Effects of Some Machining Parameters on Noise Level in Planing of Some Wood Materials

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Effects of type of wood, number of blades, and depth and width of cutting were evaluated relative to the noise level during the machining of wooden materials in a spindle moulder. Lombardy poplar, Oriental beech, and medium density fibreboard (MDF) materials, at the thickness levels of 6 mm, 12 mm, 18 mm, 25 mm, or 30 mm, were planed for 20 min for each variable at the feed rate of 5 meters per min and at the cutting depth of 1 mm, 2 mm, or 3 mm with one or four blades. During machining of the samples, the noise levels were measured using a noise level meter. According to the data obtained, the highest noise level connected to the type of materials was measured in the machining of poplar wood, followed by that of beech wood and MDF. As the thicknesses of the materials were increased, increases up to 9 dBA of the noise level were measured. Moreover, machining the materials with one blade instead of four and with a cutting width of 1 mm instead of 3 mm increased the noise level by 2 dBA and 6 dBA, respectively.

Keywords: Wood machining; Noise emission; Occupational health and safety; Oriental beech; Medium density fibreboard (MDF)

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INTRODUCTION

Noise can be defined as unpleasant or unwanted sound released into the environment. The noise rising from machining operations in a workplace of wood industry is affected by factors such as wood species; length, width, and thickness of the product's parts; feeding rate; cutting depth; sharpness of cutter; pressure tightness and homogeneity; cutter head design; dust collectors; vibration of machine components; and bearings of the machine. Exposure to high levels of noise rising from machining operations over long periods of time can cause temporary or permanent loss of hearing. High noise levels can also interfere with communications in the workshop, leading to an increased risk of accidents. Due to the adverse effects of noise on worker health, daily and weekly noise exposure limits were determined to be 85 dB and 87 dB, respectively, by the Occupational Health and Safety Administration (OSHA). Moreover, in the case of continuous working in noisy environments, working periods were also limited. While continuous working time is 16 hs in 80 dBA, it is 8 hs in 85 dBA, 15 min in 100 dBA, and 0.9 sec in 130 dBA.

In a company active in the production of wooden products in Nigeria, the noise levels of the machines used in the production were measured 15 times for 30 min within a 5-day period. According to the measurement results, the noise level of the circular saw was determined to be 117.5 dB (A); that of the chain saw, 114.1 dB (A); that of the band saw, 100.7 dB (A); that of the generator, 99.8 dB (A); that of the planer, 93.4 dB (A); and that of the tractor, 89.4 dBA (Anjorin *et al.* 2015). In this article the term "dBA" can be understood to mean "dB (A)".

Audiometric hearing tests of the 124 individuals, 88 of them in wood product manufacturing and 36 of them in timber manufacturing, in 26 companies in Nepal showed that the noise levels in different companies changed between 71.2 dBA and 93.9 dBA. In these companies, 31% of the wood products manufacturers and 44% of the timber manufacturers suffered from hearing loss due to noise levels exceeding the standard level of 85 dB (Robinson *et al.* 2015).

Ratnasingam *et al.* (2010) studied noise concentration exposure by the workers working in the machines of multi-borer, tenoner, mortiser, router, moulder, thicknesser and narrow band saw in the departments of rough and finish size cutting of 30 factories for each country in the Southeast Asian region comprising Malaysia, Thailand, Indonesia, and Vietnam. They stated that the noise concentration level changed between 40 dBA and 150 dBA according to the machine type, and the noise concentration levels were 130 dBA in the rough milling department and 67 dBA in the departments of machining and fastener montage. Furthermore, the noise concentration levels of five machines were above the standard noise concentration level (85 dBA). The results of the study by Ntalos and Papadopoulas (2005) were similar with that of Ratnasingam *et al.* (2010). According to their results, the noise levels changed between 78 dBA and 103 dBA, depending on the departments. Ratnasingam and Scholz (2007) and Ratnasingam and Scholz (2008) stated that the noise level was increased in the rough milling section because of the machining of timber and larger-sized components, therefore using more powerful engines and breaking more chips from a larger surface. The noise level was lower in the machining section since smaller engines were used, smaller dimension components were machined, and less chips were broken off.

Ratnasingam and Ioras (2010) made audiometric tests for the workers exposed to noise concentration in the Malaysian furniture industry. According to the results expressed in the Noise-Induced Permanent Threshold Shift (NIPTS), 25.8% of the workers had a slight handicap with the NIPTS between 30 and 40 dB, and 8.9% of the workers had a significant handicap with the NIPTS greater than 40 dB. The percentage of workers having no hearing handicap was 65.3%. Moreover, they analysed the personal dosimeter results and stated that 43% of the workers involved were exposed to a dose of 90 dBA/8 h, higher than the permissible one. This result was quite similar to the reports by Fairfax (1996) and Kokkola and Sorainen (2000). The workers in the rough milling sections of the wooden furniture factories were exposed to noise levels higher than the permissible one, compared to their counterparts in the machining sections.

