ISSN 2829-4998

Analysis of horizontal milling machine vibration on the influence of gear module cutters with sizes M 1 and M 1.5

Jupri Yanda Zaira [a,1,*], Muhammad Haiqal [a,2], Bherry Arif Sitinjak [a,3], Yoga Ali Prasetyo [a,4], Muhammad Refky Hasibuan [a,5], Fauzan Alhabib [a,6], Indra Sinaga [a,7], Rio Hardyanto [a,8]

[a] Politeknik Caltex Riau, No. 1 Umban Sari Street, Pekanbaru 28265, Indonesia
[1] jupri@pcr.ac.id; [2] haiqal21ms@mahasiswa.pcr.ac.id; [3] Bherry21ms@mahasiswa.pcr.ac.id; [4] Yoga21ms@mahasiswa.pcr.ac.id;
[5] Refky21ms@mahasiswa.pcr.ac.id; [6] Fauzan21ms@mahasiswa.pcr.ac.id; [7] Indra21ms@mahasiswa.pcr.ac.id; [8] rio.hardyanto16@gmail.com
* corresponding author

ARTICLE INFO

Article history
Received October 24, 2024
Revised November 26, 2024
Accepted December 20, 2024
Available online December 30, 2024

Keywords
Horizontal milling type 1216
Cutter modul M1 and M1,5
Gear
Vibration
VM-6370 vibration meter

ABSTRACT

This study examines the effect of vibrations on the horizontal milling machine type 1216 during gear manufacturing using cutter modules with diameters of 50 mm and 55.25 mm, each at a cutting depth of 1 mm. Measurements of displacement, velocity, and acceleration were conducted in vertical, horizontal, and axial directions using a VM-6370 vibration meter, with the average vibration amplitudes analyzed. The results revealed that the 55.25 mm cutter produced the highest vibration amplitude in the horizontal direction, reaching 353.270 mm/s², while the lowest was in the vertical direction at 171.293 mm/s². For the 50 mm cutter, the highest amplitude occurred in the vertical direction at 0.1336 mm, and the lowest in the horizontal direction at 0.0583 mm. These findings demonstrate that larger cutter modules generate higher vibration amplitudes, significantly affecting the precision and surface quality of gear manufacturing. The study emphasizes the importance of selecting appropriate cutter sizes to minimize vibrations, thereby optimizing the manufacturing process and improving product quality. By providing a detailed analysis of the relationship between cutter size and vibration levels, this research serves as a valuable reference for enhancing the efficiency and accuracy of gear cutting in industrial applications.

1. Introduction

The development of manufacturing technology is currently experiencing rapid progress [1]–[3], especially in the process of working or feeding the surface of workpieces for the manufacture of manufactured, components [4]. One of the machines that is often used in this process is a milling machine especially a horizontal milling machine [5]–[8]. This machine has the ability to perform various cutting operations, such as working on flat surfaces, irregular shapes, to making gears [9]–[12].

However, the workpiece feeding process on a milling machine often produces vibrations, which can affect the quality of the cutting results [13], [14]. These vibrations affect tool wear, cutting temperature, and the surface quality of the workpiece [15]–[19] . In gear manufacturing, variations in the size of the cutter module are one of the main factors that affect the level of vibration and cutting results [12], [20], [21]. The cutter module itself has various sizes and shapes that directly affect the performance of the machine and the quality of the resulting gears [22], [23].

https://doi.org/10.3176/aet.v3i3.1762 aet@ascee.org

This study aims to analyze the impact of vibrations generated during the gear cutting process using a milling machine. Testing was carried out by varying the size of the cutter module, namely 1 mm and 1.5 mm, to understand its effect on vibration characteristics, cutting quality, and gear precision levels. The results of this study are expected to contribute to optimizing the gear cutting process, especially regarding the effect of cutter module variations on vibration and production quality.

2. Method

2.1. Research Methods

This study uses an experimental approach to analyze vibrations on a horizontal milling machine during the gear cutting process using a cutter module size of M 1 and M 1.5. The design of this study includes determining the independent variables in the form of the cutter module size, namely M 1, and M 1.5, with the dependent variable in the form of vibration levels measured through displacement, velocity, and acceleration. Control variables include the machine feeding speed of 19 mm/minute, the workpiece feeding depth of 1 mm, steel material with a diameter of 31.75 mm as the workpiece, and the use of a horizontal milling machine as the main tool in the study.

