(JOURNAL ENGINEERING DESIGN AND TECHNOLOGY)

Journal Engineering Design and Technology
Vol. 26 No.2 July 2026 ; p. 95 - 102
Journal Homepage : http://ojs2.pnb.ac.id/index.php/LOGIC
p-ISSN : 1412-114X e-ISSN : 2580-5649

Evaluation of Lathe Operating Conditions Based on ISO 10816 Using Correlation Between Spindle Vibration and Surface Quality

1) Mechanical Engineering, State Polytechnic of Malang, Malang, Indonesia

Corresponding email [1)*] :
talifatim.machfuroh@polinema.ac.id

Talifatim Machfuroh [1)*], Zakiyah Amalia [1)], Siti Duratun Nasiqiati Rosady [1)], Nurlia Pramita Sari [1)], Agus Hardjito [1)], Subagiyo [1)]

Abstract. The evaluation of machine tool operating conditions is commonly performed based on mechanical reliability, while its direct relationship with the quality of machined surfaces is still rarely quantified. This study aims to evaluate the operating condition of a conventional lathe based on ISO 10816 by analyzing the correlation between spindle vibration and surface roughness. Experiments were conducted on a Dixon CQ6236X1000 lathe with variations in feed rate (0.104–0.835 mm/rev) and depth of cut (0–1.5 mm) at a constant spindle speed of 460 rpm. Spindle vibration was measured in terms of root mean square (RMS) velocity (mm/s) in the vertical and horizontal directions, and frequency-domain analysis was performed using Fast Fourier Transform (FFT). Surface roughness was evaluated using Ra, Rq, and Rz parameters. The results show that the RMS vibration values range from 0.4 to 2.5 mm/s, which correspond to Zone B and Zone C of ISO 10816-3 class I. At Zone B, the surface roughness values are relatively low (Ra = 2–6 µm), indicating stable machining conditions. However, when the operating condition shifts to Zone C, the surface roughness increases significantly, with Ra values exceeding 10 µm under certain cutting conditions. The correlation analysis between RMS vibration and surface roughness yields a coefficient of determination of R^2 = 0.399, indicating a moderate positive relationship. FFT analysis shows dominant frequency components associated with spindle rotational frequency and its harmonics, indicating the presence of forced vibration effects induced by cutting dynamics. No definitive conclusion regarding regenerative chatter is made, as further modal and stability analysis is required. These findings indicate that ISO 10816 vibration zones may serve as a supporting indicator for preliminary machining quality assessment, rather than a direct predictive tool for surface roughness. The results provide a useful reference for integrating vibration-based condition monitoring with machining quality control in both industrial and educational workshop environments..

Keywords : ISO 10816, Spindle Vibration, Surface Roughness, RMS Velocity, Turning Process

1. INTRODUCTION

A lathe is one of the primary machine tools in the manufacturing industry used to produce cylindrical components with a certain level of precision. In the machining process, the quality of the cutting results is not only determined by cutting parameters such as spindle speed, feed rate, and depth of cut, but is also strongly influenced by the dynamic stability of the spindle–tool–workpiece system. This dynamic stability plays a crucial role in maintaining

dimensional accuracy and surface quality, particularly for components that require tight tolerances.
From a physical standpoint, all objects possessing mass and elasticity are capable of undergoing vibration; therefore, almost all machines and engineered structures experience vibrations to some degree. Vibration is defined as a reciprocating or oscillatory motion of an object that has both mass and elasticity, analogous to a mass–spring system [1]. In machine tool operation, vibration is an unavoidable phenomenon. However, in most industrial applications, excessive vibration is undesirable because, in addition to increasing dynamic stress on machine components, it also leads to energy losses that should otherwise be utilized effectively in the machining process [2][3][4].

In a lathe, spindle vibration has a direct influence on machining quality. Spindle vibration can cause irregular tool motion, which results in a rougher workpiece surface [5] and reduced dimensional accuracy [6]. Fluctuations in tool position induced by vibration lead to non-uniform material removal, thereby increasing surface roughness parameters such as Ra and Rz [7][8]. Furthermore, excessive vibration accelerates tool wear and increases the risk of damage to machine components, which ultimately degrades machining precision and product quality, especially for components with high quality requirements [9].