According to the hearing test conducted by McBride (2010) on a total of 213 workers, 133 within wood processing (with a mean age of 41 years and length of service (LOS) of 9 years) and 80 within sawmilling (with a mean age of 37 years and LOS of 7.5 years), the increase in age, LOS, and frequency raised the hearing level (hence the hearing loss) up to 50 dBA. The hearing level showed a rapid increase after 1 kHz of frequency level and rose up to 50 dBA at 4 kHz of frequency in the oldest age group. The hearing level also changed depending on the LOS. Hearing levels at 250 Hz were 2 dBA for LOS of less than 1 year, 3 dBA for LOS of 1 year to 2 years, 5 dBA for LOS of 3 years to 4 years, and 8 dB for LOS of 1 year to 2 years. At the frequency of 4 kHz, the hearing levels were 5 dBA, 14 dBA, 18 dBA, and 30 dBA, respectively.

Gross and Heisel (2016) stated that the feed rate and the depth of cut between 0.5 mm and 2 mm had no significant influence on the noise emission of the thickness planer machine during the idle or operation modes. Furthermore, the cutting speed was varied within a large range and proved to be the main influencing parameter on the noise emission of the examined machines. Kvietková *et al.* (2015) stated that the number of circular saw blade teeth in the cutting process was effective on the noise level emitted and that the noise level decreased as the number of teeth was increased. According to the results of the study of Pinheiro *et al.* (2015), a reduction was observed in the noise emission with the increase in the moisture content during machining of *Pinus elliottii*. The levels of vibration speed of the motor body at low frequencies (up to 250 Hz) were 8 to 15 dB lower than that of body headstock of the woodworking machines. However directly in medium and high frequency part of the spectrum 500 to 8000 Hz levels of vibration speed of the motor body were practically the same with the body headstock (Chukarin et al. 2017). The objective of this study was to determine the effects of type and thickness of material, blade number, and cutting depth on the noise level in the machining of some wooden materials in the spindle moulder. The results obtained elucidate the mean noise level exposure by workers, maximum time to work in this noise level, acoustic comfort of working environments, and necessary measures to improve the efficiency of the workers.

EXPERIMENTAL

Materials

Lombardy poplar (Populus nigra L.) and Oriental beech (Fagus orientalis Lipsky)

Lombardy poplar and Oriental beech were supplied from the Siteler district in Ankara/Turkey. The Lombardy poplar wood had the following dimensions: 50 mm thickness, 300 mm width, and 3000 mm length. The Oriental beech wood had the following dimensions: 100 mm thickness, different width, and 5000 mm length. Importance was placed on selecting lumber that was first grade in quality and undamaged, and was naturally colored. Selected lumber had annual rings that were regular and parallel to each other, did not include defects, and had not been subjected to attack from insects and fungi. The kiln-dry densities of Lombardy poplar and Oriental beech were 0.42 g/cm^3 and 0.60 g/cm^3, respectively.

Medium density fiberboard (MDF)

The MDF boards had the sizes of 210 x 280 cm and thicknesses of 6 mm, 12 mm, 18 mm, 25 mm, and 30 mm, and the densities were 0.81 g/ cm^3, 0.74 g/cm^3, 0.70 g/cm^3, 0.72 g/cm^3 and 0.71 g/cm^3, respectively.

Noise level meter

The Extech HD 600 was used to measure the noise level to which the worker was exposed during the machining of different wood materials in the spindle moulder. With this instrument, the noise level could be measured with the sensitivity of 0.001 dBA and recorded as once per s or min, and the results could be transferred to a computer for statistical analysis. Other specifications of the noise level meter are as follows: 30 to 130 dB range with 1.4 dB accuracy, meets ANSI and IEC61672-1 Type 2 standards, data logging capability up to 20,000 records at an interval rate of 1 to 59 sec.

Spindle moulder (shaper)

The NETMAK FR 2000 SA type spindle moulder (NET MAK Machine Industry and Trade Limited Company, Ankara, Turkey) was used in planing with various cutting depths of the specimens from different wood materials. The diameter and length of the cutterhead (Fig. 1a) are 85mm and 60 mm, respectively. The shaft diameter (inner diameter of the cutterhead) of the machine was 30 mm, the engine power was 4 kW/5.5 Hp, and the speed was 6000 rpm.

