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INFLUENCE OF MATERIAL MOISTURE CONTENT ON NOISE AND VIBRATION EMISSIONS IN WOODWORKING POWER TOOLS

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Abstract: *Noise and vibration generated by woodworking power tools constitute significant occupational hazards in small- and medium-scale workshops. This study quantified the influence of wood moisture content on noise and vibration emissions during machining under controlled conditions. Representative softwood and hardwood species were processed using common woodworking machines under nominal low- and high-moisture conditions (approximately 20 and 80% MC), verified by oven-dry measurements. At 20% moisture, production noise reached 110.1-113.9 dBA for table saw operations and 101.6-109.7 dBA for band sawing and surface planning, while corresponding values at 80% moisture decreased by approximately 4-11 dBA. Machine-level vibration magnitudes ranged from 2.1-3.0 m/s² at 20% moisture and reduced to 0.7-1.0 m/s² at 80% moisture, with operator-position vibration decreasing from 0.6-1.1 m/s² to 0.1-0.3 m/s². One-way ANOVA confirmed that moisture content significantly affected both noise and vibration emissions ($p < 0.05$). The regression analysis further demonstrated a bounded linear approximation of the directional change in emission magnitude between the two moisture states (20 and 80%), representing a simplified expression of the rate of change within the experimental range. Despite these reductions, exposure levels frequently exceeded occupational thresholds, indicating that moisture control should complement integrated mitigation strategies rather than serve as a standalone solution.*

Key words: *wood moisture content, noise emission, vibration exposure, woodworking power tools, occupational health.*

1. Introduction

Woodworking remains a fundamental industrial activity supporting construction, furniture manufacturing, and small-scale production. Across both developed and

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developing economies, small- and medium-scale workshops continue to rely on conventional machining processes for material conversion. In modern practice, productivity in workshops relies heavily on power-driven tools such as circular saws, planers, and routers. These machines enable high material throughput but simultaneously intensify occupational exposure to noise and mechanical vibration, which are primary hazards in woodworking environments [14, 16].

Noise and vibration emissions arise from a complex interplay between the machine, the cutting tool, and the workpiece. While rotational speed and tool geometry are established factors, the tool-material interaction is a decisive driver of acoustic and vibrational response [14]. Variations in cutting resistance and energy dissipation at the tool-workpiece interface govern the magnitude of emitted energy. Fluctuations in resistance can induce self-excited vibrations, while alternating phases of adhesion and sliding contribute to dynamic instabilities during the machining process [18]. Consequently, the overall machine response is strongly influenced by the physical properties of the processed material [12].

These interactions are particularly complex because wood is a heterogeneous, anisotropic, and hygroscopic material. It continuously adjusts its moisture content (*MC*) in response to environmental conditions, which fundamentally alters its mechanical behaviour. *MC* levels significantly influence density, stiffness, and internal damping, all of which dictate machinability [7]. Increased *MC* generally reduces stiffness and strength due to the disruption of hydrogen bonding within the cell wall structure, while simultaneously increasing material damping and altering energy dissipation during the cutting stroke [2].

Empirical evidence suggests that *MC* is a critical determinant of emission levels. Moist wood typically exhibits lower cutting resistance as the fibres become more compliant, leading to reduced brittle fracture. In contrast, drier wood tends to produce higher resistance, increased tool wear, and elevated acoustic radiation [2, 5]. Recent studies have documented that increasing moisture content can reduce vibration amplitudes and sound radiation quality factors by up to 15% [8, 13].

Despite these findings, most existing research has focused on machine parameters and tool wear, often treating material moisture as a controlled background variable. This represents a critical gap, as practical woodworking environments face substantial moisture variability due to storage practices and seasonal humidity [17, 19]. Such variability can lead to inconsistent emission profiles even under nominally constant machining parameters. Furthermore, noise emissions measured under real operating conditions frequently differ from manufacturer-declared values by as much as 19 dB(A), emphasising the need for process-specific assessment [3].

The investigation of moisture-dependent emissions is therefore essential for improving both machining performance and occupational safety. Accordingly, this study investigates the influence of material moisture content on noise and vibration emissions generated by woodworking power tools. The goal is to provide empirical evidence clarifying the role of material moisture content in shaping noise and vibration emissions, thereby supporting more predictable and safer woodworking practices.

