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ENHANCEMENT OF THE MACHINING OF SOLID WOOD PARTS FOR UPHOLSTERED FURNITURE

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Abstract:

The primary objective of our study was to determine to what extent the productivity of profile machining of the solid wood furniture parts can be increased without compromising the precision of machining. The method of investigation was studying the changes in machine and process capability as a result of changing speed of feed and speed of cut when machining series of parts made of selected wood species. Machining was performed on a multiple-shaft moulder. The species of wood were selected on the basis of their anatomical features.

The species of wood has an effect on the precision of machining; the central tendency varies with species; softer species (spruce, poplar) generally allow higher capability indexes; machining of hardwoods may exhibit significantly changing central tendencies with different feeding and cutting parameters; doubling of the custom feeding speed with proper cutting speed in most cases results in negligible drop of capability indices.

Keywords: *solid wood, machining, process capability, machine capability, tolerances*

UPHOLSTERED FURNITURE AND THEIR MANUFACTURING

Grouping of upholstered furniture

Upholstered furniture comprises pieces of furniture purposefully equipped with padding and covering materials for the comfort and relaxation of the user and for the improvement of his/her working environment. In designing upholstered furniture the functional dimensions of the users (sitting height, depth and width, armrest height, length and distance, lumbar support slope of sitting) are taken as basis for calculating the structural dimensions. On the basis of the function of upholster furniture, we distinguish between seats, beds and furniture of combined function.
The construction of a piece of upholstered furniture is as follows:

- Frame serving as the support of the functional parts. It can be made of wood, wood-based materials, metals or plastics.
- Base of upholstery serving for the transfer of loads to the frame. It is an important structural part of the product (seat, back) since it is responsible for the direct support of the human body on a comfortable way. It can be either rigid (panel) or flexible (sheet, straps).
- Springs, prime padding, top padding in the case of traditional upholstering. The purpose with them is assuring the desired shape, flexibility of support and durability. Springs and padding are substituted by foam material in modern upholstery. They are manufactured in various thicknesses and shapes with varying hardness. In order to separate the individual layers in a structure synthetic lining is used. Today seats of smart upholstery appear, the shape, hardness and flexibility of which can be locally controlled (case of car seats).

- Covering, the function of which is to enhance the aesthetical value of the finished furniture besides providing durability and the possibility for cleaning. According to the extent of covering a piece of furniture can be:
    - Upholstery-free seat (all appearing surfaces made of wood, metal, plastic or their combination)
    - Partially upholstered seats or beds (the frame is not or only partially upholstered)
    - Fully upholstered furniture, with all frame parts upholstered besides those parts directly supporting the body.

Seats: chair of low or high upholstery, easy-chair.
Beds: divan, settee, sofa, double bed .
Upholstered furniture of multiple functions: chair-bed, couch, operated via simple transformation of the frame structure with the help of purposeful hardware.

WOODEN PARTS OF UPHOLSTERED FURNITURE AND THEIR MANUFACTURING TECHNOLOGY

The elements of the frame structure of upholstered furniture are most often made of wood and wood-based composites. Depending on the design, parts of the frame structure can be visible. In such cases the function of the visible parts includes the enhancement of the aesthetical value beyond the primary function of supporting the loads.

Figure 1: Frame structure of an upholstered chair

Structural parts of the chair of Figure 1 are as follows: 1 - legs; 2 - rails (side, front, back); 3 - seat; 4 - back (panel or frame); 5 - ties; 6 - corner blocks. Unlike in the case of the covered parts when manufacturing these parts it is of utmost importance to assure precision of the profiles, tenon or dowel joints as well as the required quality of machined surfaces.

In general, the individual members of the supporting frames are legs, rails, and ties. Figure 2 is a schematic of the manufacturing process of chair frames.

