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The Analysis Correlation of Tool Wear with Signal Frequency Domain During ST 60 Milling Process Using the Pearson Correlation Coefficient Method

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ABSTRACT
High Speed Steel Cutter (HSS) is widely used in milling processes to cut workpieces, one of them is ST 60. However, cutter weariness is a major problem that can affect the quality of milling and production costs. This is because a prolonged cutting process can cause gradual damage to the cutter's eye due to repeated friction between the cutters and the treated material. Therefore, the study aims to analyze the weariness of the HSS cutter during the ST 60 milling process by using a domain frequency vibration signal approach and periodic weight measurement of the cutter to monitor its weariness. The method to be performed in this study is to perform a milling operation on the ST 60 material using a HSS cutter as well as recording the vibration signal and measuring the cutter's weight at each experimental interval. The result of the vibration signal recording will be processed using Fourier transformation (FFT) to monitor vibration frequency changes that reflect cutter damage. It is hoped that this research will provide a deeper understanding of the mechanisms of HSS cutter depletion, thereby improving the quality of the result and optimizing the cutting conditions to slow the rate of the device.

1.0 Introduction

The sustained development of Industry 4.0 and the development of intelligent manufacturing today are increasing more than ever. Machining processes such as milling that always pay attention to quality and higher efficiency are faced with several problems that are classified as affecting production output such as cutter wear problems.

CNC milling machines are designed using an axis system based on the cartesian coordinate system (Panggabean et al., 2019). The growth system on CNC machines is set based on ISO standards. The working principle of a milling machine is that the main rotating motion is carried out by the cutting tool or cutter while the feeding motion is carried out by the workpiece mounted on the work table (Jufrizaldy, 2020). The 3-axis milling machine is capable of moving the cutting tool in three directions relative to the workpiece (Tangkemanda & Kiswanto, n.d.). The direction of axis movement on a CNC milling machine includes the X-axis for the table leveling direction, the Y-axis for the table crossing direction, and the Z-axis for the upright or vertical spindle direction.

The milling process is one of the commonly used methods for shaping ST 60 steel, where a cutter is used to remove material from the work material. However, the interaction between the cutter and the work material in this process not only creates the potential for increased productivity, but also causes problems such as tool wear and mechanism wear deformation of work materials, and process instability (Gekonde, Haron, and Subramanian, 2002) (Brito et al., 2022).

ST 60 steel is a material that is easily formed according to size and condition. It has properties that are impact-resistant, machine-resistant, and weldable. Medium carbon steel has high-strength properties. This steel has physical and mechanical properties that can be changed in many industries by heat treatment (Singh et al., 2021). Steel is used as a structure because of its excellent plasticity strength and toughness (Singh et al., 2021). In addition to limited elements, carbon steel contains phosphorus (P), silicon (Si), sulfur (S), and manganese (Mn) (Hanung Setiawan et al., 2017). ST 60 steel is a medium carbon steel with a boiling point of 1550°C and a melting point of 2900°C (Syaifullah et al., 2021). With a manganese content of 0.697%, ST 60 steel is hard (Iriandoko et al., 2020).

The machining process will not continue as desired because the tool will show signs of failure over time. Tool wear will occur and the cause must be known to determine corrective action so that in the next machining process the tool life is expected to be higher.

Cutting tools play an important role in high-tech manufacturing processes such as milling. The right material and design are required for the cutting tool to efficiently cut the work material while producing optimal accuracy and quality. High-speed steel (HSS) is one of the most popular cutting tool material options developed in the past. This material has good strength and durability at high cutting speeds. HSS has a main composition of iron (Fe), carbon (C), and some alloying elements such as wolfram (W), manganese (Mn), silicon (Si), vanadium (V), molybdenum (Mo), and cobalt (Co). (Sameh Dabees, Saeed Mirzaei, Pavel Kaspar, 2022). The content of these elements gives HSS tools good strength and durability to work at high cutting speeds.

Cutter wear can cause the production process to be interrupted on the machine and reduce machining efficiency. Several studies have explained that the time wasted due to machining discontinuities caused by tool breakage can have an impact of 20% of the total time used in the production process (Zhou et al., 2022) (Bhuiyan, M.S.H. and Choudhury, 2015). Tool wear is influenced by tool geometry, but it is also influenced by all factors related to the machining process, including type of workpiece and tool material, cutting conditions (cutting speed, depth of cut, and feed rate), coolant, and type of machining process (Rochim, 1993) (Arslan et al., 2016). Siti et al. (2024) found that the precipitation of scales caused parts to fail and become damaged. One of the most important parts of this interaction is the wear aspect. Cutter wear analysis is critical to understanding the mechanics of the machining process and optimizing the machining process parameters (Abdul Hadi et al., 2016) (Şap et al., 2022).