The tools used in this study include a horizontal milling machine, a cutter module M1 with a diameter of 55.25 mm, a cutter module M1.5 with a diameter of 50 mm, steel workpiece material, and a VM-6370 vibration measuring tool equipped with a probe to detect vibrations on the milling machine head. In addition, a workpiece clamping tool, a speed control system, and software for data analysis are used.

The research procedure begins with the preparation of the experiment, including checking the condition of the milling machine, installing the workpiece on the machine table with a clamping tool, and installing the cutter modules M1 and M1.5 alternately. Furthermore, testing was carried out by operating the machine at a feeding speed of 19 mm/min and a feeding depth of 1 mm to cut the workpiece material. Vibration was measured using a VM-6370 tool on three main parameters, namely displacement (mm), velocity (mm/s), and acceleration (m/s^2), and in three measurement directions: vertical, horizontal, and axial.

The data obtained were analyzed to compare the vibration levels generated by the M1 and M1.5 cutter modules, assess the effect of vibration on the quality of the cutting surface and gear precision, and determine the relationship between the size of the cutter module and the vibration characteristics of the horizontal milling machine. This study was conducted at the Production Machinery Laboratory of the Caltex Riau Polytechnic, with the hope of providing information on the differences in vibration levels generated by the two cutter modules, their impact on the quality of gear cutting, and recommendations for optimizing the cutting process with a horizontal milling machine.

2.2. Research Flow

The flowchart show in Fig. 1 illustrates the steps in the vibration testing process on a milling machine. The process begins with preparing the materials and tools needed for testing. Next, the milling machine is adjusted so that it is ready for material feeding operations. After that, the material is installed in a vise to ensure the workpiece is locked safely and stably during the machining process.

The next step is to turn on the machine to start the milling machine operation. After the machine is turned on, the vibration tester is installed at three main points, namely the axial, horizontal, and vertical axes, to detect vibrations that occur during cutting. The vibration data obtained from the test is then recorded in the form of a table (tabular data) to facilitate the organization of the measurement results.

The final stage is to analyze the collected data to understand the characteristics of the vibrations that occur and their effects on machine performance and cutting quality. After the analysis is complete, the vibration testing process on the milling machine is declared complete (finished). This flowchart provides a systematic overview of the testing stages, from preparation to final data analysis.

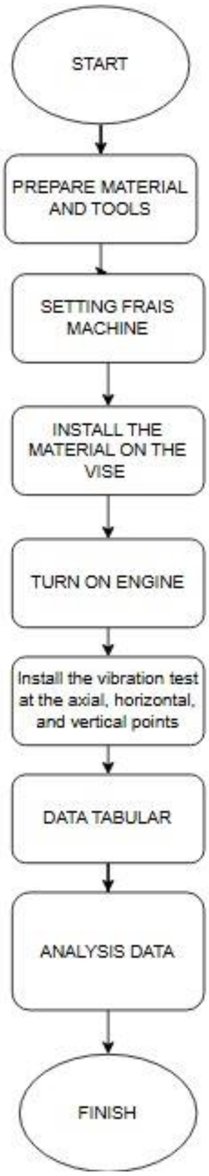

Fig. 1. Data retrieval flowchart

3. Results and Discussion

After the text edit has been completed, the paper is ready for the template. Duplicate the template file by using the Save As command, and use the naming convention prescribed by your conference for the name of your paper. In this newly created file, highlight all of the contents and import your prepared text file. You are now ready to style your paper; use the scroll down window on the left of the MS Word Formatting toolbar.