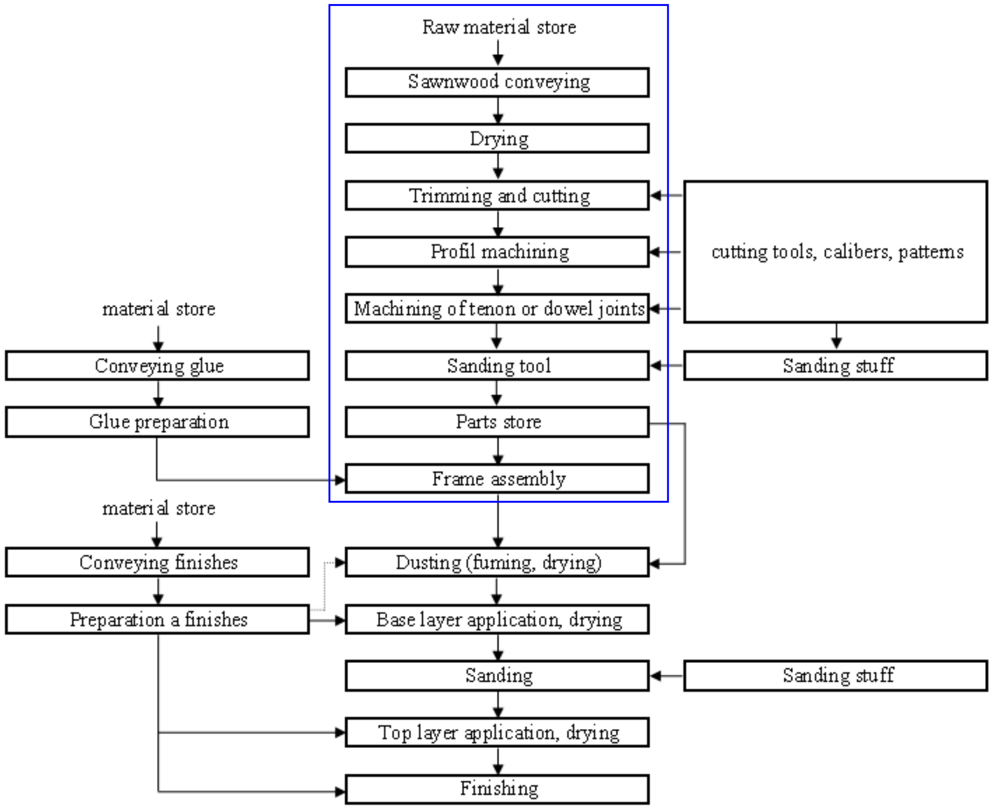

Figure 2: Manufacturing technology of an upholstered chair's wooden frame

It can be seen from the above schematic that the firs part of the process is aimed at producing frame component parts of raw dimensions. It may also be the case that the chair factory is using dimension stock as raw material; the first operation will be then profile machining (after eventual cut to length).
The first question in the solid wood processing technology is the synchronous state of machines required to a full exploitation; secondly machining quality is of importance. We will examine these requirements in the case of profiling.

CAPABILITY STUDY OF THE MACHINING OF FRAME MEMBERS OF AN UPHOLSTERED CHAIR

Objective of the study

The purpose of machining solid wood elements is to produce final dimensions. One may formulate the basic requirements with regards to quality as below:

1. Precision of shape and dimensions of the worked furniture parts that can be characterised by the deviations from the nominal dimensions.
2. Surface quality of machined surfaces that can be characterised by measures of surface roughness.

Our study extended to the examination of precision of dimensions.
To start with, we formulated the suppositions as follows:

- Enhancement of the production rate affects the machining quality of wooden furniture parts to varying extents in the case of woods of different texture. That is why we selected five species of wood of different texture for the investigations.
- The production capacity of the machines used in serial production of furniture frame parts (multi-shaft moulding machines, tenoning machines) is not utilised in the practice.

Our objective was to determine to what extent the productivity of profile machining of the solid wood furniture parts can be increased without compromising the precision of machining. It was also our objective to determine whether species of wood has an influence on the precision of profiling and what are the characteristics of the different species in machining to precise size.