Based on ASTM (American Society for Testing and Materials) definition wear is damage to the surface of a workpiece caused by the relative movement of the object and a contact substance (Blau, 1997). In the research trend of tool wear monitoring, to more easily identify tool wear, a frequency signal approach is used (Dimla Snr., 2002). The features obtained in analyzing vibration signals in the frequency domain are more sensitive to tool wear than in time domain analysis (Rahman et al., 2023). Therefore, the frequency signal approach is seen as more useful in signal processing because it can provide information related to signal components within a certain frequency range (Silva et al., 1998).

This research aims to develop a new approach for wear analysis on HSS cutters by analyzing the frequency signal generated during the milling process of ST 60 using an accelerometer. The frequency signal is expected to represent the dynamics between the cutter and the material being processed. In addition, this research will also measure the weight of the cutter before and after the process to obtain quantitative data on the level of cutter wear. The results of the research are expected to develop a faster and more efficient tool monitoring method and can contribute to the development of science and technology for the development of human civilization/welfare.

To perform frequency signal processing, a sensor is needed that will be used to collect signals or tools as an acquisition so that the signal can be processed using the Fourier Transform algorithm, namely the ADXL 345 type accelerometer sensor. The ADXL335 sensor is a 3-axis accelerometer sensor capable of measuring acceleration in the x-axis, y-axis, and z-axis. This sensor operates at a voltage of 2-3.3 Volts and can measure accelerations up to ± 3g and forward to the microcontroller via the digital in pin on the Arduino using a Serial Peripheral Interface (SPI) (Laumal, 2015). The steps of signal acquisition from the ADXL335 sensor include initializing SPI communication between the sensor and Arduino by setting certain pins. It then reads the data registers from the sensor to get the acceleration values on all three axes. The raw acceleration values are then combined into fractional numbers to get the actual value. The acceleration value is also multiplied by the scale factor to get the unit g.

The calibration program combines the maximum and minimum reference values of the three vibration sensor axes using arithmetic equations for signal processing. Then, the vector and acceleration of the three-axis values will be converted into the ideal value range of machine vibration (Laumal, 2015). The sensor measurement results are captured and stored on the Arduino. Then, this data is sent to the computer via the serial port to be displayed and stored in the database.

Furthermore, the data collected from these sensors is analyzed using signal processing techniques to be able to show the change in tool wear. Frequency domain analysis is considered to be the most useful signal processing technique as it can provide information about signal components within a specific frequency range (Silva et al., 1998).

In the process of wear research, one of the important parameters that must be considered is the measurement of tool wear. This can be done using several methods, such as using a digital microscope and measuring the mass of the cutter before and after tool use.

With their ability to make direct measurements and store data digitally, digital microscopes are considered to have advantages in measuring wear on a micro-scale. Mass measurement is one method to determine the level of tool wear that occurs during the milling process. Measurements are made using a tool in the form of a digital analytical balance. A balance sheet is a tool that serves to weigh an object based on the principle of force balance (ISO, 2020). The ideal balance sheet to use is the digital analytical type because it has high accuracy, up to 0.1 mg.

In this study, the cutting process begins and ends with measuring the tool mass. (Manta et al., n.d.). The purpose is to determine how much tool material is lost due to wear during the cutting process. The difference between the initial and final mass indicates the amount of material worn and obtains tool wear data (Manta et al., n.d.).

The purpose of the research on "The Analysis Correlation of Tool Wear with Signal Frequency Domain on Milling Process St 60 with Pearson Correlation Coefficient Approach" is to present the analysis of signals related to cutter wear, for a) Identifying HSS cutter wear with frequency signals on ST 60 workspiece, b) Identify the type of wear that occurs on the HSS cutter, c) Analyze the change in cutter weight before and after the milling process to determine the level of cutter wear quantitatively, d) Identify the relationship between the Frequency Domain and the wear value of the cutter weight.

2.0 Research Method

Figure 1 shows the flowchart in this research which is useful as a reference in conducting this research. Start from study literature to analysis and then make a report.