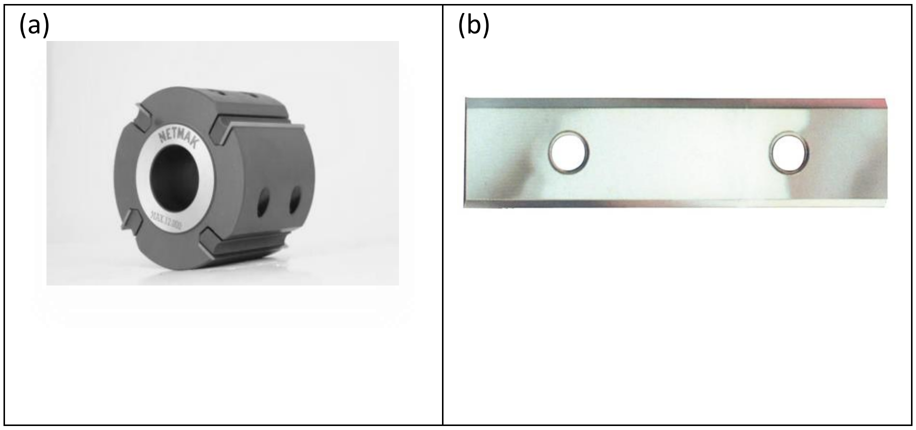

Fig. 1. Cutterhead (a) and blade (b)

Preparation of the test specimens

Narrower pieces measuring 105 cm x 30 cm were cut from the MDF plates with the size of 210 x 280 cm and the thicknesses of 6 mm, 12 mm, 18 mm, 25 mm, and 30 mm to make easy machining in the spindle moulder. First, the lumber of Lombardy poplar and Oriental beech were converted into shorter specimen's stocks by cross cutting. Then, preliminary specimens with a tolerance of +8 mm in thickness and width were sawn from the stocks. Since the planing operations in the spindle moulder would be made in the air-dry moisture content, the preliminary specimens were conditioned in a closed and heated environment with an average temperature of 20 °C. After conditioning, test specimens of a sufficient number of each thickness group (6 mm to 30 mm), with 1-m length and 9-cm width, were prepared.

Method (Measuring of the Noise Level)

Measurements were carried out in a workshop with the dimensions of 11 m x 33 m x 6.4 m (width x length x height). In the workshop, other than the spindle moulder, there were 18 machines used in furniture making such as band saw, circular saw, cut-off saw, edge banding, router, CNC router. The spindle moulder was in front of the long wall, and the distance from the machine axis to the one of side wall was 11.8 m.

One or four blades (Figure 1b) were mounted into the cutterhead (Fig. 1a) of the spindle moulder, and the cutting depth was adjusted to 1 mm, 2 mm, or 3 mm by considering the variable's requirement. To measure the noise level generated during the machining of the specimens, the noise level instrument was positioned to the side of spindle moulder so that the height of the noise sensor did not exceed the ear level of the worker by more than 30 cm. After these preparations, the noise level was measured for each set of variables in the factorial design (3 material type x 5 cutting width (thickness of specimen) x

2 blade number x 3 cutting depth = 90) by machining specimens in the spindle moulder for 20 min. The cutting speed was 26.7 m/s and the feeding rate of the specimens in planing is 5 m/min. The noise levels were automatically recorded by the instrument as once per min during 20 minutes. Thus, with 20 measurements (replications) for each variable, a total of 1800 measurements were recorded.

Noise level measurements were performed on five consecutive days between the hours of 07:30 and 21:00. The spindle moulder was the only machine operating in the workshop during the measurements. The average relative humidity of the air was 32% and the average temperature was 28 °C. At the 28 °C temperature and 32 % relative humidity of the air, the corresponding equilibrium moisture content of the wood materials was 6.6 %.

RESULTS AND DISCUSSION

The noise levels for the spindle moulder are given in Table 1. Results are provided for the various materials' kind, cutting width, blade number, and cutting depth.

Multiple analyses of variance (MANOVA) were used to determine whether or not the kind of material, cutting width, blade number, and cutting depth had a single or group effect on the noise level, according to the data given in Table 1. In case of presence of the effect after variance analyses, Duncan's Multiple Range Test was preferred to compare average noise level values by the order of magnitude. The SPSS-15 Statistical Package for the Social Sciences (IBM Corporation, New York, USA) was used to analyse the data.

The interactions of (material's type x blade number), (cutting width x blade number), (cutting width x cutting depth), (material's type x cutting width x blade number), (cutting width x blade number x cutting depth), and (material type x cutting width x blade number x cutting depth) were not effective because probability values were bigger than 0.05. Other single or group interactions were effective on the noise level emitted by the spindle moulder.