Theoretical bases of machine and process capability

In wood-working industry, such as in other industries, dimensions of product parts manufactured in machinery of serial or mass production will not be exactly the same. Variation of the dimensions (and other properties such as surface roughness) is caused by external and internal effects called noise factors.
Examples of these noise factors:

- Deviations in tuning the machine,
- Precision of moving machine parts,
- Precision of work piece guiding,
- Edge conditions of cutting tool,
- State and properties of work piece, etc.

The goal with machining is to keep the deviations of work piece dimensions between acceptable limits so that it can fulfil its function correctly.

Statistical process control

Noise factors may be either random effects that are called common causes of variation or assignable effects called special causes of variation. One of the tasks of quality control is to distinguish between common causes and special causes of variation.
A process that is operating with only common causes of variation present is said to be in statistical control. In other words, the common causes are an inherent part of the process and determine its stable state. In such cases the variability of the process quality characteristics (e.g. worked dimensions) can be described by means of a given statistical distribution. From this fact it follows that the process can be predicted, i.e. we know what will be the central value, the standard deviation and the confidence limits of a quality characteristic as long as the process stays in its **stable** state or **in statistical control**.
When worked dimensions are the object of study, lack of special causes results in normal distribution of mean μ and variance σ^2. By inspecting work-piece dimensions we want answer the question if μ and σ^2 stay at their constant value, i.e. the precision of the process is still foreseeable.

Machine and process capability

Even in the case of a stable process the question may arise whether it is capable to fulfil the expectations in relation with the extent of variation with the set processing parameters. In other words, machine capability and process capability should attain the required level. This question can be answered by conducting capability studies.
In the case of a process under control, limits of random (common-cause) variation can be calculated by using the **+/- 3σ rule**. In the case of normal distribution the variable falls with 99.73% probability

within an interval of such width around the expected mean; therefore, this interval is also called **natural tolerance**.

Capability is defined as the ratio of band-width defined by the specification limits to the natural tolerance, that is:

$$C = \frac{USL - LSL}{6 \cdot \sigma} \tag{1}$$

where:

- USL = Upper Specification Limit
- LSL = Lower Specification Limit
- σ = standard deviation of the quality characteristic

When a large sample is taken from the production within a short time period of homogeneous machining and raw material conditions, we are speaking of **machine capability**. The corresponding C_m index can be calculated by determining the sample standard deviation s as below:

$$C_M = \frac{USL - LSL}{6 \cdot s} \tag{2}$$

where

- s = standard deviation of the sample.

Machine capability is acceptable if the relationship $C_M > 1.33$ holds.

Process capability:

When several samples of small size are taken from the production over a longer time period of non-homogeneous machining and raw material conditions, we are speaking of **process capability**. The corresponding C_p index can be calculated as below:

$$C_P = \frac{USL - LSL}{6 \cdot s^*} \tag{3}$$

where

- s^*= process standard deviation calculated from the within-sample variation of sub-samples.

Process capability is acceptable if the relationship $C_P > 1.00$ holds.

When relating the bandwidth of natural tolerance to that of specification limits, one may define the three cases as below:

I. The capability is just acceptable, providing that the mean of the process can be kept at the nominal value.
II. The capability is unacceptable; one has to decide on the basis of economic consequences, whether the production should be based on a different machine, or the work-pieces sorted and reworked.
III. Capability is “too good”, mean can move out from the centre.

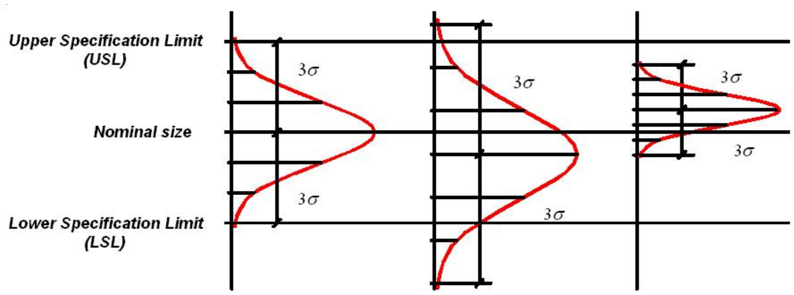

Figure 3: Three basic cases of the relation of natural tolerance and specification.