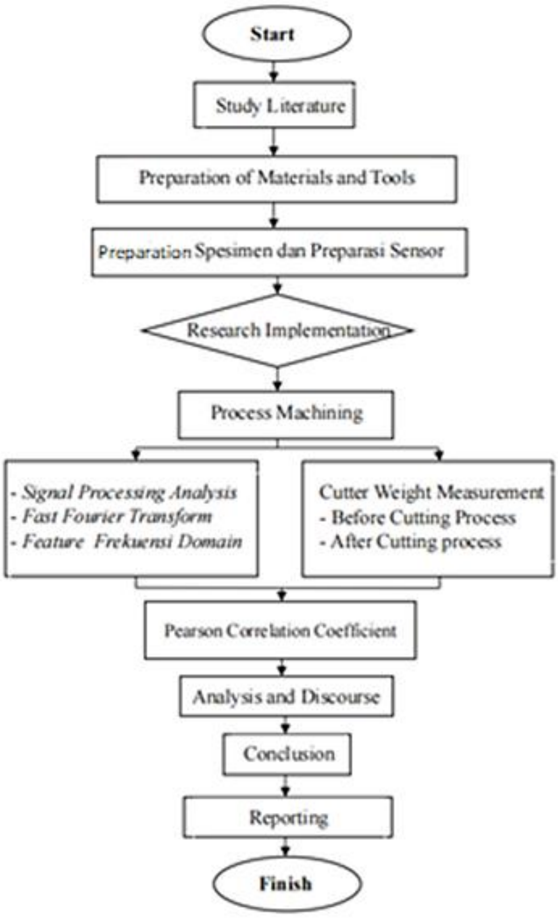

Figure 1: Research Flow chart

2.1 Preparation of Experimental Setup

The data taken in this study are the vibration frequency signal data obtained from the ADXL 345 sensor, the wear amount data from the capture results obtained from the digital microscope capture results, and the cutter weight data obtained from the analytical balance that the author has prepared on previous occasions. In this study, the authors used Workspiece with ST 60 material also known as AISI 1050 with hardness or Hardness 50-60 HRC which has a thickness of 30 mm, a width of 70 mm, and a length of 70 mm, which has specifications as shown in Table 1.

Table 1: AISI 1050 Mechanical Properties

Material	Tensile Strength (N/mm2)	Elongation (%)	Reduction (%)	Modulus of Elasticity (N/mm2)	Hardness (HRC)
S50C / ST 60 / AISI 1050	565	16	40	200	175 – 275

This research adopts an Experimental Setup that uses a CNC Machine Type EMCO T.U CNC-3A with an End Mill cutter with a diameter of 10 mm as listed in Table 2.

Table 2: Cutting tool specifications

Type	Merk	Total no.of flutes	Condition	Dia. (mm)	Dimension (mm)
HSS End Mill	SWT	4F	New	10	10 x 10 x 22 x 72

In this research, the sensors used are ADXL 345 accelerometer with ESP-32 module and two Digital Microscopes attached near the cutter as seen in Figure 2 (a) and Figure 2(b), which will be used to see the amount of cutting tool wear that has been used during the milling process. This accelerometer sensor is mounted on the workpiece which will read 3 Axis X, Y, and Z.

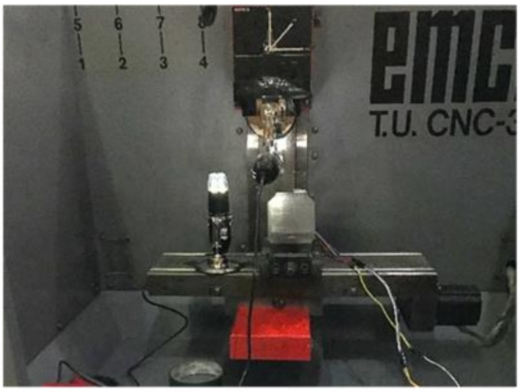

Figure 2 (a) Display of workpiece position, cutting tool, ADXL 345 sensor, and digital microscope

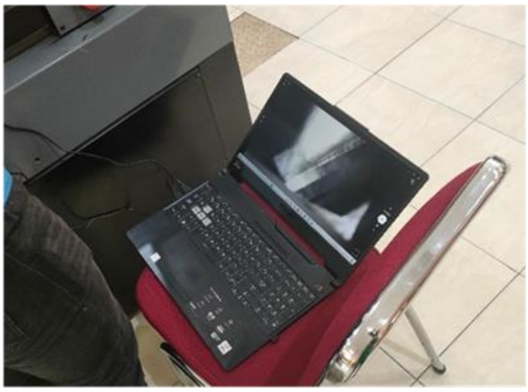

Figure 2 (b) Capture result of cutting edge by digital microscope.

This study was conducted using a Spindle Speed of 780 RPM and feeding 80 mm/min to collect vibration data, and the applied Axial depth (ADOC) was 1.0 mm and the applied Radial depth (RDOC) was 5.0 mm. All the parameters set are not far from the machining recommendations that had been planned before the research was carried out.

2.2 Fast Fourier Transform (FFT)

Fast Fourier Transform is a technique used to convert signal representations from the time domain to the frequency domain. (Smith & Lee, 2005). FFT will convert a signal in the form of a time function into its spectral representation in the form of amplitude-frequency according to a journal written by Ahmad, et al. (Rahman et al., 2023). Through FFT, several important frequency features can be extracted, such as Insert Passing Frequency (IPF), sideband, and harmonic frequency of IPF. These features are then used (Rahman et al., 2023).

The FFT allows the separation of signals based on their frequencies so that the frequencies that indicate tool wear can be identified to perform correlation analysis with tool wear rate. To determine which frequencies, indicate tool degradation, Brito, et al. conducted a study on the gearbox fault monitoring procedure (Brito et al., 2022). According to them, vibrations caused by contact in the gearbox can be compared to vibrations caused by the contact of the tool blade with the workpiece. Therefore, the contact that occurs in the gearbox, where gears rub or make contact with each other or the gear mesh frequency (GMF), becomes an important parameter in gearbox analysis.