In industrial practice, machine condition is often evaluated using vibration severity standards such as ISO 10816. However, ISO 10816 is primarily intended for mechanical condition monitoring and not directly for machining quality evaluation. This standard classifies machine operational condition into several zones according to the effective vibration velocity (RMS velocity), ranging from very good to unacceptable conditions. Nevertheless, in practical applications, it is frequently observed that a machine may still be mechanically classified as acceptable according to ISO 10816, while the surface quality of the machined products has already deteriorated. This indicates that mechanical acceptability does not always correspond directly to the quality of the resulting products.

Several previous studies have investigated the effects of cutting parameters on vibration and surface roughness. Panda et al. (2018) monitored the condition of bearing housing in a lathe through vibration analysis with variations in spindle speed and depth of cut, demonstrating that vibration characteristics are influenced by both mechanical and operational factors [10]. Fitriana et al. (2021) and Alfianto et al. (2018) reported that increasing spindle speed leads to higher vibration levels accompanied by increased surface roughness [11][12]. Retyawan et al. (2018) showed that the type of cutting process also affects vibration and surface roughness in milling operations [13]. Meanwhile, Şahinoğlu dan Rafighi (2020) demonstrated that feed rate, depth of cut, and cutting speed significantly influence vibration and surface roughness during the turning of AISI 4140 steel [14]. However, most of these studies still consider vibration and surface roughness as direct consequences of variations in cutting parameters, without directly relating them to machine acceptability zones based on ISO 10816.

Previous studies have shown that vibration affects surface roughness; however, most research focuses on parameter-based analysis rather than linking vibration severity zones with surface quality outcomes. Therefore, this study proposes an integrated approach by correlating ISO 10816 vibration zones with surface roughness behavior in turning operations. The contribution of this study lies in mapping vibration severity zones to machining surface quality trends under controlled cutting conditions..

2. METHODS

2.1. Object and Machining Parameter Variations

The research was conducted using a Dixon CQ6236X1000 lathe located in the machine tool workshop of the Department of Mechanical Engineering, Politeknik Negeri Malang. The technical specifications of the lathe are as follows:

- Lathe model : Dixon CQ6236X1000
- Main electric motor power : 3 HP
- Pump motor power : 0,05 HP
- Spindle bore : 38 mm
- Spindle nose : D12-4
- Spindle speed range : 10 – 2000 rpm
- Machine height : 1238 mm
- Machine length : 1940 mm
- Machine width : 755 mm
- Workpiece material : ST 37 solid round axle
- Diameter of material : 25,4 mm
- lenght of material : 100 mm
- Cutting tool : HSS, 5/8” x 6 inch

The machining parameter variations used in this study consisted of:

- Feed rate : 0,104; 0,325; 0,522; 0,835 mm/rev
- Depth of cut : 0; 0,5; 1; 1,5 mm

Depth of cut = 0 mm is treated as baseline (non-cutting surface reference), not machining output.

2.2. Vibration Measurement
Vibration was measured using an AMTAST digital vibration meter mounted on the spindle bearing housing.

- Direction : vertical and horizontal
- Parameter : RMS velocity (mm/s)
- Measurement repetition : 5 times per condition
- Output : averaged RMS value

The FFT analysis in this study was employed solely to identify the dominant frequency components of spindle vibration. Therefore, the results should not be interpreted as direct modal identification or as a basis for constructing a stability lobe diagram [15][16].

2.3. Surface Roughness Measurement
The surface quality of the machined workpieces was evaluated using a surface roughness tester, with Ra, Rq, and Rz as the primary roughness parameters. The Ra parameter represents the arithmetic mean of the profile deviations, while Rq and Rz provide additional information on the peak–valley distribution and extreme features of the surface profile [17]. Each measurement was performed three times for every machining condition, and the reported values represent the average of these measurements.