3.1. Analysis of Measurement Result Data

This research was conducted by the workpiece feeding process using two variations of the cutter module, namely the 1.5 mm cutter module with a diameter of 50 mm and the 1 mm cutter module with a diameter of 55.25 mm, and the measurement was carried out at a thickness of 1 mm with axial, vertical, and horizontal directions. The determination of the measurement point can be seen in Fig. 2 with time domains including (4 sec, 8 sec, 12 sec, 16 sec, 20 sec, 24 sec, 28 sec, 32 sec, 36 sec, 40 sec, 44 sec, 48 sec, 52 sec, 56 sec and 60 sec), which were then processed with a data processing tool and the average price was taken. The data from the processing can be seen in the Table 1.

Table 1. The results of vibration data processing for the milling machine at point 1 mm (a=1mm, a=1.5mm)

M 1	d= 50	a= 1 mm	
Rata Rata	Aksial	Vertikal	Horizontal
Displeacement (mm)	0,0875	0,0307	0,1131
Velocity (mm/s)	1,1940	0,0700	1,9987
Acceleration (mm./s^2)	1786,6667	1827	2593
M 1.5	**d= 55,25**	**a= 1 mm**	**M 1.5**
Rata Rata	Aksial	Vertikal	Rata Rata
Displeacement (mm)	0,0973	0,1336	Displeacement (mm)
Velocity (mm/s)	1,7940	1,2000	Velocity (mm/s)
Acceleration (mm./s^2)	10026,6667	3920	Acceleration (mm./s^2)

In harmonic vibrations, the general vibration formulas apply, namely:

$$Displacement: y = A\ x\ Sin\ \omega t \tag{1}$$

$$\text{Velocity: } \dot{y} = A\ x\ \omega \text{ x } Cos\ \omega \tag{2}$$

$$Acceleration: \ddot{y} = A\omega^2 \sin \omega t \tag{3}$$

Substituting equation 1 into equation 3 will yield

$$\ddot{y} = -y\omega^2 \tag{4}$$

The negative sign indicates that the direction of acceleration is opposite to the direction of its deflection. So we get the vibration frequency in the form of angular velocity.

$$\omega = \sqrt{\frac{\ddot{y}}{y}} \tag{5}$$

A as the maximum deviation price has the same price for displacement, velocity, and acceleration, so the following relationship applies:

$$A1 = A2 = A3 \tag{6}$$

So that it is obtained:

$$\frac{y}{sin\ \omega t} = \frac{\dot{y}}{\omega\ cos\ \omega t} = \frac{\ddot{y}}{\omega^2 sin\ \omega t} \tag{7}$$

$$\frac{y}{\dot{y}} = \frac{\sin \omega t}{\omega \cos \omega t} => \omega t = arc\ tan \frac{y\omega}{\dot{y}} \quad (8)$$

The values of y, and are obtained from the measurement results. These prices are a function of frequency (frequency domain) and time (time domain). The results of these calculations can be displayed in Table 2 as follows:

Table 2. The results of calculating ωt and amplitude from measurements in the time domain

M 1	d= 50	a= 1 mm	
arah	Axial	Vertical	Horizontal
ω	142,868	244,060	151,447
ωt(rad)	10,474	106,921	8,568
ωt(deg)	84,546	89,464	83,343
A	0,088	0,031	0,114
M 1.5	**d= 55,25**	**a= 1 mm**	
arah	Axial	Vertical	Horizontal
ω	321,067	171,293	353,270
ωt(rad)	17,408	19,071	33,309
ωt(deg)	86,712	86,998	88,280
A	0,097	0,134	0,058

3.2. Measurement Results using a Cutter Diameter of 50 mm with a feed process of 1 mm

In the vibration measurement process using test specimens. In this study, a 50 mm milling cutter was used, with a thickness variation of 1 mm. Measurements were carried out in three different directions, namely vertical, horizontal, and axial directions.