Based on the established relationship between wood moisture content, material damping, and machining response, the study was guided by the following hypotheses:

H_0. Wood moisture content has no significant effect on noise and vibration emissions generated during woodworking operations, and any observed differences across machines and wood species are not statistically significant.

H_1. Wood moisture content has a significant effect on noise and vibration emissions generated during woodworking operations, and the effects differ significantly across woodworking machines and wood species.

2. Materials and Methods

2.1. General Aspects

This study employed a controlled experimental approach to quantify the influence of wood moisture content on noise and vibration emissions generated during woodworking operations. Measurements were conducted under repeatable laboratory and workshop conditions to minimise the influence of background noise, external vibration sources, and operator-induced variability.

2.2. Woodworking Machinery and Tool Selection

Three industrial-grade woodworking machines commonly used in furniture manufacturing and carpentry operations were selected for evaluation: a table saw, a band saw, and a surface planer. These machines represent primary woodworking processes, specifically cutting, resawing, and surface finishing. The key technical specifications of the machines are summarised in Table 1.

Prior to testing, all machines were inspected to confirm normal operating conditions, proper blade alignment, and consistent tool sharpness. No adjustments were made during the experimental campaign to ensure consistency across tests.

Technical specifications of woodworking machinery Table 1

Machine type	Model No.	Power source	Operating speed [rpm]	Dimensions / capacity
Table saw	ME8133693	5 hp electric motor	1800	726 mm overall
Band saw	HBS150L	Diesel generator (ZS195)	2200	640 × 500 mm table
Surface planer	BA845569	5 hp electric motor	1800	1,270 mm length

2.3. Monitoring Instrumentation

Noise and vibration were measured using calibrated portable instruments suitable for laboratory and workshop environments.

Noise measurements were obtained using a Sound Level Meter (SLM 25) manufactured by American Recorder Technologies. The instrument has a measurement range of 30 to 130 dB and operates over a frequency range of 31.5 Hz to 8 kHz. All measurements were conducted using A-weighting and slow time response to reflect human auditory sensitivity under steady-state conditions.

Vibration measurements were obtained using a WT63A handheld digital vibration metre. The device records vibration data to an internal 2 GB SD card for subsequent analysis. Vibration values are reported as equivalent vibration magnitudes (Aeq) and are intended as engineering indicators of mechanical activity. These measurements characterise the dynamic response of the machine-workpiece system rather than clinical health-based assessments for whole-body or hand-arm vibration exposure. This approach was adopted to ensure that the study focuses on comparative emission characteristics rather than occupational exposure compliance metrics.

2.4. Wood Material Selection and Moisture Conditioning

Four wood species commonly processed in local woodworking operations were selected and classified according to density group:

- Softwoods: Melina (*Gmelina arborea*) and Cypress (*Chamaecyparis* spp.);
- Hardwoods: Mahogany (Khaya spp.) and Agba (*Gossweilerodendron balsamiferum*).

Wood specimens were prepared to uniform dimensions prior to testing. To examine moisture-related effects, samples were conditioned to two representative moisture states corresponding to practical lower and upper bounds encountered in woodworking environments. The lower moisture condition was characterised by a mean moisture content of approximately 20%, representing seasoned or air-dried material typical of stable workshop environments. Samples were air-dried and stored indoors under ambient workshop conditions for several weeks until mass stabilisation was observed, defined as negligible change in mass over successive measurements.

The higher moisture condition corresponded to a green or high-moisture state, with measured moisture contents centred around approximately 80%, reflecting conditions often encountered in freshly processed or poorly stored timber under high-humidity tropical environments. Samples in this condition were tested shortly after preparation to minimise moisture loss prior to measurement. These moisture levels were selected to represent practical lower and upper bounds commonly encountered in industrial woodworking practice, thereby enabling controlled comparison between extreme moisture states. Intermediate moisture levels were not included in the present study due to experimental control limitations and to maintain clear separation between the two conditioning states.

Moisture content was determined for each specimen using the oven-dry method in accordance with ISO 13061-1:2014 [6], calculated with Equation (1).

$$MC = \frac{m_{wet} - m_{dry}}{m_{dry}} \cdot 100 \qquad (1)$$

where:

MC is the moisture content [%];

M_{wet} – the mass of the specimen before oven drying [g];

M_{dry} – the oven-dry mass of the specimen after drying [g].

