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Effects of Cutting Parameters on Acoustic Frequency Created in Machining of Cold Work Tool Steels

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Abstract

The objective of this study is to investigate the effects of machining parameters on the acoustic frequency developed during the machining of cold work tool steels. The machining tests were carried out through a milling method with different machining parameters. Analogue acoustic signals obtained via the microphone were converted and digitized. During idle operation and cutting operation, the obtained spindle sound recordings were subjected to Fast Fourier Transform (FFT) and converted from the time domain to the frequency domain, and the statistical effects of cutting parameters were investigated by use of analysis of variance. Cutting speed was found to be the only influential factor for the acoustic frequency in idle time. In the starting of machining, the feed rate, cutting speed, and depth of cut were seen to affect the acoustic frequency, while the cutting speed, insert material, insert radius, depth of cut, and feed rate were seen to be effective in the later stages of machining.

1. INTRODUCTION

Sound is the series of vibrations formed in a liquid, gas, or solid environment which is physically present between the listener and the sound source [1]. The elastic structure of the environment allows the sound to propagate in waves from the source. When an object is exposed to vibration, it spreads some of its energy as sound to its surrounding. The sound does not travel in vacuum environments. The time-amplitude graphic of a sound wave is shown in Fig. 1. The sound continues in the air by creating pressure differences. The point to be taken into account here is that only the pressure differences propagate, while the air does not. We can associate this with an object moving up and down which meets the waves created by a stone thrown on a water surface. Therefore, no draft is formed in front of powerful loudspeakers. The speed of sound in air is about 343 m/s at one atmosphere of pressure and 20 °C ambient temperature.

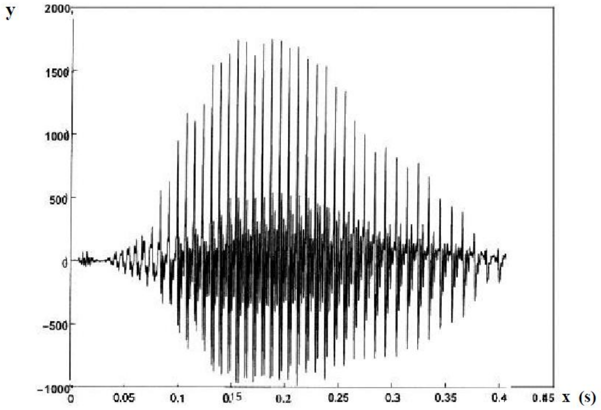

Figure 1. *Sound waveform (x represents the time and y the amplitude).*

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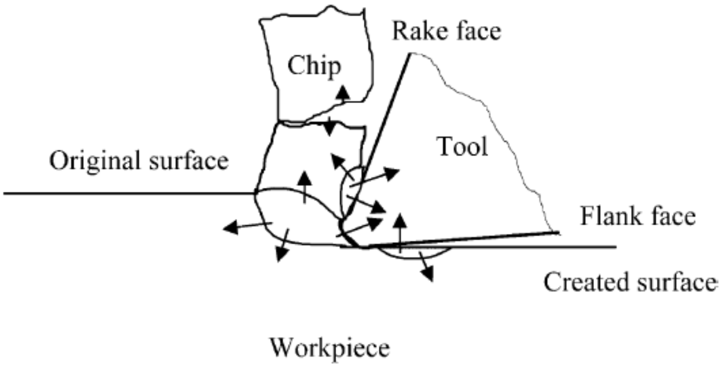
Acoustics is the science and technology of sound. Acoustic emission (AE) is the class of phenomena whereby transient elastic waves are generated by the rapid release of energy from a localized source or sources within a material, or the transient elastic wave(s) so generated' (ANSI/ASTM E 610-77). Clearly, an AE is a sound wave or, more properly, a stress wave that travels through a material as the result of some sudden release of strain energy. In recent years, AE instruments and systems have been developed for the monitoring and nondestructive testing of the structural integrity and general quality of a variety of materials, manufacturing processes, and some important devices [2].

During metal cutting, the workpiece undergoes considerable plastic deformation as the tool pushes through it. Within the deformation zones (dislocation movements), strain energy is released as the bonds between the metal atoms are disturbed. This released energy is commonly referred to as AE. Other sources of AE include phase transformations, friction mechanisms (tool-workpiece contact), and crack formation or extension fracture [3].

Tool wear is a complex phenomenon occurring in different and varied ways in metal cutting processes. Generally, worn tools adversely affect the surface finish of the workpiece and therefore there is a need to develop tool-wear-condition monitoring systems which alert the operator to the state of the tool, thereby avoiding undesirable consequences. Various methods for tool wear monitoring have been proposed in the past, even though none of these methods were universally successful due to the complex nature of the machining processes. These methods were classified into direct (optical, radioactive and electrical resistance, etc.) and indirect (AE, spindle motor current, cutting force, vibration, etc.) sensing methods according to the sensors used. Recent attempts have concentrated on development of the methods that monitor the cutting processes indirectly. Among these indirect methods, AE is one of the most effective for sensing tool wear. The major advantage of using AE to monitor tool condition is that the frequency range of the AE signal is much higher than that of the mechanical vibrations and environmental noises and does not interfere with the cutting operation [2].