2.4. ISO 10816 Evaluation and Correlation Analysis
The measured RMS vibration values were compared with the vibration zone limits defined by the ISO 10816 standard (Class I) to determine the operational condition of the machine. Furthermore, a linear regression analysis was conducted between the RMS vibration velocity and the Ra surface roughness value in order to evaluate the correlation between spindle vibration and surface quality. The correlation is interpreted as moderate and not sufficient for deterministic prediction

3. RESULTS AND DISCUSSION

3.1 Evaluation of Vibration Zones Based on ISO 10816

The results of the effective vibration velocity (RMS velocity) measurements on the spindle of the lathe for various combinations of feed rate and depth of cut are presented in Table 1. Based on the table, the RMS vibration values range from 0.4 to 2.5 mm/s. The lowest RMS value of 0.4 mm/s occurs under no-load cutting conditions (depth of cut = 0 mm) for all feed rate variations. Meanwhile, the highest RMS value of 2.5 mm/s is observed at the combination of a feed rate of 0.835 mm/rev and a depth of cut of 1.5 mm, indicating that an increase in cutting load significantly increases the spindle vibration response.

Table 1. Spindle RMS Vibration Values at Various Combinations of Feed Rate and Depth of Cut.

Spesimen	Feed Rate (mm/rev)	Depth of Cut (mm)	Velocity (mm/s)				
			1	2	3	4	5
A	0.104	0	0.4	0.4	0.4	0.4	0.4
		0.5	1.4	1.6	1.6	1.4	1.6
		1	1	1.6	1.8	1.8	1.6
		1.5	1.6	1.8	1.8	1.8	1.6
B	0.325	0	0.4	0.4	0.4	0.4	0.4
		0.5	0.6	0.8	1.2	1	0.8
		1	0.8	1.4	1.6	1.4	1.6
		1.5	0.8	1.6	1.8	1.8	1.6
C	0.522	0	0.4	0.4	0.4	0.4	0.4
		0.5	0.8	1	1	0.8	1
		1	1	1.2	1	1	1.2
		1.5	0.8	1.6	1.8	2.1	2.3
D	0.835	0	0.4	0.4	0.4	0.4	0.4

	0.5	0.8	1	1.2	1.4	1.4
	1	1	1.6	1.6	1.4	1.4
	1.5	1.2	1.8	2.3	1.9	2.5

The classification of machine operating conditions based on the ISO 10816-3 Class I standard is presented in Table 2, while the distribution of RMS values across the ISO vibration zones is illustrated in Figure 1. The mapping results indicate that most operating conditions fall within Zone B (0.71–1.8 mm/s), which signifies that the machine is in good condition and suitable for operation. However, under several extreme conditions—particularly at high feed rates and a depth of cut of 1.5 mm—the RMS values have entered Zone C (1.8–4.5 mm/s). Zone C indicates a warning condition in which the machine is still operational. however, continuous operation under this condition requires monitoring and corrective action to prevent further degradation in dynamic performance. From a mechanical standpoint, the increase in cutting force due to the larger chip cross-section leads to a higher excitation force, which is subsequently transmitted to the machine structure in the form of vibration response. This phenomenon explains why, under light cutting loads, all RMS values remain within Zones A–B, whereas under heavy cutting loads, a portion of the data shifts into Zone C.

Table 2. Machine Condition Classification Based on ISO 10816-3 (Class I)

Zone	**Vibration Velocity Range (mm/s RMS)**	**Interpretation of condition**
A	< 0.71	Machine is in excellent condition
B	0.71 – 1.8	Machine is in good / satisfactory condition
C	1.8 – 4.5	Machine condition is still acceptable but requires monitoring
D	> 4.5	Machine condition is unacceptable