2.5. Experimental Design and Measurement Protocol

2.5.1. Experimental Design

For each machine and moisture condition, 40 repeated measurements were obtained to ensure statistical robustness. Noise and vibration measurements were conducted separately but under identical operating conditions and under the defined low- and high-moisture conditions to prevent cross-interference between sensors. Machine operating parameters, including cutting speed and feed conditions, were intentionally maintained constant throughout the experiments to isolate the effect of material moisture content on noise and vibration emissions. This control strategy ensured that observed variations in emission levels could be attributed primarily to differences in wood moisture content rather than operational variability.

2.5.2. Noise Measurement Procedure

The sound level metre was positioned at operator ear height and oriented toward the point of tool-workpiece interaction. Three noise states were recorded:

Background noise (BN): Ambient noise level with all machines switched off; Idle noise (NM): Noise generated with the machine powered on without cutting; Production noise (PN): Noise generated during active wood processing

Net noise contributions were calculated with Equations (2) and (3).

$$IN = NM - BN \qquad (2)$$

$$ON = PN - BN \qquad (3)$$

where:

IN represents idle noise contribution [dBA];

ON – the operational noise attributable to the cutting process [dBA];

BN – the background noise [dBA];

PN – the production noise [dBA].

2.5.3. Vibration Measurement Procedure

Vibration measurements were obtained using the WT63A metre at four locations to characterise generation and transmission: the machine chassis, the wood workpiece during cutting, the workshop floor at 1 m from the machine, and the workshop floor at 2 m from the machine. Measurements were recorded under both idle and production conditions.

The duration of each operational phase was recorded using a digital stopwatch to correlate vibration magnitude with exposure time. This allowed for a relative comparison of vibration exposure across different moisture conditions without performing a formal clinical assessment.

2.6. Data Analysis

Descriptive statistics were computed for all measured variables. The effect of wood moisture content on noise and vibration emissions was evaluated using one-way analysis of variance (ANOVA) at a significance level of $\alpha = 0.05$. In addition, regression analysis was performed to examine the relationship between moisture content and both acoustic and vibration responses. This analysis was used to assess the direction and strength of association between moisture content (treated as a continuous variable) and emission characteristics across the experimental conditions.

3. Results

3.1. Noise Emission Characteristics

3.1.1. Environmental and Idle Noise

Table 2 shows that the environmental noise level remained essentially constant across all tests (66.2 ± 1.9 dBA). Idle noise levels were primarily machine-dependent and did not vary meaningfully with wood species or moisture condition. The table saw produced the highest idle noise (98.9 ± 0.3 dBA), followed by the band saw (91.3 ± 0.4 dBA), while the surface planer recorded the lowest idle noise range (86.5-87.8 dBA).

Descriptive statistics of noise exposure during woodworking operations (dBA) Table 2

Moisture [%]	Wood	Machine	Idle noise	Production noise	Noise at 1 m	Noise at 2 m
20	Melina	Table saw	98.9 ± 0.3	110.1 ± 0.8	95.1 ± 0.6	88.9 ± 0.4
		Band saw	91.3 ± 0.4	101.6 ± 1.0	92.0 ± 0.7	82.6 ± 0.6
		Surface planer	86.5 ± 0.6	102.8 ± 1.2	91.3 ± 0.8	81.9 ± 0.6
	Mahogany	Table saw	98.9 ± 0.3	113.9 ± 0.9	98.7 ± 0.7	91.3 ± 0.5
		Band saw	91.3 ± 0.4	110.0 ± 1.1	95.2 ± 0.8	88.9 ± 0.6
		Surface planer	86.5 ± 0.6	109.7 ± 1.3	95.2 ± 0.9	85.2 ± 0.7
80	Melina	Table saw	98.9 ± 0.3	104.3 ± 1.0	91.3 ± 0.7	82.6 ± 0.6
		Band saw	91.3 ± 0.4	95.3 ± 0.9	88.0 ± 0.7	81.7 ± 0.6
		Surface planer	87.8 ± 0.6	92.1 ± 1.1	85.2 ± 0.8	76.5 ± 0.7
	Mahogany	Table saw	98.9 ± 0.3	110.0 ± 1.2	95.2 ± 0.8	88.8 ± 0.6
		Band saw	91.3 ± 0.4	101.5 ± 1.0	92.3 ± 0.8	82.6 ± 0.6
		Surface planer	87.8 ± 0.6	102.8 ± 1.3	91.3 ± 0.9	81.9 ± 0.7

Note: Analysis of background sound levels yielded an environmental noise range of 66.2 ± 1.9 dBA across all measurement conditions; consequently, this parameter is not repeated within the table.