Research has shown that AE, which refers to stress waves generated by the sudden release of energy in deforming materials, has been successfully used in laboratory tests to detect tool wear and fracture in single point turning operations. Liang and Dornfeld [4] pointed out the following possible sources of AE during metal cutting processes (Fig. 2):

(a) plastic deformation during the cutting process in the workpiece;
(b) plastic deformation in the chip;
(c) frictional contact between the tool flank face and the workpiece, resulting in flank wear;
(d) frictional contact between the tool rank face and the chip, resulting in crater wear;
(e) collisions between chip and tool;
(f) chip breakage;
(g) tool fracture.



- Arrows indicate emitted AE

Figure 2. *AE generation during metal cutting*

Based on the analysis of AE signal sources, AE derived from metal turning consists of continuous and transient signals, which have distinctly different characteristics. Continuous signals are associated with shearing in the primary zone and wear on the tool face and flank, while burst or transient signals result from either tool fracture or chip breakage. Therefore, in Fig 3 (a)-(d), sources generate continuous AE signals, while in Fig 3 (e)-(g) they generate transient AE signals. The AE signal types in the cutting process are shown in Fig. 4 [2].

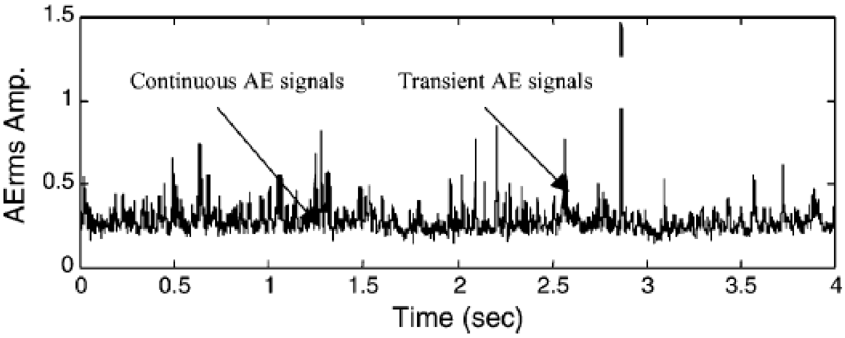


Figure 3. *Typical AE signals in turning.*

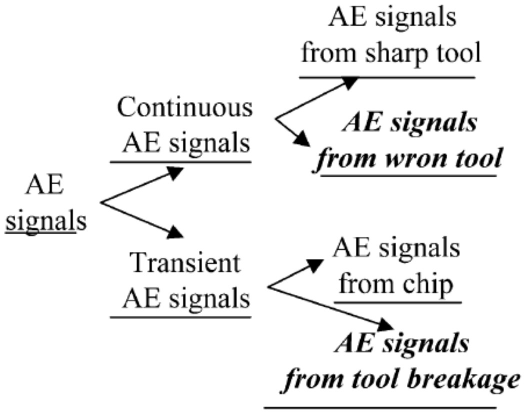


Figure 4. *AE signal type in cutting process.*

Many signal processing methods have been used to analyze AE signals, with the aim of extracting the features of AE signals for testing or monitoring. The main methods include time series analysis, Fast Fourier Transform (FFT), Gabor Transform [or window (local) Fourier transform], Wigner–Ville distribution, and wavelet transform. Since FFT was used in the experiment conducted, a brief explanation of it is given below [2].

Fourier transform

An energy-limited signal $f(t)$ can be decomposed by its Fourier transform $F(w)$, namely

$$f(t) = \frac{1}{2\pi}\int_{-\infty}^{*\infty} F(w)e^{iwt}dt \qquad (1)$$

Where

$$F(w) = \int_{-\infty}^{*\infty} f(t)e^{-iwt}dt \qquad (2)$$

$f(t)$ and $F(w)$ are known as a pair of Fourier transforms. Equation (1) implies that the $f(t)$ signal can be decomposed into a family with harmonics e^{iwt} with the weighting coefficient $F(w)$ representing the amplitudes of the harmonics in $f(t)$. $F(w)$ is independent of time; it represents the frequency composition of a random process, which is assumed to be stationary, so its statistics do not change with time. Fourier transform has been successfully used to process the AE signal during turning. Experimental results of Li and Yuan [5] have shown that the magnitude of the AE in the frequency domain was sensitive to the change of tool state. However, the AE signal is essentially non-stationary. If we calculate the frequency composition of non-stationary signals by using Fourier transform, the results are the frequency composition averaged over the duration of the signal.