Fig. 2. Measurement process with a cutter diameter of 50 mm

The calculation results obtained can be seen in Table 3 below:

Table 3. Calculation results at the measurement point with a cutter diameter of 50 mm, with a thickness variation of 1 mm

Axial	Vertical	Horizontal
142,868	244,060	151,447
10,474	106,921	8,568
84,546	89,464	83,343
0,088	0,031	0,114

Next, it can be seen in Column Chart form in Fig. 3 below:

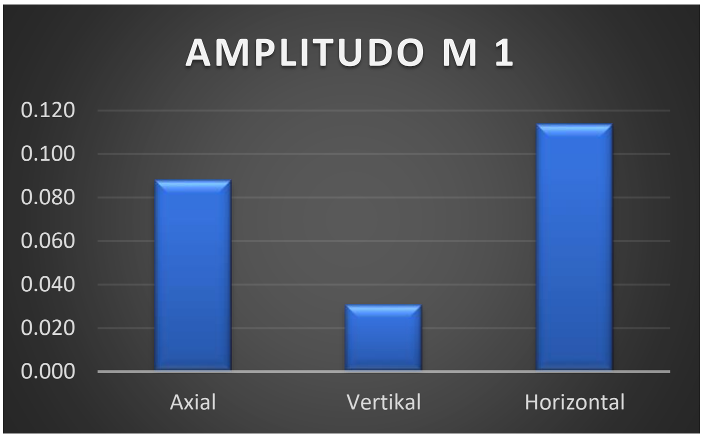

Fig. 3. Calculation results at the measurement point with a cutter diameter of 50 mm, with a thickness variation of 1 mm

From Fig. 3., it can be seen that the largest amplitude occurred in measurements with a feed thickness of 1 mm in the horizontal direction, namely 0.1131 mm. Meanwhile, the smallest occurred in the vertical direction with a value of 0.0307 mm, and in the axial direction, namely 0.0875 mm.

3.3. Measurement Results using a Cutter Diameter of 55.25 mm with a feed process of 1mm

In the vibration measurement process using test specimens. In this study, a 55.25 mm milling cutter was used, with a thickness variation of 1 mm. Measurements were carried out in three different directions, namely vertical, horizontal, and axial directions. Measurements process show in Fig. 4.

Fig. 4. Measurement process with cutter diameter 55.25 mm

The calculation results obtained can be seen in Table 4 below:

Table 4. Calculation results at the measurement point with a cutter diameter of 55.25 mm, with a thickness variation of 1 mm

Axial	Vertical	Horizontal
321,067	171,293	353,270
17,408	19,071	33,309
86,712	86,998	88,280
0,097	0,134	0,058

Next, it can be seen in Column Chart form in Fig. 5 below:

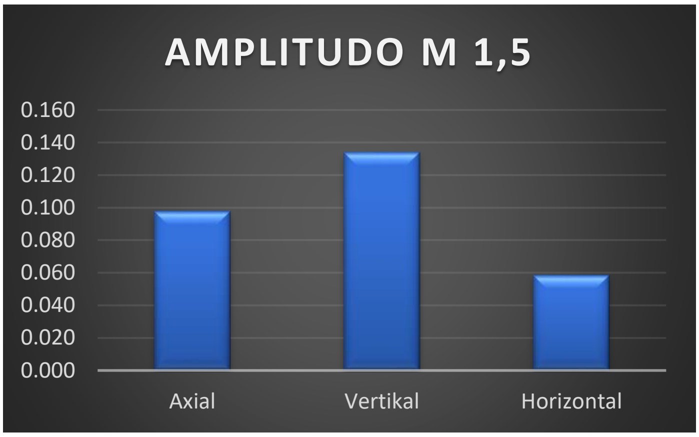

Fig. 5. The calculation results at the measurement point with a cutter diameter of 55.25 mm, with a thickness variation of 1 mm

From Fig. 5, it can be seen that the largest amplitude occurred in measurements with a feed thickness of 1 mm in the vertical direction, namely 0.1336 mm. Meanwhile, the smallest occurred in the horizontal direction with a value of 0.0583 mm, and in the axial direction, namely 0.0973 mm.

3.4. Comparison of Measurement Results for Making Gears Using Cutter Modules M1 and M1.5

After carrying out measurement calculations in making gears using cutter modules M1 and M1.5, Fig. 6 is a comparison of the measurement results produced by cutter modules M1 and M1.5.