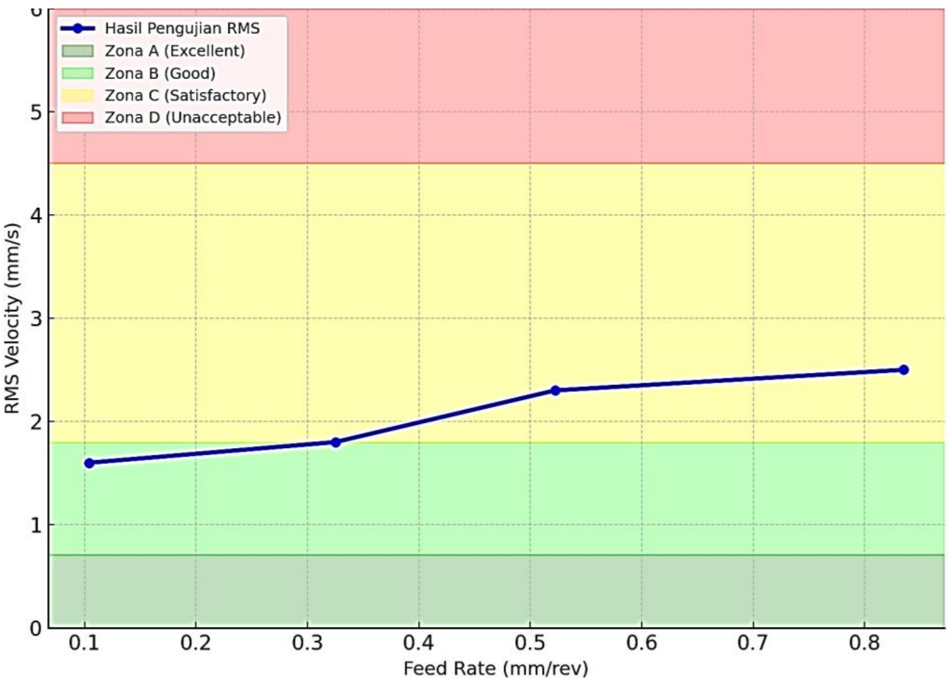

Figure 1. Distribution of RMS Vibration Values over ISO 10816 Zones

The increasing trend of RMS values with rising cutting load is consistent with the findings of Fitriana and Suryanto (2021), who reported that an increase in spindle rotational speed and feed load enhances the dynamic energy of the spindle system, thereby intensifying the vibration response [11]. From a practical perspective, the entry of RMS values into Zone C, even though the machine is still classified as “acceptable” according to ISO 10816, indicates that the machine is operating close to the limit of its dynamic stability. This condition is particularly critical in production environments because continuous operation within Zone C has the potential to accelerate structural fatigue of machine components and reduce long-term process stability, as also reported by

Alfianto and Wulandari (2018) in their study on a conventional lathe in an educational workshop environment [12]. Therefore, the results of this study confirm that ISO 10816 serves not only as a mechanical safety threshold, but also as an early indicator of degradation in the dynamic stability of the machining process.

3.2. Relationship Between ISO Zones and Surface Quality

The relationship between vibration level and surface quality was analyzed using the surface roughness data presented in Table 3, with the primary focus on the Ra parameter. Based on the table, under operating conditions where the RMS values fall within Zone B, the Ra values generally range from 2 to 6 µm. For instance, at a feed rate of 0.104 mm/rev and a depth of cut of 1 mm, the average Ra values range between 1.45 and 3.52 µm. These values indicates stable surface formation.

Table 3. Surface Roughness (Ra) Values in Various ISO Vibration Zones

Spesimen	Spindle rotation	Feed Rate (mm/rev)	Depth of Cut (mm)	Ra			Rz			Rq		
				1	2	3	1	2	3	1	2	3
A	460	0.104	0	4.03	3.491	2.414	11.39	9.874	6.828	4.151	4.134	3.196
			0.5	5.189	8.547	6.712	14.67	24.17	18.98	5.599	8.877	5.872
			1	1.451	1.412	3.525	4.103	3.994	9.969	1.903	1.331	3.55
			1.5	2.389	3.328	3.038	6.759	9.413	8.592	2.697	3.653	3.141
B		0.325	0	4.03	3.491	2.414	11.39	9.874	6.828	4.151	4.134	3.196
			0.5	3.549	6.452	4.472	10.03	18.24	12.64	2.048	6.691	4.507
			1	6.145	3.226	3.622	17.37	9.124	10.24	6.623	3.567	3.328
			1.5	8.125	6.35	8.671	22.97	17.95	24.52	8.193	6.521	8.741
C		0.522	0	4.03	3.491	2.414	11.39	9.874	6.828	4.151	4.134	3.196
			0.5	5.872	5.496	9.223	16.6	15.54	26.08	6.248	6.623	9.355
			1	12.93	7.818	13.04	45.06	22.1	36.87	12.08	7.955	11.6
			1.5	7.533	4.273	8.877	21.3	12.08	25.1	6.999	4.079	9.628
D		0.835	0	4.03	3.491	2.414	11.39	9.874	6.828	4.151	4.134	3.196
			0.5	4.609	9.223	9.175	13.03	26.08	25.94	4.95	10.24	9.15
			1	11.1	8.354	6.555	31.4	25.73	18.53	10.44	7.867	6.999
			1.5	8.399	8.451	11.68	23.75	23.89	33.04	9.492	8.125	10.24