In research of Tekiner and Yeşilyurt [6], they aimed to determine the most suitable cutting parameters for use in processing AISI 304 stainless steel according to the sound of processing. By comparing the pressure levels of ideal cutting parameters and processing sounds, they revealed that the most suitable cutting parameters can be determined by analysing the processing sound. In consequence, they found that the ideal cutting parameters were a cutting speed of 165 m/min and spindle speed of 0.25 rev/min [6].
Automation and optimization of the manufacturing process, monitoring, and diagnostic systems are becoming increasingly necessary in manufacturing. The research was done to extract the maximum information from AE signals acquired during machining. A statistical method, the time series modeling technique, was used to extract parameters called features representing the state of the cutting process. Autoregressive (AR) parameters, the power of the AE signal, and AR residual signals are studied here as features and found to be effective in tool condition monitoring. Once all these features are extracted after the preliminary processing of AE signals, the tool status, that is, whether it is worn out or not (serviceable), is decided on the basis of a pattern recognition technique [7].

The monitoring of tool wear is a most difficult task in the case of various metal-cutting processes. Artificial Neural Networks have been used to estimate or classify certain wear parameters using continuous acquisition of signals from multi-sensor systems. Most of the research has been concentrated on the use of supervised neural network types like the multi-layer perceptron (MLP), using the back-propagation algorithm and the Radial Basis Function network. In a research, a new constructive learning algorithm proposed by Fritzke, namely Growing Cell Structures (GCS), was used for tool wear estimation in face-milling operations in order to monitor the condition of the tool. GCS generates a compact network architecture in less training time and performs well on new untrained data. The performance of this network was compared with that of another constructive learning algorithm-based neural network, namely the Resource Allocation Network (RAN). In order to establish the effectiveness of GCS, the results obtained were compared with those obtained using the MLP, which is a standard and widely used neural network [8].

Du [9] presented a new method, called signal understanding, for the monitoring of engineering processes, in particular for the monitoring of tool conditions in machining processes. The new method is based on the blackboard system, an artificial intelligence method developed in the 1980s. It emulates a group of experts examining sensor signals from various aspects and making monitoring decisions step by step. The blackboard system consists of two blackboards: an event blackboard, used to track the interpretations of the signal by the experts, and a control blackboard, used to direct the interpretation process leading to monitoring decisions. In end milling process, the method has a number of advantages over the existing methods, including improved reliability and reduced decision time.

AE can be effectively used for tool-condition-monitoring applications because the emissions from process changes like tool wear, chip formation, that is, plastic deformation, and so on can be directly related to the mechanics of the process. Also, AE can very effectively respond to changes like tool fracture, tool chipping, and so on when compared to cutting force and, since the frequency range is much higher than that of machine vibrations and environmental noises, a relatively uncontaminated signal can be obtained. AE signal analysis was applied for sensing tool wear in face milling operations. Cutting tests were carried out on a vertical milling machine. Tests were carried out for a given cutting condition, using a single insert, two inserts (adjacent and opposite), and three inserts in the cutter. AE signal parameters like the ring down count and RMS voltage were measured and were correlated with flank wear values (VB max). The results of this investigation indicated that AE can be effectively used for monitoring tool wear in face milling operations [10].

Chip formation in metal cutting is inevitable and has a remarkable effect on tool state and therefore on the tool life. A customized tool holder and sensor setup are designed and integrated with the conventional tool holder to capture the signals from chip formation independently during turning. The signals acquired by the AE sensor represented the effect of chip formation on the tool state. The frequencies remaining below the transient offset signal mostly came from the tool wear and plastic deformation of the work material. It was observed that the acoustic emission was more susceptible to entire occurrences in turning. The time domain signal and corresponding frequency response can predict the tool state effectively. From raw AE signals and their RMS values, the tool wear and plastic deformation were observed to increase with increases in cutting speed, feed rate, and depth of cut. However, the tool wear was found to decrease with chip breakage even at higher cutting speeds and feed rates, and this was verified by measuring the tool wear. The chip formation frequency was found to vary between 68.3 and 634.83 kHz, and the maximum intensity was observed at 97.7 kHz [11].

The purpose of studies conducted by AE measurements is often to detect tool fracture, tool wear, or tool wear status or to monitor them. Although many researches have been conducted and published on this topic, no research is available regarding which acoustic frequency is affected during machining.

The objective of this study is to determine acoustic sound changes during the machining process from the workpiece using the cutting tool based on the cutting parameters that change during the milling process, in other words, to focus on the characterization of AE signals which occur in different cutting conditions. In order to manage that, when AISI D2 and AISI D3 materials were milled using different inserts (coated and non-coated) and cutting speeds (spindle revolutions per minute), feed rates, depth of cuts, and insert radius parameters, the acoustic signals generated during processing were analyzed and the work aimed to determine the effects of cutting parameters on acoustic frequency.

2. MATERIAL AND METHOD

In the conducted study, AISI D2 (DIN 1.2379) and AISI D3 (DIN 1.2080), which have a broad usage area in manufacturing industry as experimental materials, were used with cold work tool steels with 20 HRC and 28 HRC hardness values respectively. The chemical composition of the workpiece materials (Table 1) were specified by energy dispersive spectroscopy (EDS) analysis and their physical properties are given in Table 2 [12-14].