Homogeneity tests (Duncan's Multiple Range Test) were conducted to determine whether or not the differences among the values of noise levels of the effective variables were significant. Some important results are given below.

Table 1. Statistical Results for Noise Levels

Cutting Width (thickness of specimen) (mm)	Blade No.	Cutting Depth (mm)	X_{min}(dBA)			X_{max}(dBA)			X_{mean}(dBA)		
			Poplar	Beech	MDF	Poplar	Beech	MDF	Poplar	Beech	MDF
6	1	1	81.00	76.90	75.70	88.00	88.10	84.30	83.06	80.07	78.62
		2	77.80	77.20	79.00	92.80	90.90	86.40	85.26	84.23	83.75
		3	84.60	84.10	83.90	89.40	89.20	88.50	86.87	86.70	85.85
	4	1	79.20	78.40	77.30	84.02	82.27	79.60	82.75	79.74	78.14
		2	80.00	76.90	77.20	88.90	87.40	88.00	84.01	82.90	82.24
		3	82.60	77.10	82.53	89.40	92.90	88.50	84.94	84.59	84.39
12	1	1	79.80	77.30	78.30	87.80	87.40	89.00	84.56	81.43	83.49
		2	78.00	77.90	78.40	93.70	93.40	89.59	87.81	87.90	84.89
		3	87.20	86.60	86.10	93.60	97.50	89.80	90.86	91.12	88.05
	4	1	78.40	77.40	76.90	86.60	84.10	84.70	82.98	80.76	81.32
		2	78.80	78.70	78.40	89.00	97.00	90.30	85.83	86.61	83.15
		3	77.10	77.20	84.18	94.50	98.70	89.30	89.46	87.60	86.51
18	1	1	81.00	76.70	77.80	90.90	94.30	93.70	86.20	82.86	84.20
		2	87.12	87.40	82.30	91.80	93.10	89.30	88.29	89.16	86.94
		3	84.60	91.67	81.20	96.40	93.95	99.30	91.19	92.71	89.99
	4	1	82.23	77.70	77.80	92.50	85.50	87.00	84.66	81.92	83.50
		2	76.90	88.60	77.60	89.26	90.00	89.60	86.93	89.05	85.75
		3	77.30	88.60	83.70	97.10	90.40	90.50	89.94	89.52	88.48
25	1	1	84.84	79.50	79.00	91.30	100.70	99.30	87.13	86.63	86.23
		2	83.30	88.21	81.50	96.80	96.40	95.40	91.87	91.22	88.22
		3	82.00	90.29	90.23	96.10	103.40	100.50	93.91	94.56	92.86
	4	1	79.20	78.80	80.30	89.60	87.99	90.70	85.99	85.46	85.54
		2	77.30	76.90	79.10	93.70	98.40	95.20	89.16	90.52	87.46
		3	84.20	78.00	87.40	95.00	94.75	95.70	91.35	91.22	90.27
30	1	1	79.80	79.60	84.64	96.80	101.20	96.80	89.50	88.82	89.86
		2	91.93	84.30	83.70	98.90	94.70	99.70	94.59	92.19	91.31
		3	92.94	90.50	90.16	100.70	98.10	105.40	96.33	95.11	93.71
	4	1	78.00	81.20	77.70	93.50	92.90	94.50	86.75	87.94	87.57
		2	87.40	90.22	86.59	95.20	96.00	94.80	92.60	91.56	89.97
		3	78.80	86.40	78.20	101.10	95.43	102.10	94.54	93.54	91.88

Effects of Type of Material, Cutting Width, Blade Number, and Cutting Depth on Noise level

The highest noise level (91.5 dBA) depending on the cutting width was obtained in machining of materials at the cutting width of 30 mm, followed by that of 25 mm, 18 mm, 12 mm, and then 6 mm (89.4 dBA, 87.3 dBA, 85.8 dBA, and 83.2 dBA, respectively) (Fig. 2a). When considering these results, it can be seen that the noise level increased as the cutting width is increased. Depending on the material's kind, the highest noise level (88.31dBA) was with poplar, followed by beech, and then MDF (87.6 dBA and 86.5 dBA, respectively) (Fig.2b). The noise level increased as the cutting width was increased.

The noise level in machining of materials with one blade (88.2 dBA) was higher than that of four blades (86.7 dBA) (Fig. 2c). The noise level increased as the cutting depth was increased. While noise level was 90.3 dBA in machining with cutting depth of 3 mm, this value was 87.85dBA for 2 mm and 84.3 dBA for 1 mm (Fig. 2d).