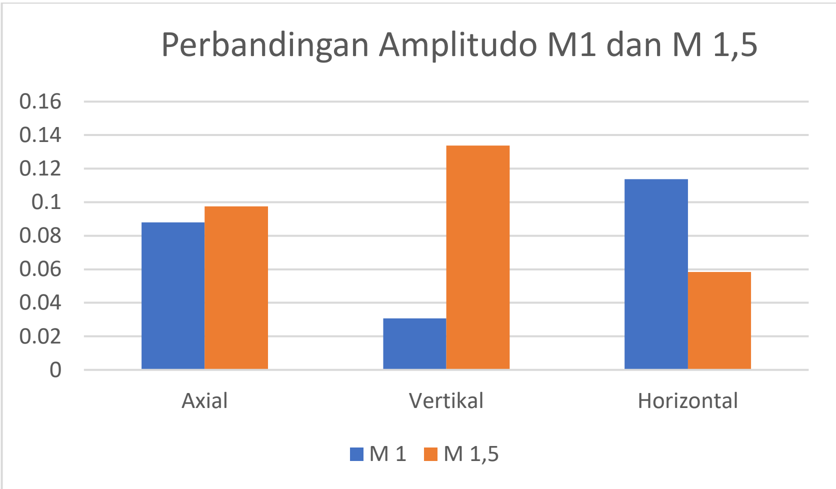

Fig. 6. Comparison graph of vibration results using the M1 and M1.5 cutter modules

Based on the vibration measurement results displayed on the graph, significant differences can be seen in the vibration amplitudes produced by the M1 and M1.5 cutter modules in the three vibration directions (horizontal, vertical and axial). In the horizontal direction, the M1 module produces a greater vibration amplitude than the M1.5 module, indicating that the M1 module is more dominant in producing vibrations in this direction. In contrast, in the vertical direction, the M1.5 module has a much larger amplitude than M1, indicating that vertical vibrations are more significant when using this module. In the axial direction, the vibration amplitude produced by M1.5 is also greater than M1, although the difference is not as big as in the vertical direction. Overall, the M1 module is more suitable for use if you want to maximize horizontal vibrations, while the M1.5 module is more dominant in producing vibrations in the vertical and axial directions. The choice of cutter module should be adjusted to the application needs and the direction of vibration to be controlled.

4. Conclusion

In carrying out vibration measurements in the manufacture of gears using cutter modules M 1 and M1.5, data was collected with a focus on 3 points divided into horizontal, vertical and axial. In collecting data for making gears, there are several important things in the process, such as placing the vibration meter in a good position and the vibration meter holder must be stable. 1) Amplitude Measurement Results (The largest horizontal position amplitude is found when using the M 1 eye with a figure of 0.11383 mm, The largest vertical position amplitude is found when using the M 1.5 eye with a figure of 0.13378 mm, The largest Axial position amplitude is found when using the M 1.5 eye with a figure of 0.09743 mm, The highest amplitude of the two types of eyes used is in the vertical measurement position with the M 1.5 eye of 0.13383 mm). Data obtained from vibration measurements in the manufacture of gears obtained the largest amplitude data in the vertical position using the M 1.5 module cutter eye and the figure was 0.13378 mm. while the smallest amplitude is found in the measurement section in the vertical position using the cutter module M1 with a figure of 0.030668 mm. From all the measurements that have been carried out, the results show that the largest amplitude occurs in the manufacture of gears with an M 1.5 module cutter type. 2) Measurement Process (Using two cutter modules; 1.5 mm module with a diameter of 50 mm, 1 mm module with a diameter of 55.25 mm. Measurements were carried out at a thickness of 1 mm in three directions: axial, vertical and horizontal); 3) Data preprocessing (Data is taken at certain time intervals (4 seconds to 60 seconds), Data is processed using a data processing tool, then the average is calculated to produce the final result). Based on the measurement and analysis results which show significant differences in vibration amplitude between the M1 and M1.5 cutter modules in three vibration directions (horizontal, vertical and axial), it is recommended that the cutter module selection be adjusted to the specific needs of the machining process. If the main priority is to minimize vibrations in the horizontal direction, the M1 module may be a more appropriate choice as it produces larger horizontal vibration amplitudes, which may be useful for certain applications. On the other hand, for needs that prioritize stability in the vertical or axial direction, the M1.5 module is recommended because it produces a higher vibration amplitude in both directions. In addition, it is important to consider other aspects such as material type, cutter geometry, and cutting parameters (spindle speed and feed rate) in order to optimize the quality of machining results while reducing the potential for tool wear or damage to machine components. Further studies are also recommended to evaluate the long-term effects of vibration on tool life and cutting process efficiency. By selecting the appropriate cutter module and optimizing operating parameters, the machining process can be more efficient and produce more consistent quality

Declarations

Author contribution. All authors contributed equally to the main contributor to this paper. All authors read and approved the final paper.