Table 1. *Chemical compositions of AISI D2 and AISI D3 cold work tool steel materials (wt%)*

	Si	**V**	**Cr**	**Mn**	**Fe**	**Ni**	**Nb**	**Mo**
AISI D2 (DIN 1.2379)	0.235	0.756	10.492	1.665	83.972	0.891	0.884	1.103
AISI D3 (DIN 1.2080)	0.704	0.305	11.263	0.591	83.784	0.676	0.394	2.283

Table 2. *Mechanical properties of AISI D2 and AISI D3 cold work tool steels*

Workpiece	Mechanical properties				
	Density, kg/dm3	Hardness, HRC	Yield strength, N/mm2	Tensile strength, N/mm2	Heat conductivity, W/m K
AISI D2 (DIN 1.2379)	7.70	20	820	940	20
AISI D3 (DIN 1.2080)	7.86	28	850	970	20

The purchased AISI D2 and AISI D3 materials were cut into a rectangular prism shape, and their three long surfaces were processed with a face mill to obtain dimensions of 20 × 26 × 102 mm and 1 mm of chip was removed in a milling machine from all outer surfaces of the workpieces before the machinability tests in order to prevent the tests from being affected by hardening of the outer surface layers and inclined surfaces. Then machinability and acoustic tests were performed.

Machinability and acoustic tests were performed in a Johnford VMC-850 CNC vertical processing center with a FANUC control unit, which has three axes, 6 kW motor power, and a variable speed of up to 3500 revolutions per minute. As cutting inserts, coated and non-coated cemented carbide tools with Sandvik R390-11T3 04M-KM3040 and R390-11T3 08M-H13A geometries were used. As the tool holder, a specially produced double-edged scan head with the Sandvik R390-032A32-11L code was used. The cutting width (radial depth) and cutting length were taken as 20 and 25 mm respectively. The processing experiments performed were up-milling and discontinuous milling in dry cutting conditions. Every test began with a new cutting tool.

In the experiments conducted, the elements used in the apparatus setup to numerically record sound data generated between the tool and workpiece material are listed in Table 3, and the schematic diagram of the apparatus is shown in Fig. 5.

Table 3. *Devices used for sound recording*

Used Device	Explanation
PCB 377B02	½ inches of Sensitive Prepolarized Condenser Microphone
PCB 426E01	ICP Microphone Preamplifier
PCB 480C02	Microphone Signal Conditioner
Larson Davis CAL200	Sensitive Acoustic Calibration Tool
NextView v4	Data Acquisition Software
BMCM USB-AD16f	Data Acquisition Card
Laptop Computer	Computer With Windows 7 Operating System

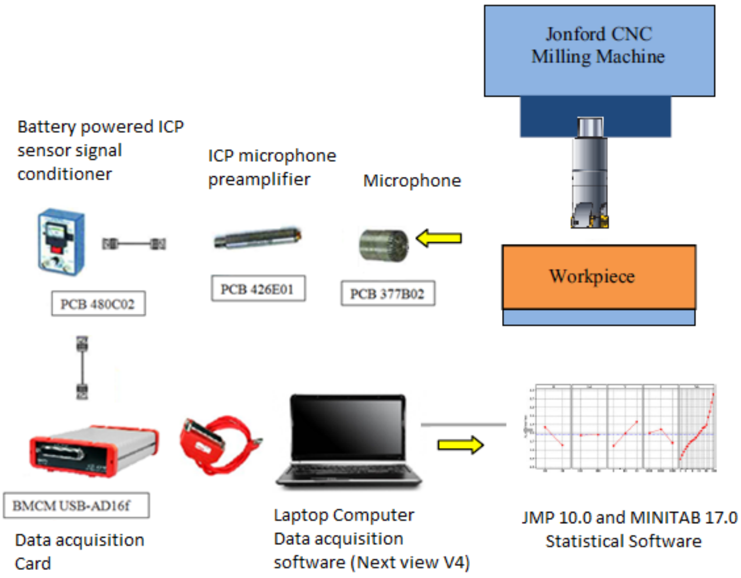


Figure 5. *Schematic diagram of the apparatus setup used to obtain acoustic signals in the study*

In the experiments, acoustic changes of the sounds, which were fixed as close as possible to the cutting tool and were received by a sensitively oriented microphone, were obtained, and the data were recorded by computer by converting them to numerical values.

The microphone used in the study is the cost-effective ½-inch PCB 377B02 model microphone from the Platinum series of PCB Piezotronics Company, which was developed for use in acoustic measurements. The typical sensitivity of this microphone can be defined as 50 mV/Pa (± 1.5 dB) with a frequency range of 3.15 Hz to 20 kHz (±2 dB). For the calibration of the microphone, a Larson Davis CAL200 model calibrator was used (Fig. 6). The calibration factor was detected and this value was considered in the software used during data collection. In order to increase the signals from the microphone with very low amplitude, a PCB 426E01 model preamplifier was used. To provide the constant DC current required for the microphone and preamplifier, a PCB 480C02 signal conditioning device which operates with a 9 V battery was used. To numerically convert the acoustic signals which can already be obtained as analogue in this way, a BMCM USB-AD16f model data acquisition card that can be used from the USB port of the computer was used; numerical values were transferred to the computer by 16-bits 11050-Hz sampling. To record these values which can be obtained from the computer, NextView v4 software was used.