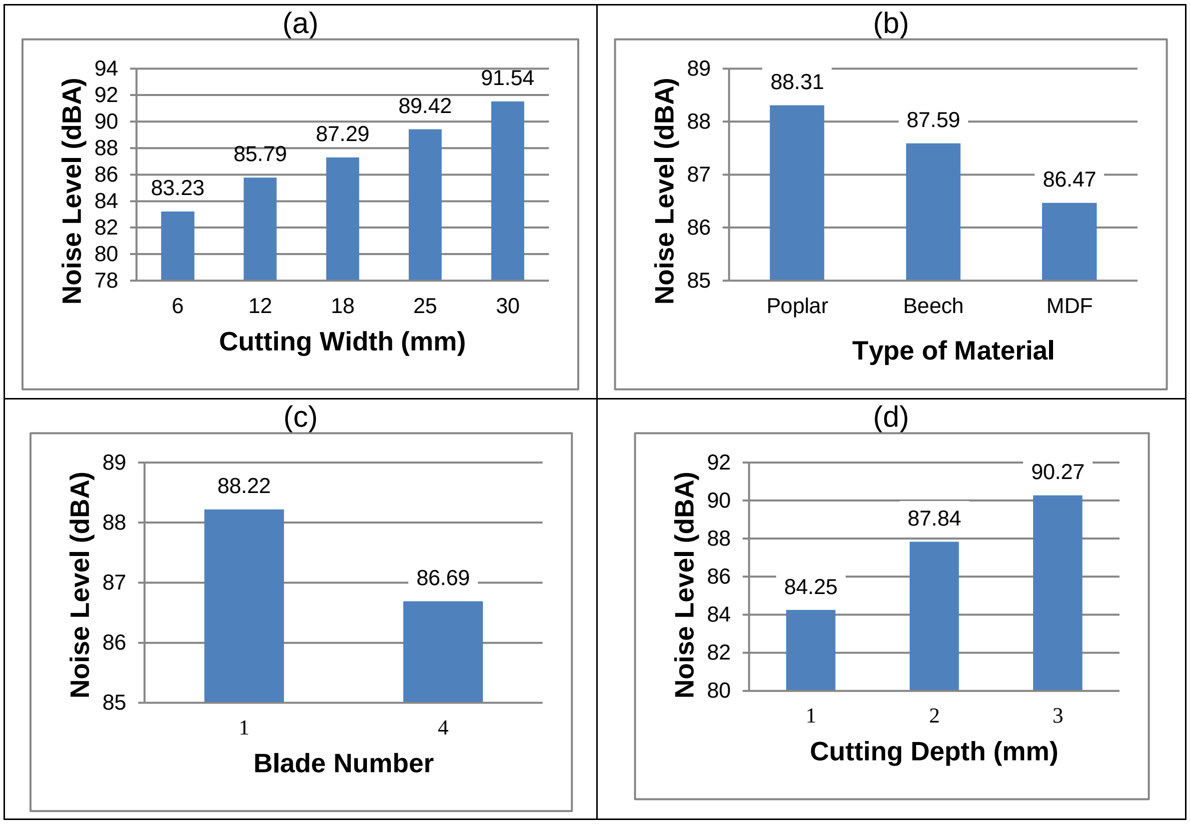

Fig. 2. Noise levels depending on the cutting width, type of material, blade number, and cutting depth

Effects of the Cutting Width, Blade Number, and Cutting Depth on Noise Level in Machining of Poplar Wood

Multiple analyses of variance according to the data given in Table 1 for poplar wood were made to determine whether or not the cutting width, blade number, and cutting depth had a single or group effect on the noise level.

Out of the interactions of (cutting width x blade number) and (blade number x cutting depth), all single or group interactions were found to be effective on the noise level emitted by the spindle moulder. Homogeneity tests were conducted to determine whether or not the differences among the values of noise levels of the effective variables were significant. In machining of poplar wood, the triple interaction of cutting width, blade number, and cutting depth is given in Table 2.