Funding statement. None of the authors have received any funding or grants from any institution or funding body for the research.

Conflict of interest. The authors declare no conflict of interest.

Additional information. No additional information is available for this paper.

References

[1] K. Haricha, A. Khiat, Y. Issaoui, A. Bahnasse, and H. Ouajji, "Recent Technological Progress to Empower Smart Manufacturing: Review and Potential Guidelines," *IEEE Access*, vol. 11, pp. 77929–77951, 2023, doi: 10.1109/ACCESS.2023.3246029.

[2] A. S. Duggal *et al.*, "A sequential roadmap to Industry 6.0: Exploring future manufacturing trends," *IET Commun.*, vol. 16, no. 5, pp. 521–531, Mar. 2022, doi: 10.1049/cmu2.12284.

[3] R. Chaudhary, P. Fabbri, E. Leoni, F. Mazzanti, R. Akbari, and C. Antonini, "Additive manufacturing by digital light processing: a review," *Prog. Addit. Manuf.*, vol. 8, no. 2, pp. 331–351, Apr. 2023, doi: 10.1007/s40964-022-00336-0.

[4] J. J. Beaman, D. L. Bourell, C. C. Seepersad, and D. Kovar, "Additive Manufacturing Review: Early Past to Current Practice," *J. Manuf. Sci. Eng. Trans. ASME*, vol. 142, no. 11, p. 110812, Nov. 2020, doi: 10.1115/1.4048193/1086507.

[5] D. G. Subagio, R. A. Subekti, H. M. Saputra, A. Rajani, and K. H. Sanjaya, "Three axis deviation analysis of CNC milling machine," *J. Mechatronics, Electr. Power, Veh. Technol.*, vol. 10, no. 2, pp. 93–101, Dec. 2019, doi: 10.14203/j.mev.2019.v10.93-101.

[6] M. Góralczyk, P. Krot, R. Zimroz, and S. Ogonowski, "Increasing Energy Efficiency and Productivity of the Comminution Process in Tumbling Mills by Indirect Measurements of Internal Dynamics—An Overview," *Energies*, vol. 13, no. 24, p. 6735, Dec. 2020, doi: 10.3390/en13246735.

[7] M. V. Reddy, H. S. Banka, S. K. Kaleru, and P. K. Peyyala, "Design and development of a 3D printer and machine prototyping CNC milling machine operation," *AIP Conf. Proc.*, vol. 2492, no. 1, p. 040037, May 2023, doi: 10.1063/5.0116965.

[8] K. Saptaji, M. A. Octaviani, M. Yetti, B. Hadisujoto, O. A. Juniasih, and A. Azhari, "Structural Analysis Of A Mini Three-Axis Cnc Micro-Milling Machine With Horizontal Spindle Configuration," *J. Adv. Manuf. Technol.*, vol. 18, no. 2, pp. 1–16, Aug. 2024. [Online]. Available at: https://jamt.utem.edu.my/jamt/article/view/6733.

[9] Z. M. Oo and Y. Myint, "Design Analysis of Gear in Horizontal Milling Machine," *Int. J. Sci. Res. Publ.*, vol. 9, no. 8, p. p9297, Aug. 2019, doi: 10.29322/IJSRP.9.08.2019.p9297.

[10] J.-P. Hung, W.-Z. Lin, Y.-J. Chen, and T.-L. Luo, "Investigation of the Machining Stability of a Milling Machine with Hybrid Guideway Systems," *Appl. Sci.*, vol. 6, no. 3, p. 76, Mar. 2016, doi: 10.3390/app6030076.