Top: calibrator stands vertically above mounted preamplifier.

Bottom: mounted preamplifier, fixed vertically

Figure 6. *Microphone calibration by Larson Davis CAL200*

A general view of the devices placed and installed on the Johnford VMC-550 CNC machine tool for voice recording in the workshop is given in Fig. 7.

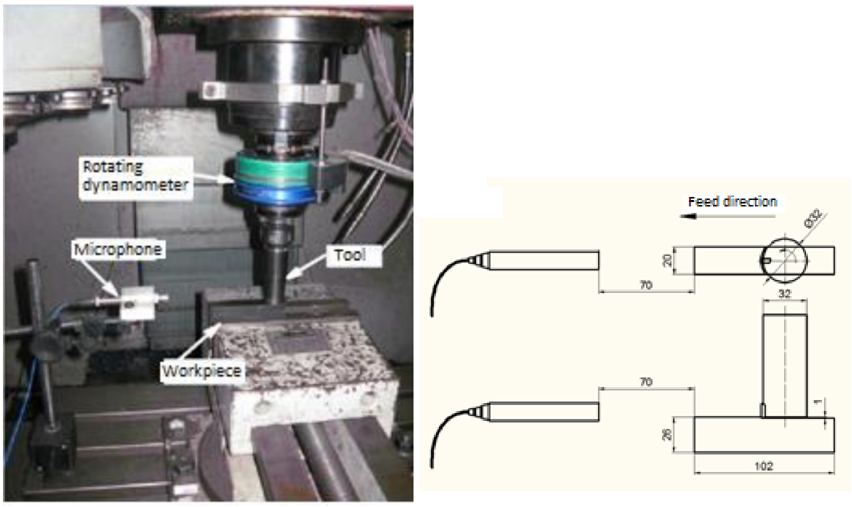


Figure 7. *View of the experiment set and placement of the microphone and workpiece.*

End mill cutter moves on the workpiece during metal removal and distance to microphone ranges from 70 to 150 mm. This small range does not make any significant change in terms of acoustic frequency in measurements.

The experiments were performed according to a full factorial (FF) design. The FF tests all possible combinations of the levels of each factor and is the combination obtained by the multiplication of levels (with each other) in tests having at least two or more factors and at least two or more levels belonging to these factors/parameters. At the different levels of parameters given in Table 4, a total of 360 (2x2×2×3×5×3) tests were carried out by using the FF technique. As a result, the tests were halted and repeated, and faulty measurements showing excessive deviations were eliminated. A total of 328 measurement results were evaluated, considering the number of tests (machined by the tools without losing insert life) and the accurate measurements observed. Analysis of variance and regression analysis technics are used in this study. Analysis of variance (ANOVA) is a statistical technique used to investigate and model the relationship between a response variable and one or more independent variables. Each explanatory variable (factor) consists of two or more categories (levels). Regression analysis is used in the analysis of tests designed by FF in order to determine the existence of a net mathematical relation between the cause (independent input variable) and effect (dependent input variable). It is possible to estimate the effect of a factor on the test via these methods. JMP 10 and MINITAB 16 software programs were used for the statistical analysis.

The cutting parameters used in the experiments and the levels of these parameters are listed in Table 4.

Table 4. *Cutting parameters used in milling experiments and their levels*

Cutting parameters	Symbol	Unit	Levels
Workpiece material	-	-	AISI D2, AISI D3
Cutting tool	*T*	-	Coated, Uncoated
Insert radius	*r*	mm	0.4, 0.8
Depth of cut	*a*	mm	1, 1.5
Cutting speed	*V*	m/min	150, 175, 200, 225, 250
Feed rate	*f*	mm/teeth	0.05, 0.10, 0.15

3. RESULTS AND DISCUSSION

The acoustic signal data, which were obtained in 0.0002 s intervals during milling tests, were recorded on the computer as an ASCII format file. Raw data are shown in the graphics in Fig. 8.

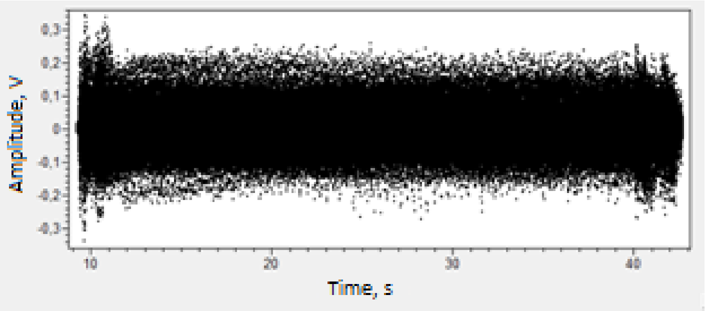


Figure 8. *Data obtained throughout a full cutting test.*

Acoustic signal (sound) data recorded numerically as a file were monitored in the time plane (Fig. 9). There is no difference between this graphic and the graphic in Fig. 8.