As a practical procedure of capability studies the method of control cards is commonly used.
In the course of Statistical Process Control samples of small size (1 to 9 elements) are taken from the process at predetermined intervals. The sample characteristics are plotted against time (or just in sequence of sampling). In the case of measured properties two sample characteristics are calculated and plotted: sample mean and within-sample variability (range or standard deviation).
The graph plotted includes a Central Line (the centre of the sample characteristic in question) and Control Limits. With the use of this "Control Card" hypothesis tests are being performed on the sample mean and the sample standard deviation respectively. The upper and lower control limits *(UCL* and *LCL*) correspond to the confidence limits of the relevant statistical test at the chosen level of significance.

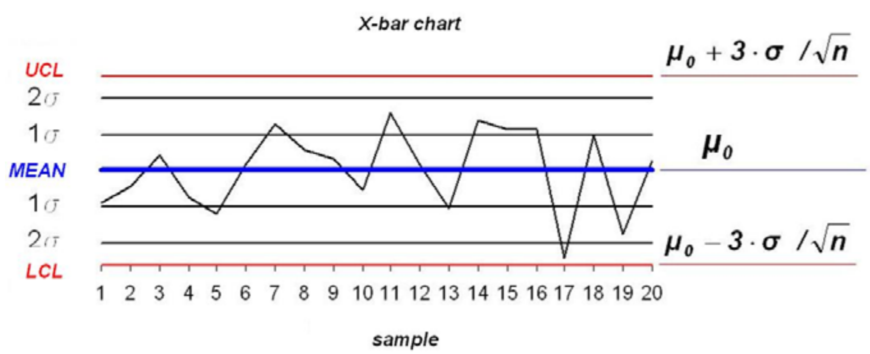

Figure 4: Control card of the central tendency (process mean)

CAPABILITY MEASUREMENTS IN THE PRACTICE

Capability experiments started with the selection of wood species for the study. This was followed by the preparation of suitable quantities of work pieces that were then machined in series at given machining parameters. The worked dimensions were measured and registered in the sequence of the piece's leaving the machine.
Material. In the selection of wood species we relied on the tables of mechanical properties compiled by Kurt and Koloc. Each group of species considered was represented by a species regarded as the most typical of its group. Beech (Fagus silvatica) was selected as a hardwood of diffuse pores and uniform, dens texture. Poplar (Populus spp.) represented the low-density, diffuse pore hardwoods. Oak (Quercus robur) was considered a good example of ring-porous, high-density hardwoods. Black locust (Robinia pseudoacacia) was selected being a ring-porous, dense hardwood, the vessels being highly penetrated by tyloses. Finally, spruce (Picea abies) is a coniferous wood of low density.

Moisture content. In the case of wood, moisture content is an important factor influencing all the properties. To check our samples we used an equipment of indentation probe type (Viva 12 System Vanicek Sn.:12:11.925). The moisture content of the samples was found close to the lower limit of air-dry condition which can be said a stable condition. Since neither the between species nor the within species differences of moisture content were found important we concluded that there will be no need of taking moisture content into consideration in the evaluation of machining experiments.
Test pieces. Test pieces were not prepared with the same cross-section in the case of the species involved, but this fact does not influence the evaluation. In terms of length we had to observe the minimum working length of the machine which was 350 mm. Samples of 120 numbered pieces were prepared by species by using table saw and planing machine.
Profiling machine – Weinig Powermat 1000. For shafts of the 8-spindle machine hade to be used and adjusted to working size: two horizontal shafts for machining the thickness and two vertical shafts for the width of work pieces. Depth of cut of 2.5 mm was chosen for all the four shafts aiming at a reduction of 5 mm of the respective dimension.
Set-up of experiment and measurement. Three sets of machining parameters (feed speed *u* m/min and cutting tool rotation speed *v* rot/min) were adjusted in the case of all species involved. Adjustments also had to include working width and thickness for the respective species, amounting to 15 different runs. Sets of machining parameters used were as below:

1. u=20 m/min v= 12000 rot/min (60 test pieces per species)
2. u=20 m/min v= 8000 rot/min (30 test pieces per species)
3. u=1 m/min v= 12000 rot/min (30 test pieces per species)

A total of 600 test pieces were machined. A digital calliper of 0.01 mm precision was used for the measurement of worked dimensions. All work pieces were measured at three locations: front end, middle and rear end. This way 3 thickness data and 3 width data were obtained for each test piece.

Evaluation of the measurements of capability study

Evaluation of the experimental data was performed by using the software package STATISTICA© release 8. As a first step we wanted to decide if the data in the individual samples are normally distributed. For this purpose we visualised the data by histograms and probability plots. We established as below:

- In the majority of samples the assumption of normal distribution is acceptable.
- From a total of 180 runs in 35 cases the normality of the distribution could not be verified.
- In such cases we either found outliers attributable to assignable causes or a mix of two or more distributions could be supposed.

Significance test using t-test

Besides performing descriptive statistics of the measured data the individual samples were compared by t-test in order to find out if there exist significant differences in sample means. The level of significance of the Student test was set to $\alpha=0.05$ (confidence level of 0.95). The STATISTICA software calculates the probability p of the test statistics' taking the current value at random. It means that in cases of $p<0.05$ the difference of means is significant at the $\alpha=0.05$ level. T-tests were performed for testing differences of means for the cases as follows:

1. measurements taken at different locations, i.e. the front end, middle and rear end of test pieces;
2. measurements of pieces machined with different parameters within species;
3. measurements of the different species.

Comparison of the measurements taken at different locations

1. From a total of 180 two-sample t-test differences were found significant 18 cases. It can be assumed that these differences are not the result of some systematic source of error. That is why we decided to apply filtering of data to find end exclude elements causing significant differences.
2. Differences within a species. 12 two-sample t-tests conducted by species revealed significant differences in 6 cases for oak, 3 cases for poplar, 2 cases for beech and 6 cases for black locust. These results support the finding that in the majority of the machining runs the changing of machining parameters has no significant effect on the central tendency and variability of the worked dimensions.
3. Differences between species. The majority of the 30 possible two-sample t-tests (i.e. 15 tests for thickness and 15 tests for width), namely 21 cases resulted in the indication of significant differences. An interpretation of this result is, that the same depth of cut applied for species of wood of different texture result in different final dimensions. It was also shown by the results that these differences are even more pronounced in the case of width.

Conclusions of the tests of significance

- Our assumption relating to the influence of wood species on the precision of machining proved true. We could the effect of the species.
- The best stability of worked dimensions in the course of changing the machining parameters was found in the case of poplar.
- Black locust exhibited good stability in the course of machining parameter sets No. 2 and No. 3; however measurements at parameter set 1 turned out to be different.
- Oak and spruce behaved in a similar way, parameter set No 3 resulted in no difference.
- Beech was found the species for which none of the parameter sets used proved satisfactory. At the best one of the two dimensions checked (either width or thickness) remained stable in the course of the different machine settings.
- Means of the spruce test piece dimensions have not changes at all in over the range of machining parameter settings.
- Comparing the cross-section measurements of the different species it can be established that none of the machine settings applied in the experiments guarantee that no significant differences of the width or thickness of work-pieces occur.
- It is probable that due to the differences in texture of the individual species an optimal set of machining parameters suitable for all species can not be found.
- On the basis of more extended experimentation it would be possible to work out recommendations to choose suitable machining parameters (adjustment to size, speed of feed, cutting speed) for the different species in order to reach maximum effectiveness and precision of dimensions.