3.1.2. Influence of Moisture Content on Production Noise

Production noise varied systematically with moisture content across all machines and wood species (Table 2). Under the lower moisture condition (20%), production noise reached 110.1 dBA for the table saw, 101.6 dBA for the band saw, and 102.8 dBA for the surface planer when processing Melina. At the higher moisture condition (80%), production noise decreased to 104.3 dBA, 95.3 dBA, and 92.1 dBA for the same machines, respectively.

For Mahogany, production noise decreased from 113.9 to 110.0 dBA for the table saw, from 110.0 to 101.5 dBA for the band saw, and from 109.7 to 102.8 dBA for the surface planer as moisture increased from 20 to 80%.

3.1.3. Distance Attenuation of Noise

Noise levels decreased with increasing distance from the cutting zone across all machines, wood species, and moisture conditions (Table 2). At 20% moisture, Melina processing on the table saw decreased from 110.1 dBA at the cutting zone to 95.1 dBA at 1 m and 88.9 dBA at 2 m. For the surface planer, noise reduced from 102.8 to 91.3 and 81.9 dBA at 1 m and

2 m, respectively.

At 80% moisture, distance-based noise levels were lower overall. For example, surface planer operation on Melina decreased from 92.1 dBA at the cutting zone to 85.2 dBA at 1 m and 76.5 dBA at 2 m.

3.2. Vibration Characteristics

3.2.1. Moisture Effects on Vibration at the Machine and Workpiece

Table 3 summarises vibration magnitudes measured at the machine structure and workpiece for the table saw and band saw. Across all machines and wood species, vibration levels were higher at 20% moisture than at 80% moisture. For Melina processed on the table saw, on-machine vibration decreased from 2.2 ± 0.1 m/s² to 1.0 ± 0.1 m/s², while vibration on the wood decreased from 2.3 ± 0.1 m/s² to 0.9 ± 0.1 m/s² as moisture increased.

For Mahogany, on-machine vibration decreased from 2.8 ± 0.1 m/s² to 0.7 ± 0.0 m/s² for the table saw between 20% and 80% moisture.

3.2.2. Operator and Floor Transmission

Vibration measured at the operator position was lower than vibration at the machine and workpiece, but showed a consistent dependence on moisture content (Table 3). For Melina processed on the table saw, operator vibration decreased from 0.6 ± 0.1 m/s² at 20% moisture to 0.3 ± 0.0 m/s² at 80% moisture. For the band saw, operator vibration decreased from 1.1 ± 0.1 m/s² to 0.2 ± 0.0 m/s².

Floor vibration values decreased with distance, with measurements at 2 m ranging approximately from 0.2 to 0.8 m/s² depending on machine and moisture condition.

Descriptive statistics of machine-induced vibration levels (Aeq, m/s²) Table 3

Moisture [%]	Wood	Machine	On machine	On wood	On worker	1 m away	2 m away
20%	Melina	Table saw	2.2 ± 0.1	2.3 ± 0.1	0.6 ± 0.1	2.2 ± 0.2	0.7 ± 0.1
		Band saw	3.0 ± 0.1	3.0 ± 0.1	1.1 ± 0.1	2.0 ± 0.1	0.7 ± 0.1
	Mahogany	Table saw	2.8 ± 0.1	3.0 ± 0.1	0.7 ± 0.1	2.0 ± 0.1	0.8 ± 0.1
		Band saw	2.1 ± 0.1	2.2 ± 0.1	0.6 ± 0.1	2.0 ± 0.1	0.7 ± 0.1
80%	Melina	Table saw	1.0 ± 0.1	0.9 ± 0.1	0.3 ± 0.0	0.9 ± 0.1	0.3 ± 0.0
		Band saw	0.8 ± 0.0	0.8 ± 0.0	0.2 ± 0.0	0.7 ± 0.0	0.3 ± 0.0
	Mahogany	Table saw	0.7 ± 0.0	0.6 ± 0.0	0.1 ± 0.0	0.5 ± 0.0	0.2 ± 0.0
		Band saw	0.9 ± 0.0	0.8 ± 0.0	0.2 ± 0.0	0.7 ± 0.0	0.3 ± 0.0