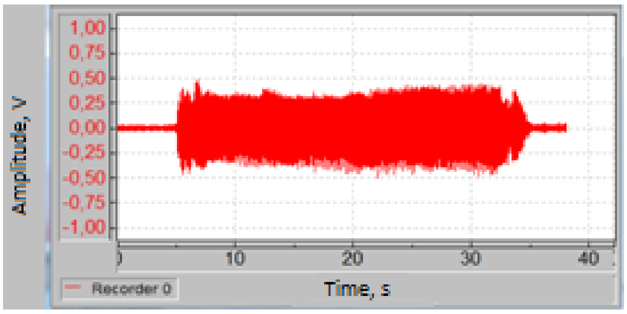


Figure 9. Monitoring of acoustic signal waveform in the time plane.

After that, the signal's frequency change with time was made into a graphic by considering such data with a 1024-block size and cumulatively evaluating the arithmetic averages of the signal's frequency values to which FFT had been applied. Time is shown in seconds on the x-axis, while frequency is presented on the y-axis (Fig. 10). During cutting, the principal frequencies were also monitored numerically on screen.

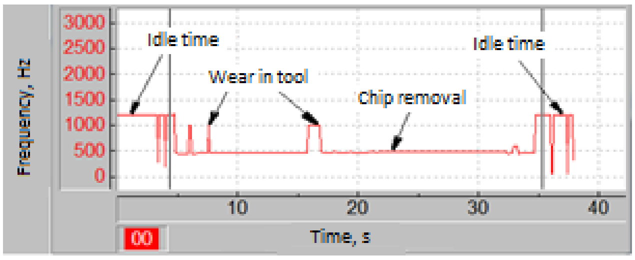


Figure 10. *Time-frequency graphic of acoustic signals obtained during the cutting process*

In Figure 10, the frequencies which formed during the idle time of the machine tool can be seen at the starting and end of the graphic, and the frequencies formed during machining in the middle section can be seen on the graphic. Sudden increases are observed in acoustic frequencies which are formed during machining. It can be said that is why such increases result from wear on the insert.

Figure 11 shows the Power Spectral Density (PSD) graphic of acoustic signals recorded in the test. The PSD gives the energy value that the signals carry according to different frequency values. When the PSD graphic is reviewed, two different frequency peaks are observed. The frequency on the left side, which has a high energy value, represents the principal frequency during machining, while the frequency on the right side, having a low energy value, represents the principal frequency during idle time.

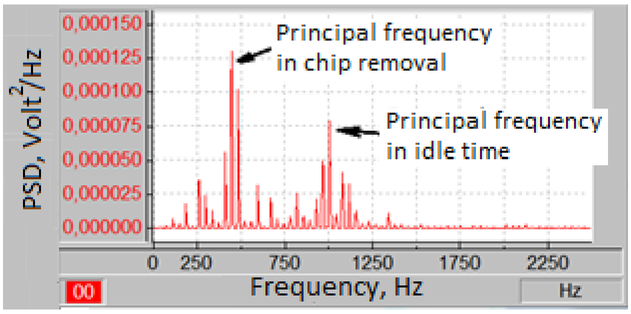


Figure 11. *PSD graphic of the recorded acoustic signals*

Principal frequency values obtained in different numbers of revolutions during the idle operation of the CNC machine tool are presented in Table 5. This was not the only frequency value obtained during the voice recordings; sometimes other frequencies may be observed. It can be said that this is due to wearing of the machine tool, namely wearing of the bearings in the spindle.

Table 5. *Principal acoustic frequency values of the spindle in the CNC machine tool used in the test during idle running.*

Spindle speed		Frequency, Hz
m/min	rev/min	
150	1492	759.89
175	1741	927.73
200	1990	1059.57
225	2239	1191.41
250	2488	1323.24
275	2736	1455
300	2985	1591.8

When the principal frequency values obtained during idle running were subjected to variance analysis, it was observed that only the spindle speed had an effect on the frequency values. When the data were subjected to regression analysis, it was observed that there was an increasing linear relationship between spindle speed and frequency (Fig. 12).