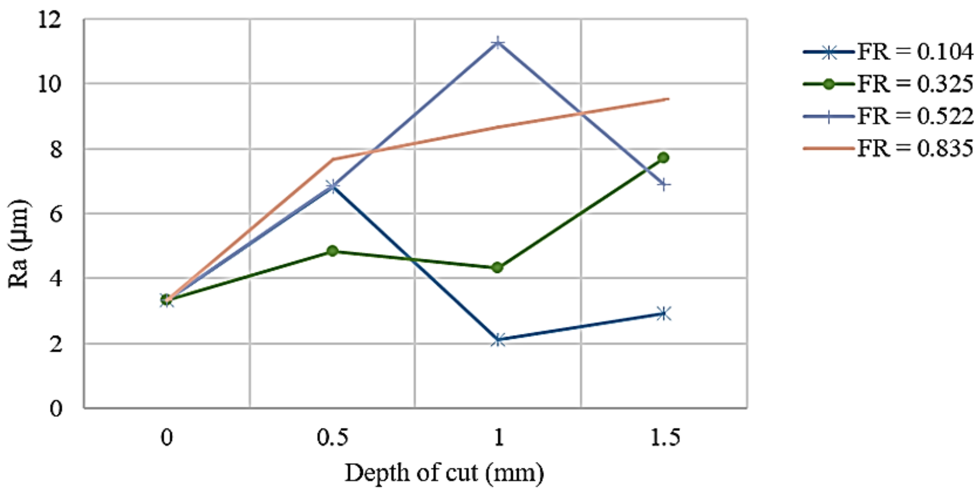

Figure 2. Comparison of Ra Value to Depth of Cut

Under operating conditions where the RMS values have entered Zone C, Ra increases significantly (up to >10 µm). At the combination of a feed rate of 0.522 mm/rev and a depth of cut of 1 mm, the Ra value reaches

12.93 µm, whereas at a feed rate of 0.835 mm/rev and a depth of cut of 1.5 mm, the Ra value increases to 11.68 µm. This trend is visually illustrated in Figure 2, which shows that an increase in depth of cut leads to a sharper rise in Ra values at higher feed rates.

The surface roughness data in Table 3 and Figure 2 demonstrate that an increase in RMS values, which shifts the operating condition from Zone B to Zone C, is accompanied by a substantial rise in Ra. From a physical standpoint, this phenomenon occurs due to vibration-induced tool displacement, which affects chip thickness uniformity and surface generation mechanism.

These results indicate that although the machine may still be mechanically classified as acceptable according to ISO 10816, the resulting surface quality can experience a considerable level of degradation. This phenomenon is consistent with the findings of Rosandi et al. (2021), who stated that increased vibration during turning amplifies tool position fluctuations, leading to a pronounced rise in surface roughness [8]. Similar results were also reported by Firmansyah et al. (2021), who concluded that vibration amplitude has a direct contribution to the increase in Ra and Rz values in turning operations [7].

3.3. Correlation Between Spindle Vibration and Surface Roughness

The relationship between spindle vibration and surface roughness was analyzed using linear regression between the RMS vibration values and Ra, as presented in Figure 3. The graph shows a positive relationship between RMS velocity and Ra, with a coefficient of determination of $R^2 = 0.399$. This indicates a moderate correlation, meaning vibration contributes partially to surface roughness variation, while the remaining variation is influenced by tool wear, machine stiffness, clamping rigidity, and material heterogeneity.

Each increase in RMS of 1 mm/s tends to be followed by an increase in the Ra value by several micrometers, indicating a high sensitivity of surface quality to relatively small changes in vibration level. This finding is consistent with the results reported by Retyawan et al. (2018), who demonstrated a positive correlation between increasing vibration and rising surface roughness across various cutting processes [13]. Furthermore, Şahinoğlu and Rafighi (2020) also reported that vibration has a dominant contribution to changes in surface quality in addition to the cutting parameters themselves [14]. Therefore, the results of this correlation analysis reinforce that spindle vibration not only serves as an indicator of the mechanical condition of the machine but can also be utilized as a predictive parameter for the surface quality of machined products.