DETERMINATION OF THE CAPABILITY INDICES, RESULTS AND DISCUSSION

On the basis of the descriptive statistics of the measurements we considered separately all the width and thickness data obtained for a set of machining parameters as large samples of preliminary survey in the case of the individual species. Distribution fitting using Chi-square test was then performed in order to see if the assumption of normal distribution is acceptable.

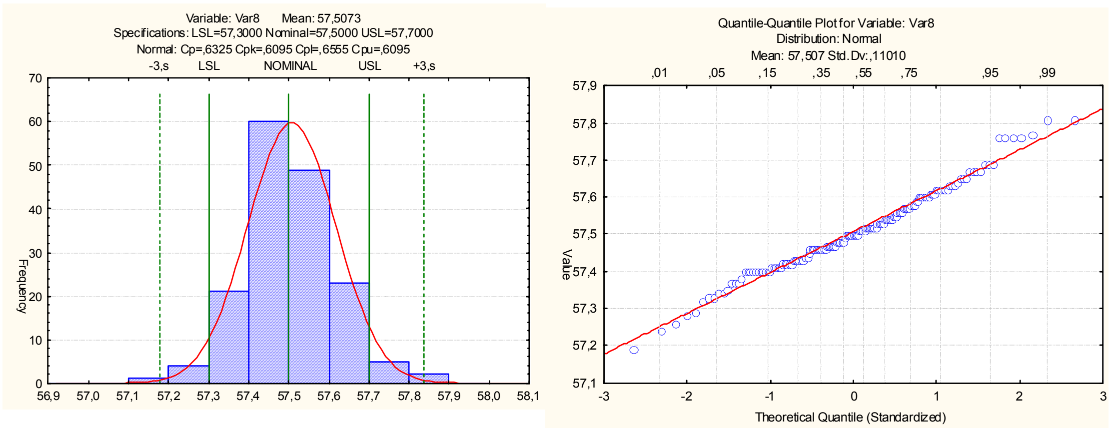

Figure 5: Normality test of spruce width data, parameter setting No 3.

In order to determine the process capability index the data within a large sample were divided into sub-samples of size 5 by taking all the elements in the order of machining. Sub-sample statistics (within-sample mean and within-sample range) were calculated and used to construct x-bar – range control chart.

In cases when the Chi-square test did not verify the assumption of normal distribution, filtering of the data was applied by inspecting the histogram and/or the control chart.