To calculate GMF, there is a need to know the number of gears (T), and the rotational speed of the engine (n) in units of rpm.

$$\mathrm{GMF} = \frac{\mathrm{T}\ .\ \mathrm{n}}{60}\ [\mathrm{Hz}] \quad [1]$$

Analogous to gearbox vibration analysis, impulses that occur due to the contact of the tooltip with the workpiece in the frequency domain can be referred to as the insert passing frequency (IPF), which is closely related to the Spindle Frequency (SF).

$$SF = \frac{n_s}{60}[Hz] \quad [2]$$

$$IPF = SF \cdot N_T [Hz] \quad [3]$$

Where n_s is the spindle speed on the CNC machine, measured in RPM and N_T is the number of flutes on the tool used.

Consistent with the gearbox damage monitoring analysis method, some sidebands - small signals between the IPF and its harmonics - can also be in line with the tool wear rate. The magnitude of these sidebands varies greatly depending on the tool wear rate. A simple calculation to identify sidebands between frequencies can be obtained as follows:

$$SB = IPF \pm h \cdot SF [Hz] \quad [4]$$

As in the previous equation, h represents a multiple of the sideband (h = 1, 2, 3, …..).

In this calculation, IPF and SB can be expressed in terms of the cutting frequency (CF), the value of this CF will be used to determine the value of correlation with the cutting process.

$$CF = \frac{Frequency}{IPF} \quad [5]$$

If the resulting value is an integer, such as (1, 2, 3,….), then the resulting frequency must be a harmonic fund. If the value shown is fractional (0.25, 0.5, 0.75, 1.25,……), then it is included in the sideband and if CF is not an integer and a fraction, then it is an unknown frequency (Rahman et al., 2023).

2.3 Pearson Correlation Analysis

Pearson Correlation Coefficient (PCC) or Person correlation is a coefficient used to determine the strength or closeness of the relationship between two or more variables. By calculating PCC, the relationship between vibration signal frequency and tool wear can be determined. This method has been widely used in feature selection research (Brito et al., 2022).

A formula that can be used to calculate PCC:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x}).(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}.\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad [6]$$

Where X is the frequency being analysed and Y is the value obtained from the weight measurement of cutter wear. Pearson correlation coefficients range from -1 and 1. Values close to +1 indicate a strong positive correlation, and coefficients close to 0 indicate that the correlation is weak.

3.0 Results and Discussion

3.1 Signal analysis

The most significant stage in this research is the signal processing stage. At this stage, the monitoring process was carried out on the signal obtained from the ADXL 345 Accelerometer sensor installed on the AISI 1050 or ST 60 Workspiece. The signal obtained from the first milling result is a reference or basis for comparing the vibration signals obtained from the machining process. The pattern of inequality, amplitude, and frequency of the resulting vibrations will be the main indicators for monitoring the wear and tear of the cutting tool.

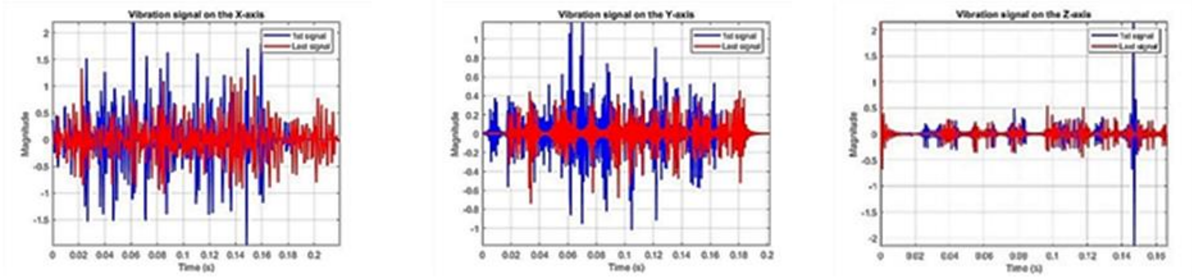

Figure 3: a) On the X-Axis of the Workpiece, b) On the Y-Axis of the Workpiece, c) On the Z-Axis of the Workpiece

Figure 3 shows a comparison of the experimental signals between the first experiment (Blue) and the last experiment (Red) in the time domain. The difference showed that the last signal has a smaller amplitude than the amplitude of the reference signal or the first signal. According to Ahmad et al., a decrease in the magnitude of the signal vibration amplitude detected during a cutting session indicates wear or damage at the cutting tool tip (Oberg et al., 1915).