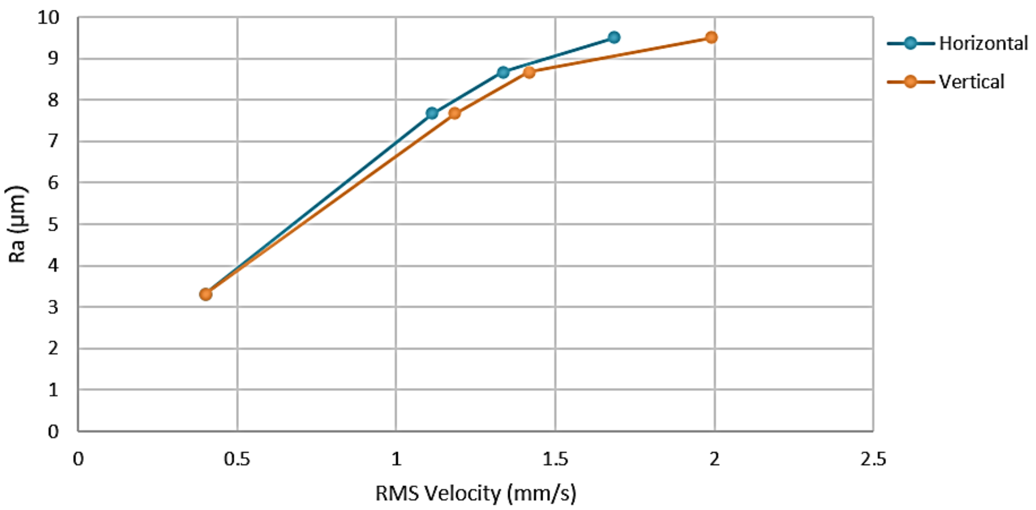

Figure 3. Relationship between Spindle Vibration RMS and Surface Roughness (Ra)

3.4. FFT Analysis and Its Relationship with the ISO Zones

The frequency spectrum of spindle vibration obtained from the FFT analysis at a spindle speed of 460 rpm is presented in Figure 4. The spectrum shows that the dominant frequency appears at approximately 7.6 Hz, which corresponds to the spindle rotational frequency. In addition, several harmonics are observed up to around 30 Hz, indicating the vibration behavior is mainly governed by cutting-induced forced excitation, while chatter identification requires further experimental validation.

The increase in vibration under Zone C conditions is not attributed to bearing damage or serious mechanical defects, but is instead primarily influenced by dynamic cutting forces and instability in the machining system. This is evidenced by the absence of significant high-frequency peaks in the spectrum. This finding is consistent with the results reported by Panda et al. (2018), who stated that variations in the vibration frequency spectrum of a lathe are more strongly induced by changes in cutting load than by structural damage to the machine [10]. Therefore, the FFT results reinforce that the increase in RMS values, which causes the operating condition to shift from Zone B to Zone C, is predominantly driven by operational factors rather than by mechanical degradation of machine components. This indicates that controlling the cutting parameters is a critical aspect in maintaining the dynamic stability of the machine while simultaneously preserving the surface quality of the machined products.