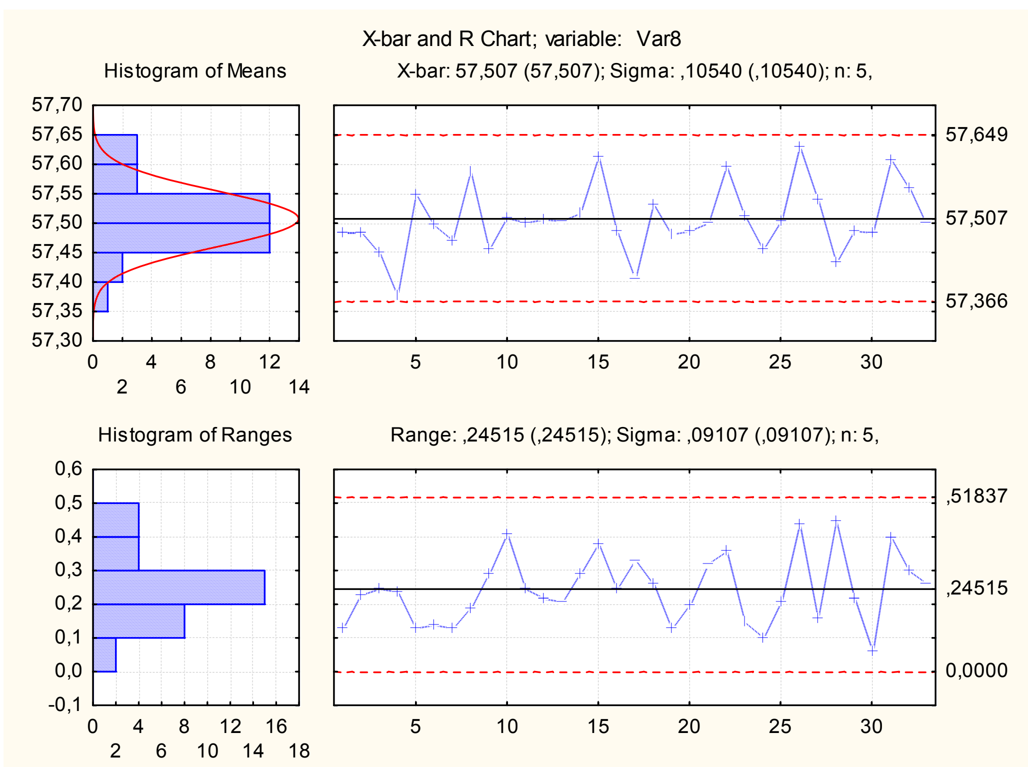

Figure 6: Control chart for spruce, width data, parameter setting No 3, after filtering

Capability indices were calculated on the basis of the date filtered as required to attain in-control state. Values of the capability indices were determined by using the software STATISTICA as below:

- Index CP potential capability calculated on the basis of the sub-samples of size 5. This index is the equivalent of process capability.
- Index PP potential performance calculated on the basis of the large sample. This index, when the sample taken within a short interval is equivalent of machine capability.

The aim with our examinations was to evaluate the potential capability of the machining processes that can be expected when the processes are in statistical control.
The capability indices obtained are shown in the table 1 below:

Table 1: Capability indices obtained in the case of different machining parameters for the species of wood investigated

Species	Machining parameters	width		thickness		all data		width/ thickness		CP/PP		**v20u12000** versus **v10u12000**			
												width		thickness	
		CP	PP	CP	PP	CP	PP	CP	PP	sz	v	CP	PP	CP	PP
Black locust	10/12000	1,08	1,07	1,80	1,96	1,43	1,31	1,67	1,83	1,01	0,92	0,95	0,93	1,08	0,91
	20/8000	0,90	0,84	1,48	0,86	1,11	0,92	1,64	1,02	1,07	1,72				
	20/12000	1,03	0,99	1,94	1,79			1,88	1,81	1,04	1,08				
Beech	10/12000	0,88	0,79	0,82	0,75	0,89	0,81	0,93	0,95	1,11	1,09	0,80	0,86	1,16	1,13
	20/8000	0,93	0,90	0,98	0,79	0,92	0,84	1,05	0,88	1,03	1,24				
	20/12000	0,70	0,68	0,95	0,85	0,70	0,64	1,36	1,25	1,03	1,12				
Spruce	10/12000	0,62	0,63	1,50	1,21	0,84	0,77	2,42	1,92	0,98	1,24	1,02	0,95	0,81	0,95
	20/8000	0,72	0,74	1,42	1,31	0,90	0,87	1,97	1,77	0,97	1,08				
	20/12000	0,63	0,60	1,21	1,15			1,92	1,92	1,05	1,05				
Poplar	10/12000	0,71	0,75	2,35	2,29	0,90	0,69	3,31	3,05	0,95	1,03	1,39	1,05	0,74	0,63
	20/8000	0,93	0,82	1,90	1,84	1,29	1,08	2,04	2,24	1,13	1,03				
	20/12000	0,99	0,79	1,75	1,45	1,38	0,99	1,77	1,84	1,25	1,21				
Oak	10/12000	1,12	1,08	1,73	1,81	1,33	1,28	1,54	1,68	1,04	0,96	1,74	0,87	0,84	0,81
	20/8000	0,76	0,72	1,53	1,38	1,00	0,89	2,01	1,92	1,06	1,11				
	20/12000	1,95	0,94	1,45	1,47	1,12	1,09	0,74	1,56	2,07	0,99				