This implies that the cutting tool used during the machining process has lost its sharpness, so when it is used in the next milling process, the product will no longer be precise. This has also been explained by Zhang in his research that the decrease in amplitude in the vibration signal that occurs along with the wear of the cutting tool can be attributed to the occurrence of plastic deformation or permanent shape change in the processed object. This plastic deformation factor has an impact on the decrease in cutting force produced by the cutter. This is because cutter wear results in reduced friction during cutting. Finally, this decrease in cutting force leads to a weakening of the amplitude of the vibration signal generated during the cutting process (Ahmad et al., 2015).

In monitoring or diagnosing the wear signal that occurs, it is necessary to first identify and select the cutting signal, especially those related to the spindle as well as the X, Y, and Z axes. However, in this study, the authors previously identified the frequency indicating the spindle frequency (SF) as follows:

$$\mathrm{SF} = \frac{\mathrm{n_s}}{60}[\mathrm{Hz}] = \frac{780}{60} = 13\ \mathrm{Hz}$$

It is also possible to determine the Gear Mesh Frequency (GMF) by multiplying the spindle speed (SF) by the number of eyes (sickle) of the cutter used:

$$\mathrm{GMF} = \frac{\mathrm{T}\ .\ \mathrm{n}}{60}\ [\mathrm{Hz}] = \frac{780\ \mathrm{x}\ 4\mathrm{F}}{60} = 52\ \mathrm{Hz}$$

So, the eye (sickle) frequency of the cutter is 13 Hz. The IPF (Insert Passing Frequency) of the cutting process is equal to 4x 13 Hz or 52 Hz. Not all frequencies can be presented in the form of graphs or figures because there is no significant frequency that shows the frequency that matches the spindle frequency that has been listed previously.

