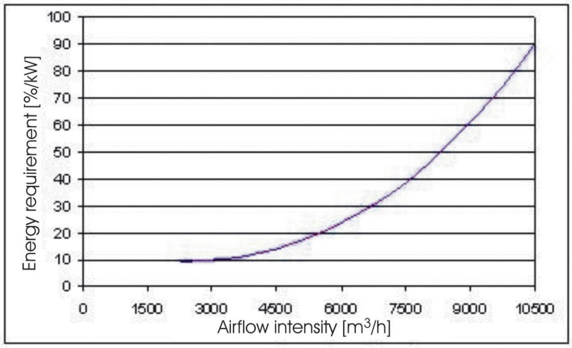

Fig. 9: Energy requirement as a function of airflow intensity, when using a variable frequency fan (Kiss 2002)

It is our hope that our research results will eventually lead to the development of a new extraction attachment construction for CNC machines, while cutting tools whose geometry is appropriate not only for cutting, but also for facilitating chip removal, already exist.

The basic goal of our research is providing the necessary database for the above tasks, and based on this database, developing technical solutions and making suggestions for reducing workplace dust exposure at CNC processing centres.

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