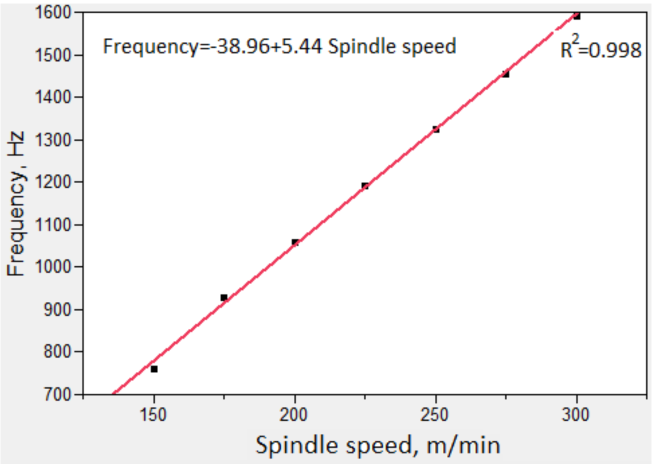


Figure 12. *Sound frequency obtained according to the CNC machine tool's spindle speed when running idle*

Average principal frequency value in the starting of cutting was 449 Hz. Minimum and maximum frequency values were 429 Hz and 463 Hz respectively. When the principal frequency values at the starting of cutting were subjected to variance analysis, it was observed that the workpiece material, insert material, and insert radius did not affect the frequency values, while the feed rate, cutting speed, and depth of cut did affect them (Table 6).

Table 6. *Variance analysis of effects of cutting parameters on acoustic frequency in the starting of cutting.*

Source	DF	Sum of squares	Mean of square	F	P-Value
Material	1	106.8	106.8	0.996	0.319
Insert material	1	102.1	102.1	1.045	0.308
Insert radius	1	27.1	27.1	0.264	0.607
Depth of cut	2	1035.5	517.7	5.046	0.007
Cutting speed	4	1484.7	371.1	3.618	0.006
Feed rate	2	1940.5	970.2	9.457	0.001
Error	316	32420.2	102.5		
Total	327	36995.9			

With regard to the feed rate, cutting speed, and depth of cut, which have effects on the sound's principal frequency at the start of cutting, it is observed that these three parameters express the volume of machining. Thus, it can be said that the machining volume has an effect on the sound frequency generated when the insert is new and does not yet have any wear. It can be stated that this determination seems to be in agreement with Dimla and Dimla [3], who stated that the sound resulted from the energy released during plastic deformation that was generated during cutting.

Each of the cutting experiments had a duration ranging from 15 to 85 s according to the cutting speed and feed rate values. Wear may occur on the insert based on the length of cutting time, quality of insert, workpiece material, speed, feed rate, and cutting depth. During the experiments, too little wear was observed on coated inserts, while flank wear and notch or fractures occurred on uncoated inserts (Fig. 13, Fig. 14 and Fig.15) [15–19].

The coated cutting tool is too little wear in cutting of AISI D2 and AISI D3 metal materials *r*=0.4, *a*=1.5, *V*=275, *f*=0.1. Principal acoustic frequency is usually 454.1 Hz in few times increases up to 1000.9 Hz frequency (Fig. 13).

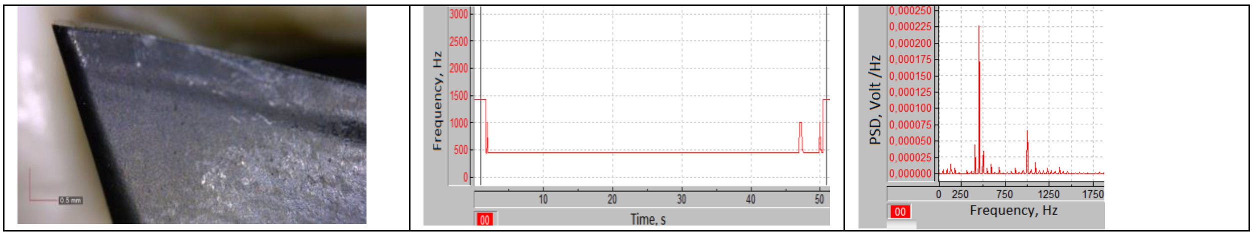


Figure 13. *Wears occurred on inserts and theirs time vs frequency and PSD acoustic records in machining of AISI D2, with coated insert, r=0.4, a=1.5, V=275 and f=0.1*

The uncoated cutting tool is flank wear in cutting of AISI D2 materials *r*=0.4, *a*=1, *V*=300, *f*=0.15. Principal acoustic frequency is 454.1 Hz in starting of cutting and increased up to 498.0 Hz at the starting of flank wear and increased up to 830 Hz in middle of cutting and later then acoustic frequency is 454.1 Hz again. (Fig. 14).

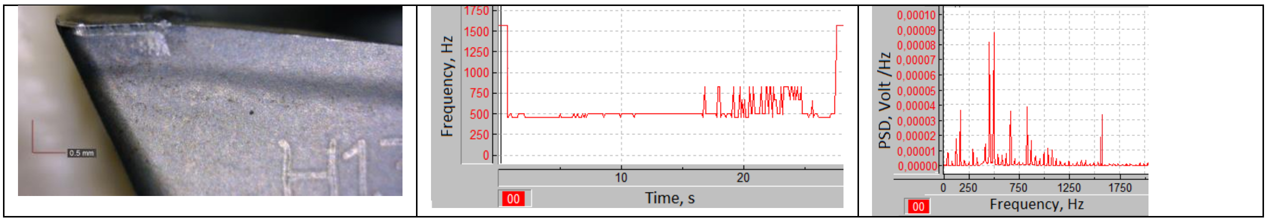


Figure 14. *Flank Wears occurred on inserts and theirs time vs frequency and PSD acoustic records in machining of AISI D2 with non-coated insert r=0.4, a=1, V=300 and f=0.15*

The uncoated cutting tool is notch wear in cutting of AISI D2 materials r=0.4, a=2, V=275, f=0.15. Principal acoustic frequency is 444.3 Hz in starting of cutting and increased up to 966.8 Hz at the starting of notch wear and then acoustic frequency is reduced to 449.2 Hz. (Fig. 15).