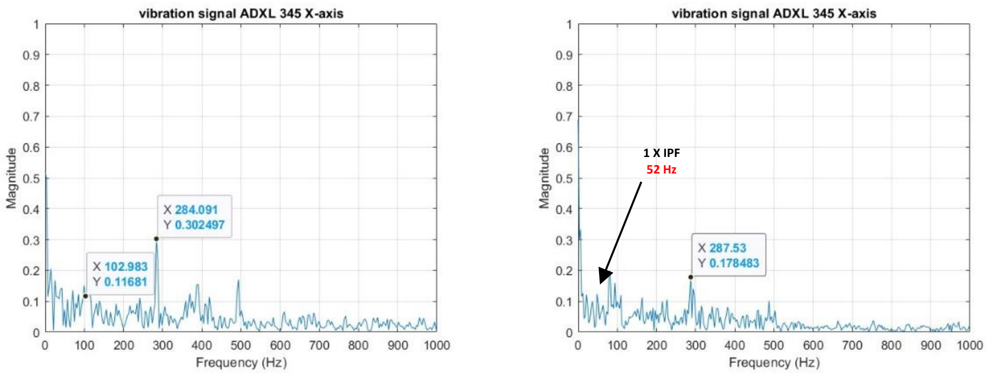

Figure 1: 1st Vibration Signal On X-Axis

Figure 2: 100th Vibration Signal On X-Axis

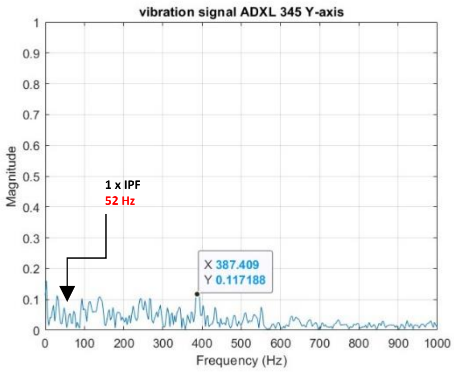

Figure 3: 1st Vibration Signal on Y-Axis

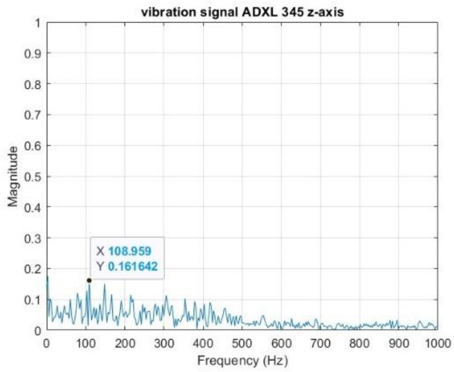

Figure 4: 100th Vibration Signal on Y-Axis

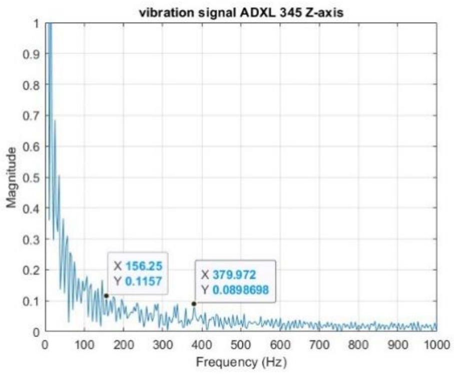

Figure 5: 1st Vibration Signal on Z-Axis

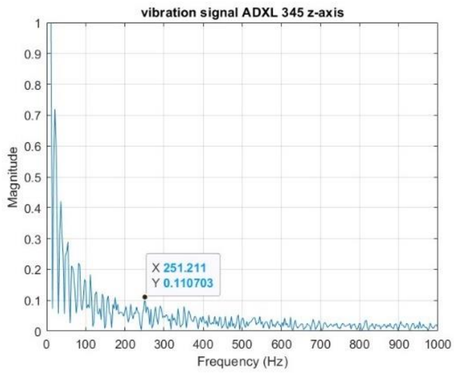

Figure 6: 100th Vibration Signal on Z-Axis

The dominant frequency detected in the 1st experiment was 284.091 Hz (Figure 4). This was not the cutting frequency, and it was identified as an unknown frequency. Meanwhile, in the 100th experiment, it was found that the dominant frequency detected was 287.53 (Figure 5), with different amplitudes. This amplitude difference phenomenon indicated that the cutting tool used has experienced wear and tear (Ahmad et al., 2015). A frequency signal of 387.409 Hz (Figure 6) generated by the Y axis was detected at the beginning of the experiment while in the 100th experiment, the detected frequency was nearly two times the IPF of 102 Hz, which is the cutting frequency. However, the detected frequency was 108.959 Hz (Figure 7).

On the Z axis, the frequency signal detected showed the cutting frequency (Figure 8) but at the 100th signal, the frequency observed at the beginning was no longer present (Figure 9), there was only a decrease in the amplitude of the dominant signal detected by the accelerometer sensor.

3.2 Identification of Tool Wear Experiment

This research used a 10mm End Mill to cut AISI 1050 or ST 60 workspiece. As the cutting session or experiment progresses, the cutting tool used will experience increasing wear. This research clarified and identified the type of wear that occurred on the cutting tool during the milling process of an AISI 1050 workpiece using a digital microscope.

Figure 10: a) The position of the digital microscope during the capture of the tool (left), b) Result of capture

Figure 11: a) Initial condition of sharp cutter (left), b) Cutter condition starting to wear (normal), c) Cutter condition - worn heavily (damaged)

Figure 10 a) shows that the cutting tool used still looks sharp and new. Figure b) shows that the cutting tool has experienced normal wear, which can still be considered stable and this condition was found in the 28th experiment. Figure 10 c) shows the condition of the cutting tool which has experienced heavy wear, which was predicted to occur in the 55th experiment.

After the experimental session was completed, the cutting tools used were then inspected using a digital microscope, which was prepared to examine cutter wear on each flute or cutter eye.

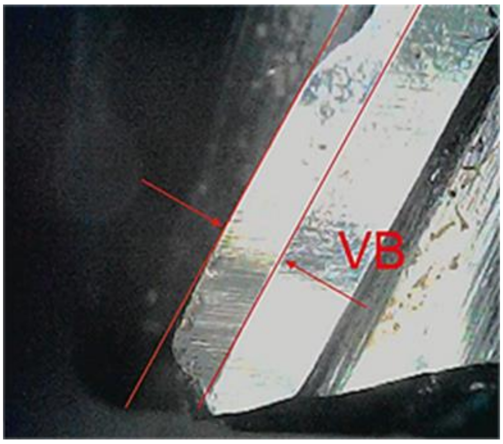

Figure 12: Measurements to determine the wear value

In the results of wear measurement with a digital microscope, the wear on the cutter was identified as edge wear, also known as Flank Wear (VB), as shown in Figure 12.

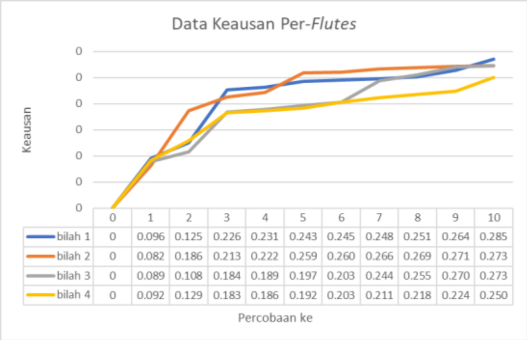

Figure 7: Cutter wear values on individual flutes

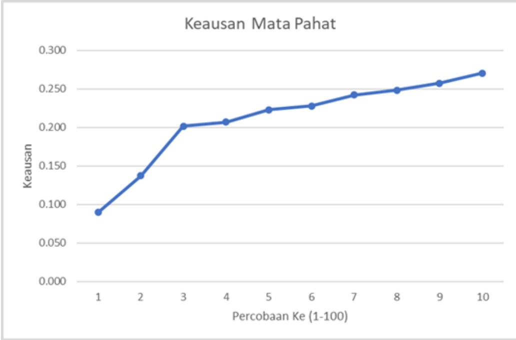

Figure 8: Cutting tool wear during cutting session 1-100

Figure 13 is a graph of the measured cutting results, presented in graphical form. Wear that occurs on cutting tools is a complex phenomenon because it is caused by various factors in machining, such as cutting parameters, cutter geometry, and the material of the workpiece. The phenomenon that often indicates that the cutting tool has experienced wear will affect the vibration pattern detected by the sensor.