Table 2. Homogeneity Test Connected to the Triple Interaction of Cutting Width, Blade Number, and Cutting Depth

Cutting width (mm)	Blade number	Cutting depth (mm)					
		1		2		3	
		NL(dBA)	HG	NL (dBA)	HG	NL (dBA)	HG
6	1	83.06	OP	85.26	LMN	86.87	İJKL
	4	82.75	P	84.01	NOP	84.94	MN
12	1	84.56	MNO	87.81	IİJ	90.86	EFG
	4	82.98	OP	85.83	KLM	89.46	GH
18	1	86.20	JKLM	88.29	HIİ	91.19	DEF
	4	84.66	MNO	86.93	İJKL	89.94	FGH
25	1	87.13	İJK	91.87	DE	93.91	BC
	4	85.99	KLM	89.16	HI	91.35	DEF
30	1	89.50	GH	94.60	B	96.33	A
	4	86.75	İJKL	92.60	CD	94.54	B

Notes: LSD (Least Significant Difference) ± 0,295 dBA; NL: Noise Level, HG: Homogeneity Group (The letters in Column HG indicate rank of the interactive values of the variables after Multiple Range Test)

According to Table 2, the highest noise level (96.33dBA), by including all of the variables, was obtained in machining of poplar wood with one blade in 30 mm cutting width and 3 mm cutting depth, followed by machining operations with four blades in 30 mm cutting width and 3 mm cutting depth and with one blade in 30 mm cutting width and 2 mm cutting depth (94.54 dBA and 94.60 dBA, respectively), as the difference between them was not statistically important. The lowest noise level was seen in the operation with four blades in the 6 mm cutting width and 1 mm cutting depth.

It was determined from other homogeneity tests for poplar wood that the noise level increased as the cutting width was increased (from 84.5 dBA at 6 mm cutting width to 92.4 dBA at 30 mm cutting width), higher noise level was seen in machining with one blade compared to four blades (87.5 dBA and 89.2 dBA), and the noise level increased as the cutting depth was increased (85.4 dBA, 88.6 dBA, and 90.9 dBA for the cutting depths of 1 mm, 2 mm, and 3 mm, respectively).

Effects of the Cutting Width, Blade Number, and Cutting Depth on Noise Level in Machining of Beech Wood

Excluding the interaction of (cutting width x blade number), all single or group interactions were found to be effective on the noise level emitted by the spindle moulder in multiple analyses of variance according to the data given in Table 1 for beech wood. Homogeneity tests were conducted to determine whether or not the differences among the values of noise levels of the effective variables were significant. In machining of beech wood, triple interaction of cutting width, blade number, and cutting depth is given in Table 3.

Table 3. Homogeneity Test Connected to the Triple Interaction of Cutting Width, Blade Number, and Cutting Depth

Cutting Width (mm)	Blade Number	Cutting Depth (mm)					
		1		2		3	
		NL (dBA)	HG	NL (dBA)	HG	NL(dBA)	HG
6	1	80.07	M	84.23	İJ	86.70	HI
	4	79.74	M	82.90	JK	84.59	İJ
12	1	81.43	KLM	87.90	GH	91.12	CDE
	4	80.76	LM	86.61	HI	87.60	GH
18	1	82.86	JK	89.16	FG	92.71	BC
	4	81.92	KL	89.05	FG	89.52	EFG
25	1	86.63	HI	91.22	CDE	94.56	A
	4	85.46	Iİ	90.52	DEF	91.22	CDE
30	1	88.82	FG	92.19	BCD	95.11	A
	4	87.94	GH	91.56	CD	93.54	AB

Notes: Least Significant Difference (LSD) ± 0,289 dBA; NL: Noise Level, HG: Homogeneity Group

According to Table 3, the highest noise level (95.1 and 94.6 dBA) by including all of the variables appeared in the machining of beech wood, with one blade in the cutting widths of 30 mm and 25 mm and a cutting depth of 3 mm. The difference between them was insignificant. This operation was followed by the machining operations with four blades in a 30-mm cutting width and 3-mm cutting depth (93.5 dBA) and with one blade in a 18-mm cutting width and 3-mm cutting depth (92.7 dBA). The lowest noise level (79.7 dBA) was seen in the operation with four blades in the 6-mm cutting width and 1-mm cutting depth.

Other homogeneity tests for beech wood showed that the noise level increased as the cutting width was increased (from 83.0 dBA dBA at a 6-mm cutting width to 91.5 dBA at a 30-mm cutting width), a higher noise level was seen in machining with one blade compared to four blades (86.9 and 88.3 dBA), and the noise level increased as the cutting depth was increased (83.57 dBA, 88.54 dBA and 90.67 dBA for the cutting depths of 1 mm, 2 mm, and 3 mm, respectively).

Effects of the Cutting Width, Blade Number, and Cutting Depth on Noise Level in Machining of MDF

In multiple analyses of variance according to the data given in Table 1 for MDF, out of the interactions of cutting width x blade number and blade number x cutting depth, all single or group interactions were found to be effective relative to the noise level emitted by the spindle moulder. Homogeneity tests were conducted to determine whether or not the differences among the values of noise levels of the effective variables were significant. In the machining of MDF, the triple interaction of cutting width, blade number, and cutting depth is given in Table 4.