As can be seen in the table machining parameter set No 1 (speed of feed 20 m/min, tool rotation speed 12 000 rot/min) resulted in several cases essentially identical, and in a few cases higher values of capability indices than the application of half as high speed of feed.
Working precision of thickness generally turned out to be better than that of width and this tendency has not disappeared nor became more expressed when doubling the speed of feed. The phenomenon may be explained by the fact that in the case of machining to thickness the work piece is supported by a rigid table of high inertia while it is only supported by a less fixed guide of small inertia against tools of vertical shaft. The analysis of our measurement allowed a quantitative description of this tendency.

FINAL CONCLUSIONS

In summary, with regard to the criteria of working precision it can be stated that the efficiency of profile machining on the multiple-shaft moulding machine is possible do double by increasing the speed of feed to twice as high value as commonly used, since the capability indices are not deteriorated.

REFERENCES

Boronkai, László szerk *FAIPARI KÉZIKÖNYV III.* (WOOD HANDBOOK III. IN HUNGARIAN) FAIPARI TUDOMÁNYOS ALAPÍTVÁNY SOPRON 2003

Kánitsch, Balázs *A FAFAJ BEFOLYÁSOLÓ HATÁSA A MEGMUNKÁLÁS PONTOSSÁGÁRA A TECHNOLÓGIAI MUTATÓK TÜKRÉBEN. (THE INFLUENCE OF SPECIES OF WOOD ON MACHINING PRECISION. DIPLOMA THESIS, IN HUNGARIAN)* NYME FMK SOPRON 2010

Koczor, Zoltán *BEVEZETÉS A MINŐSÉGÜGYBE. A MINŐSÉGÜGY GYAKORLATI KÉRDÉSEI. (INTRODUCTION INTO QUALITY MANAGEMENT. PRACTICAL PROBLEMS, IN HUNGARIAN)* MŰSZAKI KÖNYVKIADÓ – MAGYAR MINŐSÉGI TÁRSASÁG BUDAPEST 2000

Kovács, Zsolt: *8.2. A MEGMUNKÁLÁS MINŐSÉGÉNEK BIZTOSÍTÁSA STATISZTIKAI FOLYAMATSZABÁLYOZÁSSAL IN: FAIPARI KÉZIKÖNYV II. (ASSURANCE OF MACHINING QUALITY THROUGH STATISTICAL PROCESS CONTROL PP. 415-435. IN WOOD HANDBOOK II.EDIT DR. MOLNÁRNÉ POSCH PAULA, IN HUNGARIAN)* FAIPARI TUDOMÁNYOS ALAPÍTVÁNY SOPRON 2002

Kemény, Sándor - Papp László – Deák András: *STATISZTIKAI MINŐSÉG- (MEGFELELŐSÉG-) SZABÁLYOZÁS. (STATISTICAL QUALITY (CONFORMITY) CONTROL, IN HUNGARIAN)* MŰSZAKI KÖNYVKIADÓ – MAGYAR MINŐSÉGI TÁRSASÁG BUDAPEST

Molnár, S. Bariska, M. *MAGYARORSZÁG IPARI FÁI. (INDUSTRIAL WOODS IN HUNGARY, IN HUNGARIAN)* SZAKTUDÁS KIADÓ HÁZ, BUDAPEST 2002

Montgomery D. C.: *INTRODUCTION TO STATISTICAL QUALLITY CONTROL*. JOHN WILEY & SONS, INC. 1997

Sitkei, György szerk.*: A FAIPARI MŰVELETEK ELMÉLETE. (THEORY OF WOOD PROCESSING OPERATIONS, IN HUNGARIAN)* MEZŐGAZDASÁGI SZAKTUDÁS KIADÓ KFT. BUDAPEST. 1994

Smith G. *STATISTICAL PROCESS CONTROL AND QUALITY IMPROVEMENT* MACMILLAN PUBLISHING COMPANY NEW YORK 1991

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