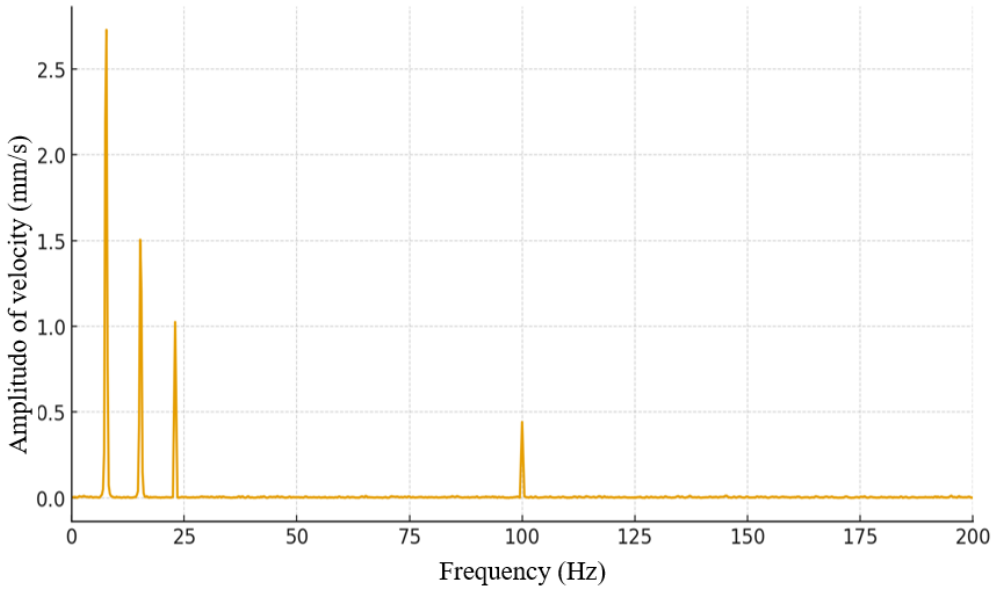

Figure 4. FFT Spectrum of Spindle Vibration at 460 rpm

4. CONCLUSION

Based on the experimental results and analysis, it can be concluded that the operating condition of the lathe is significantly influenced by the combination of cutting parameters, which directly affect spindle vibration behavior and surface roughness characteristics. The measured RMS vibration velocity ranges from 0.4 to 2.5 mm/s, corresponding to Zone B and Zone C according to the ISO 10816-3 Class I classification. Zone B represents stable and satisfactory operating conditions, whereas Zone C indicates a warning condition in which the machine remains operational but requires continuous monitoring and possible process adjustment to maintain machining stability.
The surface roughness results indicate that an increase in vibration level is generally accompanied by an increase in Ra values, particularly when the operating condition transitions from Zone B to Zone C. However, the correlation analysis shows a coefficient of determination of $R^2 = 0.399$, indicating a moderate relationship between spindle vibration and surface roughness. This suggests that vibration contributes to surface quality variation, but it is not the dominant influencing factor. Other factors, such as tool wear, machine stiffness, clamping rigidity, and material properties, also significantly affect the machining results. The FFT analysis reveals that the dominant vibration components are associated with spindle rotational frequency and its harmonics. This indicates that the vibration response is primarily driven by forced excitation resulting from machining dynamics. However, no definitive conclusion regarding regenerative chatter can be established without further validation using modal analysis or stability lobe diagram methods. Overall, this study demonstrates that ISO 10816 vibration classification can be used as a complementary indicator for evaluating machining stability and trends in surface quality. However, it should not be interpreted as a direct predictive model for surface roughness in machining operations. These findings provide a useful basis for integrating vibration-based condition monitoring with machining quality assessment in conventional turning processes, particularly in industrial and educational environments. Further research is recommended to include advanced dynamic characterization, tool wear analysis, and multi-machine validation to improve prediction accuracy and generalizability.

5. ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to the Center for Research and Community Service (P3M), Politeknik Negeri Malang, for the financial support provided through the research grant scheme that enabled this study to be conducted successfully. The authors also extend their appreciation to all parties who contributed to the data collection process and the implementation of this research at the Mechanical Engineering Workshop of Politeknik Negeri Malang.

6. REFERENCES

[1] S. S. Rao, *Mechanical Vibrations*, vol. 33, no. 6. 1981.

[2] T. Machfuroh and H. Laksana Guntur, "Studi Pengaruh Penambahan Dual Dynamic Vibration Absorber (DDVA)-Dependent Terhadap Respon Getaran Translasi Dan Rotasi Pada Sistem Utama 2-DOF," 2015, pp. 240–244. https://doi.org/10.36040/seniati.vi0.1560

[3] T. Machfuroh, Z. Amalia, F. Aida, and N. Aini, "Response of Vibration Reduction with Additional of Dual Dynamic Vibration Absorber to The Main System," vol. 01, no. 01, pp. 1–8, 2023. https://doi.org/10.70822/journalofevrmata.vi.4

[4] A. Lostari, S. Susastro, and T. Machfuroh, "Modeling and Vibration Response Analysis of Pellet Machine Grinder and Gearbox," *SINTEK J. J. Ilm. Tek. Mesin*, vol. 14, no. 2, p. 99, 2020, doi: 10.24853/sintek.14.2.99-106.