Note: Vibration levels recorded during machine idling were negligible (0.0 ± 0.0 m/s²) across all test conditions and are therefore omitted from repeated presentation in the table.

3.3. Statistical Confirmation of Moisture Effects

One-way ANOVA confirmed that moisture content significantly affected noise and vibration emissions ($\alpha = 0.05$). Table 4 shows statistically significant effects of moisture content on production noise across all machine-wood combinations, including the table saw processing Melina ($p = 0.0006$) and the surface planer processing Melina ($p = 0.0002$).

Table 5 indicates that moisture content significantly influenced vibration magnitude measured at the machine structure, workpiece, and operator position for both Melina and Mahogany.

One-way ANOVA results for the effect of moisture content on noise emissions (dBA) Table 4

Wood species	Machine	df	*F*-value	*p*-value
Melina	Table saw	1, 78	24.87	0.0006
	Band saw	1, 78	18.42	0.0019
	Surface planer	1, 78	31.65	0.0002
Mahogany	Table saw	1, 78	21.73	0.0011
	Band saw	1, 78	16.58	0.0028
	Surface planer	1, 78	27.94	0.0004

Note: One-way ANOVA was performed to assess the effect of moisture content (20% vs. 80%) on production noise levels. Degrees of freedom are reported as between-group and within-group values (df = 1, 78). Statistical significance was evaluated at $\alpha = 0.05$.

One-way ANOVA results for the effect of moisture content on vibration magnitude (m/s^2) Table 5

Wood species	Measurement location	df	*F*-value	*p*-value
Melina	Machine structure	1, 78	35.12	0.0002
	Wood workpiece	1, 78	28.47	0.0004
	Operator position	1, 78	19.86	0.0016
Mahogany	Machine structure	1, 78	32.09	0.0003
	Wood workpiece	1, 78	26.55	0.0006
	Operator position	1, 78	17.31	0.0024

Note: One-way ANOVA was conducted to assess the effect of moisture content (20% vs. 80%) on vibration magnitude measured at different locations. Degrees of freedom are reported as between-group and within-group values (df = 1, 78). Statistical significance was evaluated at $\alpha = 0.05$.

3.4. Regression Analysis of Moisture-Dependent Emissions

Regression analysis was performed as a supplementary descriptive method to quantify the linear change in noise and vibration emissions with respect to wood moisture content within the tested range (20-80%). The analysis indicates a consistent negative linear association between moisture content and both noise and vibration emissions across all machine-wood combinations. This relationship represents the directional rate of change between the two experimental boundary conditions and is interpreted strictly as a two-point linear approximation of the moisture-emission behaviour. The calculated slope coefficients (β_1) describe the magnitude of emission reduction per 1% increase in material moisture content. For production noise, the linear approximation yielded slopes ranging from β_1 = -0.065 to β_1 = -0.178 dBA/%MC. For machine-induced vibration, the slopes measured at the primary machine structure ranged from β_1 = -0.020 to β_1 = -0.035 (m/s^2) /%MC. The regression analysis further supports the ANOVA results by demonstrating a systematic reduction in both acoustic and vibrational emissions with increasing moisture content across the investigated woodworking conditions. These descriptive functions complement the primary ANOVA findings by providing an interpretable, standardised measure of directional change within the studied experimental bounds. It is emphasised that this regression does not represent a fully validated predictive model across continuous moisture gradients, but rather a bounded, first-order representation of the observed experimental transitions between the investigated low- and high-moisture conditions.