Figure 15: a) Condition of the first flute at the end of the experiment (left), b) Condition of the second flute at the end of the experiment (right)

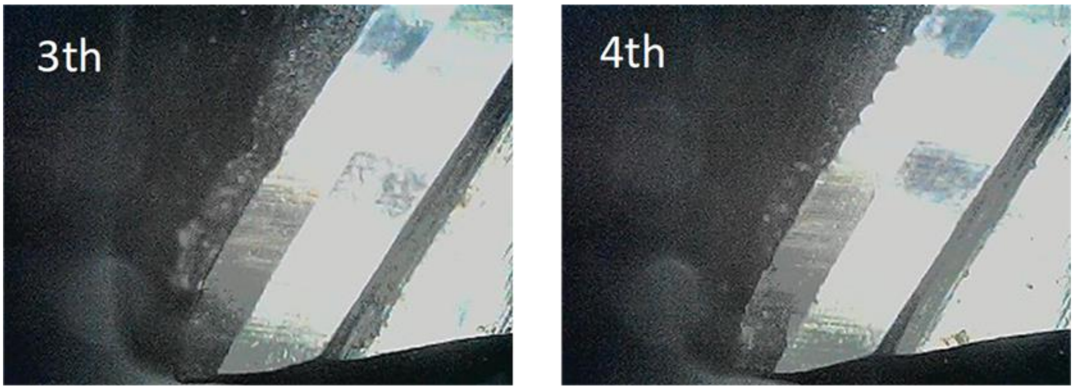

Figure 16: c) Condition of the third flute at the end of the experiment (left), d) Condition of the fourth flute at the end of the experiment (right)

3.3 Cutter Weight Analysis

A weight measurement of the cutting tool in each experimental session was carried out by weighing the cutting tool with a balance sheet. The weighing was carried out before the cutter performed the cutting process and once the cutting had been completed. This weight measurement was intended to find out the amount of wear on the cutting tool by measuring the weight loss of the cutter during the cutting process.

Figure 17: a) Initial Cutter Weight before 1st Cutting Process, b) Cutter Weight after Cutting Process (100th)

Figure 17 shows that before the experiment, the weight of the cutter was 89.27 g and at the end of the experiment, the weight of the cutter was 88.62 g. So, the total weight loss of the cutter during the cutting process, which resulted in wear was 0.646g.

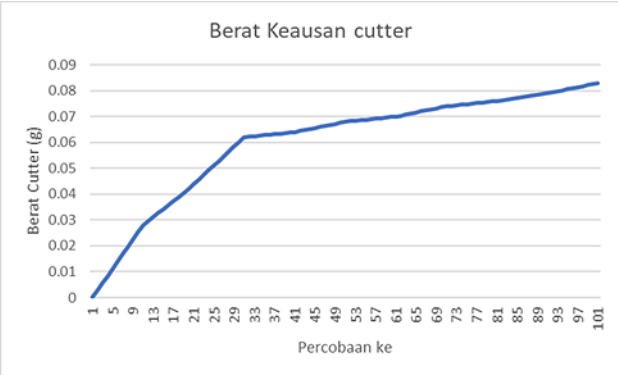

Figure 18: Cutter weight loss due to wear

In Figure 18, the progression of wear values from the beginning to the end of the experiment is shown.

3.4 Pearson Correlation Coefficient with Cutter Weight

The PCC (Pearson Correlation Coefficient) approach in equation (6) was the method used in this study to calculate the correlation of all frequency signals that occurred or were detected with cutting tool wear, where cutting tool wear in this study was measured by the weight of the cutter used.

In this study, the correlation between frequency and wear was divided into 3 categories, namely Highly Correlated, Correlated, and Weakly Correlated.

Table 3: PCC Calculation analysis results

PCC	Correlation Category	Number of frequencies on		
		X-Axis	Y-Axis	Z-Axis
0,67 – 1,00	Highly Correlated	-	-	-
0,34 – 0,66	Correlated	6	-	20
0,00 – 0,33	Weakly Correlated	329	344	310
Total frequency signals		336	345	331

In this study, no frequencies with a high correlation were identified, but the correlated category (Correlated Frequency) was found on the X and Z axes only. Among the three axes, the Y-axis recorded the highest number of frequency signals, with a total of 345 frequencies but neither HCF (High Correlated Frequency) nor CF (Correlated Frequency) was found, with only WCF (Weakly Correlated Frequency) detected at 344 frequencies.