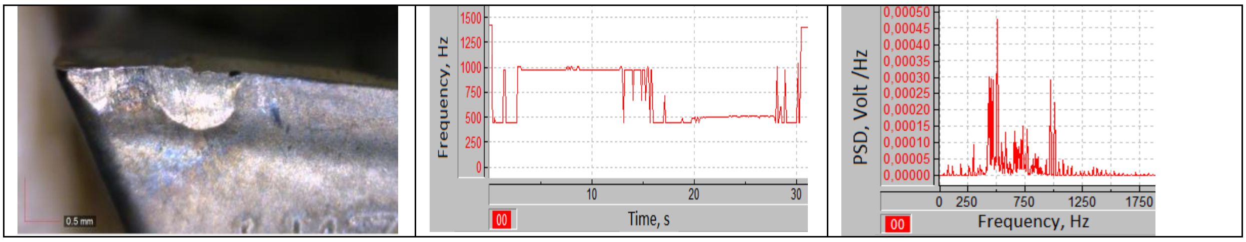


Figure 15. *Notch wears occurred on inserts and theirs time vs frequency and PSD acoustic records in machining of AISI D2 with non-coated insert, r=0.4 a=2 V=275 and f=0.15*

When the principal frequency values in the middle of cutting were subjected to variance analysis, it was observed that the workpiece material did not affect the frequency values, while the cutting speed, quality of insert material, insert radius, depth of cut, and feed rate did affect it (Table 7).

Table 7. *Variance analysis of cutting parameter effects on the principal acoustic frequency in the middle of cutting.*

Source	DF	Sum of squares	Mean square	F	P-Value
Material	1	12598.6	12598.6	0.407	0.523
Insert material	1	462355.6	462355.6	14.943	0.001
Insert radius	1	172278.9	172278.9	5.568	0.018
Depth of cut	2	228271.6	114315.8	3.688	0.026
Cutting speed	4	1529588.8	382397.2	12.395	<0.001
Feedrate	3	19791.0	98395.5	3.180	0.042
Error	316	9777303.0	30941.0		
Total	327	12472187.0			

The lack of difference in frequency between the AISI D2 and AISI D3 materials used in the tests may be attributed to the close similarity in hardness and physico-mechanical properties of such materials. It can be said that other parameters—cutting speed, quality of insert material, insert radius, depth of cut, and feed rate—arise from their effects on both the volume of machining and thus the released energy and wear on the insert, and this directly affects the sound frequency. During machining, when wear occurs on the insert, the frequency suddenly increases and this high frequency continues for a short or longer time according to the wear type, after which the frequency returns to the previous frequency. This issue suggests that the wear was rasped and lost the sharpness cutting edge of insert that provides to result in a different frequency. At the starting of cutting of the material or in gradual tool wear, the dominant frequency range was between 410 and 502 Hz for the tool-workpiece–material combination used. These frequency values in milling were higher than the values of frequency obtained in turning [20]. This could be due to the discontinuous milling in particular as well as other cutting parameters.

4. CONCLUSION

Acoustic records obtained during the milling operation were evaluated after the signal processing had been done. On the basis of the experimental data, the following can be said for acoustic principal frequencies:

- When PSD graphics are reviewed, two principal frequency peaks are observed during milling. These are the frequencies related to idle running and machining.
- Spindle speed affects the principal frequency generated during idle running. An increasing linear relationship occurs between the principal frequency and spindle speed. The principal frequency range lies between 760 and 1592 Hz, depending on the spindle speed during the idle time of the machine tool used.

- When the principal frequency created at the start of machining is reviewed, it is observed that the feed rate, cutting speed, and depth of cut affect the principal frequency. When it is considered that these three parameters give the volume of machining, it can be said that the frequency is determined by the energy released as a result of the deformation that occurred during machining.
- In the starting of cutting, the dominant principal frequency range lies between 429 and 463 Hz for the coated and uncoated tool–cold work tool steel material combination used.
- During machining of workpieces that is why sudden increases in acoustic frequency occurred wear on insert.
- After the machining process has continued for some time, the cutting speed, quality of insert material, insert radius, depth of cut and feed rate have effects on the frequency values. In other words, the volume of machining and wearing of the insert affects the frequency.
- Determining the effects of cutting parameters on the acoustic frequency will be very important for diagnostics of machining operations. Furthermore, it must be made new researches related to this subject.

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CONFLICT OF INTEREST

No conflict of interest was declared by the authors

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