[5] S. A. Shasheekant, "Analyzing the Vibration Effect of Cutting Tool on Surface Roughness of Turning Work Piece in Lathe Machine," *Int. J. Res. Appl. Sci. Eng. Technol.*, vol. 9, no. VII, pp. 1654–1657, 2021, doi: 10.22214/ijraset.2021.36446.

[6] P. H. Jain and S. P. Bhosle, "A Review on Vibration Signal Analysis Techniques Used for Detection of Rolling Element Bearing Defects," *Int. J. Mech. Eng.*, vol. 8, no. 1, pp. 14–29, 2021, doi: 10.14445/23488360/ijme-v8i1p103.

[7] S. Firmansyah, H. Suryanto, and Mudjijanto, "Pengaruh Jenis Material Benda Kerja Terhadap Getaran Saat Proses Penyayatan Dan Kekasaran Permukaan Produk Yang Dihasilkan Dengan Menggunakan Mesin Bubut," *J. Tek. Mesin*, vol. 1, no. 1, pp. 30–37, 2021.

[8] A. Rosandi, W. Sumbodo, H. Yudiono, and K. Kriswanto, "Analisis Variasi Kecepatan Potong Dan Kedalaman Potong Terhadap Nilai Kekasaran Permukaan Dan Getaran Pada Pembubutan Silindris Material Baja ST 60," *J. Inov. Mesin*, vol. 3, no. 1, pp. 1–12, 2021, doi: 10.15294/jim.v3i1.46597.

[9] A. Sulthoni, "Rancang Bangun Sistem Pendeteksi Vibrasi Pada Motor Sebagai Indikator Pengaman Terhadap Perubahan Beban Bambang Suprianto," pp. 147–155, 2018.

[10] A. Panda, Š. Olejárová, J. Valíček, and M. Harničárová, "Monitoring of the condition of turning machine bearing housing through vibrations," *Int. J. Adv. Manuf. Technol.*, vol. 97, no. 1–4, pp. 401–411, 2018, doi: 10.1007/s00170-018-1871-7.

[11] S. Nurul Fitriana and H. Suryanto, "Pengaruh Kecepatan Putaran Spindle Terhadap Getaran Mesin Frais Pada Proses Pemakanan Dan Kekasaran Permukaan Benda Kerja," *J. Tek. Mesin*, vol. 1, no. 01, pp. 13–18, 2021.

[12] R. Alfianto and D. Wulandari, "Studi Eksperimen Kecepatan Putar Spindle Dan Kedalaman Potong Terhadap Getaran Pahat Dan Tingkat Kekasaran Pada Proses Pembuatan Poros Menggunakan Mesin Bubut," *Jtm*, vol. 6, no. 2, pp. 61–68, 2018.

[13] O. N. Retyawan, I. Yaningsih, and H. Sukanto, "Pengaruh jenis proses pemotongan pada mesin milling terhadap getaran dan kekasaran permukaan dengan material aluminium 6061," *J. Tek. Mesin Indones.*, vol. 12, no. 1, pp. 8–13, 2018, doi: 10.36289/jtmi.v12i1.63.

[14] A. Şahinoğlu and M. Rafighi, "Investigation of Vibration, Sound Intensity, Machine Current and Surface Roughness Values of AISI 4140 During Machining on the Lathe," *Arab. J. Sci. Eng.*, vol. 45, no. 2, pp. 765–778, 2020, doi: 10.1007/s13369-019-04124-x.

[15] A. Rastegari, *Vibration analysis of machine tool spindle units*. 2017.

[16] A. Nitin, K. Dinesh, and C. Satish, "Prediction of cutting tool vibration and surface roughness in hard turning of AISI52100 steel," vol. 03011, pp. 1–6, 2018. https://doi.org/10.1051/matecconf/201821103011

[17] J. Dobes *et al.*, "Effect of mechanical vibration on Ra, Rq, Rz, and Rt roughness parameters," *Int. J. Adv. Manuf. Technol.*, vol. 92, no. 1, pp. 393–406, 2017, doi: 10.1007/s00170-017-0137-0.