Table 4. Homogeneity Test Connected to the Triple Interaction of Cutting Width, Blade Number, and Cutting Depth

Cutting Width (mm)	Blade Number	Cutting Depth (mm)					
		1		2		3	
		NL (dBA)	HG	NL (dBA)	HG	NL (dBA)	HG
6 mm	1	78.62	P	83.75	LMN	85.85	IİJ
	4	78.14	P	82.24	NO	84.39	JKLM
12 mm	1	83.49	LMN	84.89	İJKL	88.05	FG
	4	81.32	O	83.15	MN	86.51	GHIİ
18 mm	1	84.20	KLM	86.94	FGHI	89.99	DE
	4	83.50	LMN	85.75	IİJK	88.48	EF
25 mm	1	86.23	HIİ	88.22	F	92.86	AB
	4	85.54	IİJK	87.46	FGH	90.27	D
30 mm	1	89.86	DE	91.31	CD	93.71	A
	4	87.57	FGH	89.97	DE	91.88	BC

Notes: Least Significant Difference (LSD) ± 0,313 dBA; NL: Noise Level, HG: Homogeneity Group

The highest noise level by taking into account all of the variables was 93.7 dBA in the machining of MDF with one blade in the cutting widths of 30 mm and cutting depth of 3 mm, and the difference between them was insignificant. This was followed by the machining operations with one blade in 25 mm cutting width and 3 mm cutting depth (92.8 dBA) and with four blades in 30 mm cutting width and 3 mm cutting depth (91.9 dBA). The lowest noise levels (78.1 and 78.6 dBA) were seen in the operations with one and four blades in the 6-mm cutting width and 1-mm cutting depth and the difference between them was insignificant.

It was determined from other homogeneity tests for the MDF that the noise level increased as the cutting width increased (from 82.16 dBA at 6 mm cutting width to 90.72 dBA at 30 mm cutting width), a higher noise level was seen in machining with one blade compared to four blades (85.75 and 87.20 dBA), and the noise level increased as the cutting depth was increased (83.85 dBA, 86.37 dBA and 89.20 dBA for the cutting depths of 1 mm, 2 mm, and 3 mm, respectively).

The following generalizations could be made when the results were considered as a whole. Increasing the cutting width and cutting depth and decreasing the blade number caused a rise in the noise level. It was thought that this rise stemmed from an increment in the cell cavities and cell wall components that were contacted by the blade at the moment of cutting by increasing the cutting width and cutting depth at the constant feeding rate. Furthermore, when the blade number is stepped down at the conditions of the constant feeding rate and revolutions per min, the cutting path in the period of pitching into and leaving material of the blade is extended, and hence the level of breakout force besides cutting effect increases. The attachment of the blades to the cutterhead at 4 points may have provided some damping of the vibration by providing a more stable rotation of the spindle. The increase in the noise level by stepping down the number of blades may be caused by these effects.

The highest noise level depending on the density was obtained at the density of 0.42 g/cm^3 (poplar wood), followed by that of 0.60 g/cm^3 (beech wood) and then 0.75 g/cm^3 (MDF). The noise level increased as the density was decreased. Decreasing the density causes a reduction in the elements of the cell wall or amount of substance and an increment in the cavities. In this case, the amount of substance responding to the cutting force decreases and more breaking and crushing effect reveal. Furthermore, as the amount of substance or density increases, the vibration also decreases. These effects could be reasons of the density- dependent decrease in the noise level.

The Occupational Health and Safety Administration (OSHA) has recommended that all worker exposures to noise should be controlled below a level equivalent to 85 dBA for eight hours to minimize occupational noise induced hearing loss. According to the results of the study, the noise levels during machining of selected wood materials ranged from 78 dB to 96 dB. Increasing the cutting width and cutting depth and decreasing the blade number caused the permissible noise exposure level to be exceeded. Loud noise can create physical and psychological stress, reduce productivity, interfere with communication and concentration, and contribute to workplace accidents and injuries by making it difficult to hear warning signals. In order to avoid the aforementioned negativities, measures should be taken to reduce noise and to prevent harmful effects to worker health.