On the X axis, CF (Correlated Frequency) was found at 6 frequencies while WCF (Weakly Correlated Frequency) was at 330 frequencies. The Z-axis found the weak of CF (Correlated Frequency) which is 20, but no HCF was found (High Correlated Frequency), while the WCF (Weakly Correlated Frequency) is 310. These findings also validate the identification of wear that occurred in Figure 14, which means that wear occurred along the entire axis observed, especially on the X-axis and Z-axis, which show a correlation (PCC) ranging between 0.34 - 0.66.

Table 1: Frequency that Correlates with (Weight) Cutting tool wear.

No.	X-Axis			Y-Axis			Z-Axis		
	Freq (Hz)	PCC	IPF/SB	Freq (Hz)	PCC	IPF/SB	Freq (Hz)	PCC	IPF/SB
1	4,55	0,491	SB	0	0	-	43,97	0,630	SB
2	494,24	-0,486	SB	0	0	-	18,19	-0,624	SB
3	495,76	-0,431	SB	0	0	-	16,68	0,551	SB
4	283,51	-0,420	SB	0	0	-	31,84	0,505	SB
5	18,19	-0,353	SB	0	0	-	45,48	-0,495	SB
6	10,61	0,343	SB	0	0	-	89,45	0,492	SB

In Table 4, among the signals that correlate with the cutting tool wear (weight), no cutting frequency is penalized by CF (Correlated Frequency). There were only frequency signals that showed sidebands (SB) or small signals between the IPF signal and its harmonics.

However, in the weakly correlated frequency (WCF) category, there was a cutting frequency signal that correlates with the weight of cutting tool wear.

Table 2: Frequencies that are Weakly Correlated with (Weight) Cutting tool wear

No.	X-Axis			Y-Axis			Z-Axis		
	Freq (Hz)	PCC	IPF/SB	Freq (Hz)	PCC	IPF/SB	Freq (Hz)	PCC	IPF/SB
1	33,35	-0,319	SB	244,09	-0.265	SB	137,96	0.334	SB
2	109,16	-0,300	SB	391,15	-0.294	SB	122,80	0.276	SB
3	24,26	-0,290	SB	1,52	0.260	SB	6,06	0.269	SB
4	16,68	0,255	SB	10,61	0.259	SB	142,51	0.251	SB
5	107,64	0,191	SB	81,87	0.222	SB	160,70	0.225	SB
6	322,92	0,120	SB	307,76	0.216	SB	148,57	0.198	SB
7	488,18	0,112	SB	157,67	0.196	SB	203,15	0.193	SB
8	306,25	0,108	SB	52	0.141	IPF x 1	175,86	0.189	SB
9	156	0,100	IPF x 3	156	-0.118	IPF x 3	80,35	0.183	SB

In Table 5, it is shown that the signal that correlates with the cutting tool wear weight was not only the SB signal but also the cutting frequency. On the X axis, a frequency of 156 Hz, which is IPF x 3 of the cutting frequency was found, and on the Y axis, a frequency of 52 Hz, which was IPF x 1, and 156 Hz IPF x 3 was found. Meanwhile, on the Z axis, no cutting frequency that correlates with the weight of cutter wear was found.

4.0 Conclusion

This research focused on the correlation of vibration signal frequency with cutting tool wear (weight) during the milling machining process on AISI 1050 or ST 60 workpieces. This research has provided new insights or reinforced existing understanding and opened new gaps for new methods in the theme of monitoring signals.

The results of this study reveal a fairly significant relationship between the vibration frequency signal of the cutting tool and the weight of cutter wear, as detailed below. The reduced amplitude produced by the vibration signal which was detected by the sensor indicates that the tool has experienced severe wear or damage. The wear that occurs on HSS cutters during machining processes on AISI 1050 or ST 60 workpieces is a type of flank wear, which is also known as edge wear that occurs on the first cutter flutes.

Based on the experimental results in this study, it was found that the signal frequency generated by cutter vibration correlates with cutter weight, which validates and accepts the Hypothesis stating that: Certain frequencies correlate with the weight of HSS cutter wear during the milling process of ST 60. The lowest frequencies that are said to correlate well with wear are 4.55 Hz and 43.97 Hz with PCC >50%.

Suggestions from this research include paying attention to the specifications of tools and machines used because these factors will impact the research results. As in this research, a CNC-type machine production unit should ideally be used but a Training type CNC machine unit was used instead. Signal monitoring acquisition equipment is required in monitoring to identify any possible setup error. For future research, it is recommended to collect more data to identify higher correlation values and to add sensor accelerometers on the spindle to obtain secondary frequency data.

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Author Contributions

Elvis Adril: Conceptualization, Methodology, Software, Formal Analysis, Investigation, Data Curation, Writing- Original Draft Preparation; **Yuliarman**: Data Curation, Validation, Supervision; **Maheka Restu Araliz**: Software, Visualisation; and **Afif Elqudsi:** Project Administration, Supervision.

Conflicts of Interest

The manuscript has not been published elsewhere and is not being considered by other journals. All authors have approved the review, agree with its Submission, and declare no conflict of interest in the manuscript.

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