[11] A. Nürnberger *et al.*, "Advantages in the production of power transmitting gears by fineblanking," *Int. J. Adv. Manuf. Technol.*, vol. 128, no. 9–10, pp. 4413–4425, Oct. 2023, doi: 10.1007/s00170-023-12160-z.

[12] P. Boral, R. Gołębski, and R. Kralikova, "Technological Aspects of Manufacturing and Control of Gears—Review," *Materials (Basel).*, vol. 16, no. 23, p. 7453, Nov. 2023, doi: 10.3390/ma16237453.

[13] C. David, D. Sagris, E. Stergianni, C. Tsiafis, and I. Tsiafis, "Experimental Analysis of the Effect of Vibration Phenomena on Workpiece Topomorphy Due to Cutter Runout in End-Milling Process †," *Machines*, vol. 6, no. 3, p. 27, Jul. 2018, doi: 10.3390/machines6030027.

[14] M. Baraya, J. Yan, and M. Hossam, "Improving and Predicting the Surface Roughness and the Machining Accuracy in Ultrasonic Vibration-Assisted Milling," *J. Vib. Eng. Technol.*, vol. 12, no. S1, pp. 127–140, Dec. 2024, doi: 10.1007/s42417-024-01406-z.

[15] N. Zhao, Y. Su, S. Wang, M. Xia, and C. Liu, "Chatter Detection in Variable Cutting Depth Side Milling Using VMD and Vibration Characteristics Analysis," *Electronics*, vol. 11, no. 22, p. 3779, Nov. 2022, doi: 10.3390/electronics11223779.

[16] C. Ni, L. Zhu, and Z. Yang, "Comparative investigation of tool wear mechanism and corresponding machined surface characterization in feed-direction ultrasonic vibration assisted milling of Ti–6Al–4V from dynamic view," *Wear*, vol. 436–437, p. 203006, Oct. 2019, doi: 10.1016/j.wear.2019.203006.

[17] F. J. G. Silva *et al.*, "A Comparative Study of Different Milling Strategies on Productivity, Tool Wear, Surface Roughness, and Vibration," *J. Manuf. Mater. Process.*, vol. 8, no. 3, p. 115, May 2024, doi: 10.3390/jmmp8030115.

[18] S. Ehsan *et al.*, "Understanding the effects of cutting conditions on vibrations, surface integrity, machining temperature and tool wear mechanisms in end milling of AISI D2 Steel," *Tribol. Int.*, vol. 198, p. 109894, Oct. 2024, doi: 10.1016/j.triboint.2024.109894.

[19] M. C. Gomes, L. C. Brito, M. Bacci da Silva, and M. A. Viana Duarte, "Tool wear monitoring in micromilling using Support Vector Machine with vibration and sound sensors," *Precis. Eng.*, vol. 67, pp. 137–151, Jan. 2021, doi: 10.1016/j.precisioneng.2020.09.025.

[20] P. Wang, L. Han, J. Li, and F. Liu, "Research on design and manufacturing of gear slicing cutter for circular arc tooth," *Int. J. Adv. Manuf. Technol.*, vol. 113, no. 7–8, pp. 2017–2029, Apr. 2021, doi: 10.1007/s00170-021-06757-5.

[21] Z. Ren *et al.*, "Understanding local cutting features affecting surface integrity of gear flank in gear skiving," *Int. J. Mach. Tools Manuf.*, vol. 172, p. 103818, Jan. 2022, doi: 10.1016/j.ijmachtools.2021.103818.

[22] N. Hodgyai, M. Máté, G. Oancea, and M.-V. Dragoi, "Gear Hobs—Cutting Tools and Manufacturing Technologies for Spur Gears: The State of the Art," *Materials (Basel).*, vol. 17, no. 13, p. 3219, Jul. 2024, doi: 10.3390/ma17133219.

[23] M. Elahi, S. O. Afolaranmi, J. L. Martinez Lastra, and J. A. Perez Garcia, "A comprehensive literature review of the applications of AI techniques through the lifecycle of industrial equipment," *Discov. Artif. Intell.*, vol. 3, no. 1, p. 43, Dec. 2023, doi: 10.1007/s44163-023-00089-x.