CONCLUSIONS

1. The highest noise level (91.5 dBA) depending on the cutting width was obtained in machining of materials at the cutting width of 30 mm, followed by that of 25 mm, 18 mm, 12 mm, and then 6 mm (89.4 dBA, 87.3 dBA, 85.8 dBA, and 83.2 dBA, respectively). The noise level increased as the cutting width increased.
2. Depending on the kind of material, the highest noise level (88.31 dBA) was that of poplar, followed by beech, and then MDF (87.6 dBA and 86.5 dBA, respectively).
3. The highest noise level (96.3 dBA) by including all of the variables was obtained in machining of poplar wood, with one blade in a 30-mm cutting width and 3-mm cutting depth. The lowest noise level was seen in the operation with four blades with the 6-mm cutting width and 1-mm cutting depth.
4. The highest noise level (95.1 dBA and 94.6 dBA) by including all of the variables appeared in the machining of beech wood with one blade with the cutting widths of 30 mm and 25 mm and the cutting depth of 3 mm. The difference between them was insignificant. The lowest noise level (79.7 dBA) was seen in the operation with four blades with a 6-mm cutting width and 1-mm cutting depth.

5. The highest noise level by taking into account all of the variables was 93.71 dBA in the machining of MDF with one blade with the cutting widths of 30 mm and cutting depth of 3 mm. The lowest noise levels (78.1 and 78.6 dBA) resulted in operations with one and four blades with the 6-mm cutting width and 1-mm cutting depth.

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REFERENCES CITED

Anjorin, S. A., Jemiluyi, A. O., and Akintayo T. C. (2015). “Evaluation of industrial noise: A case study of two Nigerian ındustries,” *European Journal of Engineering and Technology* 3(6),1-16. DOI: 10.1179/2049396714Y.0000000084

Chukarin, A. N., Buligin, Y. I., Alexeenko, L. N., and Romanov, V. A. (2017). “Integrated development of noise-dust woodworking machines at the design stage,” IOP Conf. Ser.: Earth Environ. Sci., Vol. 50, 012014. DOI:10.1088/1755-1315/50/1/012014

Fairfax, R. (1996). “Solvent and noise exposure at a wood furniture manufacturing facility,” *Applied Occupational and Environmental Hygiene* 11, 1045-1057. DOI: 10.1234/12437866

Gross, L., and Heisel, U. (2016). “Parameters influencing the noise emission of planing machines,” *Journal of Environmental Science and Engineering A* 5, 102-108. DOI: 10.17265/2162-5298/2016.02.007

Kokkola, H., and Sorainen, E. (2000). “Optimal noise control in a carpentry plant,” *Applied Acoustics* 61, 37-43. DOI: 10.1016/S0003-682X(99)00069-9

Kvietková, M. S., Gaff, M., Gašparík, M., Kminiak, R., and Kriš, A. (2015). “Effect of number of saw blade teeth on noise level and wear of blade edges during cutting of wood,” *BioResources* 10(1), 1657-1666. DOI:10.15376/biores.10.1.1657-1666

McBride, D. (2010). *Noise Control in the Wood Processing Industry*, (http://hdl.handle.net/10523/2259).

Ntalos, G. A., and Papadopoulas, A. N. (2005). “Noise emission levels in greek wood and furniture processing ındustry,” *Journal of the Institute of Wood Science* 175(98), 99-103. DOI: 10.1179/wsc.2005.17.2.99

Pinheiro, C., Alves, M. C. S., and Amaral, S. S. (2015). "Moisture content and its ınfluence on the roughness and noise emission during wood machining," *Advanced Materials Research* 1088, 680-685. DOI: 10.4028/www.scientific.net/AMR.1088

Ratnasingam, J., and Ioras, F. (2010). “The safety and health of workers in the Malaysian wooden furniture ındustry: An assessment of noise and chemical solvents exposure,” *Journal of Applied Sciences* 10(7), 590-594. DOI: 10.3923/jas.2010.590.594

Ratnasingam, J., and Scholz F. (2007). “Characterizing surface defects in machine-planing of rubberwood (*Hevea brasiliensis*),” *European Journal of Wood and Wood Products* 65, 325-327. DOI: 10.1007/s00107-006-0163-3

Ratnasingam, J., and Scholz, F. (2008). *Noise Level Evaluation in the Malaysian Wood Working Industry* (Report No.10/08), International Furniture Research Group (IFRG), USA.

Ratnasingam, J., Natthondan, V., Ioras, F., and McNulty, T. (2010). "Dust, noise and chemical solvents exposure of workers in the wooden furniture industry in South East Asia," *Journal of Applied Sciences* 10, 1413-1420. DOI: 10.3923/jas.2010.1413.1420

Robinson, T., Whittaker J., Acharya A., Singh D., and Smith M. (2015). "Prevalence of noise-induced hearing loss among woodworkers in Nepal: A pilot study," *International Journal of Occupational and Environmental Health* 21(1), 14-22. DOI: 10.1179/2049396714Y.0000000084

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