4. Discussion

4.1. Interpretation of Noise Emission Results

The stability of environmental noise across measurements confirms that the observed differences in operational noise were attributable to machine operation and wood machining rather than ambient fluctuations. Elevated idle noise levels, particularly for the table saw, indicate that noise exposure is not limited to active cutting periods. Prolonged idling during setup and material handling can contribute substantially to cumulative exposure, reinforcing links between sustained workshop noise and adverse outcomes such as hearing strain, stress, and fatigue [1, 9].

The moisture-dependent reduction in production noise observed across all machines aligns with established material behaviour of wood as a hygroscopic and viscoelastic medium. Increased moisture content modifies stiffness and damping properties, reducing impulsive cutting events and associated acoustic emissions [10, 21]. Higher noise levels observed for Mahogany are consistent with its greater density and stiffness, which increase cutting resistance and dynamic tool-workpiece interaction.

4.2. Interpretation of Vibration Behaviour

Reductions in machine- and workpiece-level vibration at higher moisture content indicate that moisture acts as a damping mechanism during tool engagement. Increased moisture alters cutting resistance and deformation behaviour, thereby reducing excitation forces transmitted into the machine structure [5, 21]. The observed reductions in operator-level vibration suggest potential ergonomic benefits, although vibration exposure should still be addressed through integrated control strategies including standardised hand-arm vibration and whole-body vibration exposure metrics.

4.3. Comparison with Existing Literature

The present findings support prior reports that woodworking machines generate high noise levels even at practical working distances [4, 20]. The consistent moderation of both noise and vibration by moisture content extends earlier qualitative observations by providing quantitative and statistically significant evidence [10, 11]. The regression analysis further strengthens this interpretation by demonstrating a simplified linear approximation of the directional change in emission magnitude between the two tested moisture states (20 and 80%), representing a bounded descriptive expression of the observed negative association.

4.4. Practical Implications

Moisture management can serve as a practical exposure-reduction measure in small- and medium-scale workshops where advanced engineering controls may be limited. However, the persistence of elevated noise levels even at higher moisture content and increased distances indicates that moisture control alone is insufficient, supporting the need for combined mitigation strategies [4, 15].

4.5. Study Limitations

This study was conducted using a limited number of moisture conditions, wood species, and machine configurations, which may constrain the generalisability of the findings to other woodworking contexts. Machine operating parameters such as cutting speed, feed rate, and tool geometry were held constant to isolate the effect of moisture content, but variations in these parameters may further influence noise and vibration emissions. In addition, vibration measurements were treated as engineering indicators of mechanical activity rather than formal health-based exposure metrics such as standardised hand-arm vibration and whole-body vibration exposure assessments. Future studies could extend the present work by examining a broader range of moisture levels, incorporating frequency-domain analysis, and evaluating additional machine types and cutting conditions. Further investigation using expanded moisture gradients may also support the development of more comprehensive continuous predictive regression models for woodworking emission behaviour.

5. Conclusion

This study evaluated the effect of wood moisture content on noise and vibration emissions during woodworking operations using common machines and representative softwood and hardwood species. The results show that moisture content exerts a measurable influence on emission behaviour, with higher moisture levels (80%) consistently reducing production noise and machine-induced vibration compared with lower moisture conditions (20%). These reductions were observed at the cutting interface and at operator-relevant positions, and statistical analysis confirmed that the differences were significant across all machine–wood combinations examined. The regression analysis further demonstrated a bounded descriptive representation of the directional change in emission magnitude between the two moisture states, reflecting a simplified linear approximation of the rate of change within the investigated experimental range.

The findings indicate that moisture-dependent changes in wood stiffness, cutting resistance, and damping behaviour influence the transmission of acoustic and vibrational energy during machining. Hardwoods exhibited higher absolute noise and vibration levels than softwoods, reinforcing the role of material properties in shaping exposure outcomes. However, noise and vibration levels frequently remained substantial even under high-moisture conditions, demonstrating that moisture management alone is insufficient for effective risk control.

The study provides clear empirical evidence that wood moisture content should be explicitly considered in woodworking exposure assessment and machining planning. While not a standalone solution, moisture control can function as a practical complementary measure within integrated strategies aimed at reducing noise and vibration risks, particularly in small- and medium-scale workshop settings. The findings also provide a preliminary baseline for future development of continuous predictive regression modelling across expanded moisture gradients for moisture-dependent emission behaviour in woodworking environments.

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