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Development of a Theoretical Model for Prediction of Surface Roughness of Metallic Surfaces using Acoustic Signals

S. P. Harisubramanyabalaji, C. A. Sribalaji, A. Vivek, G. Vigneshwaran, S. Abhishek, R. Balamurugan and R. Panneer*

School of Mechanical Engineering, SASTRA University, Thanjavur-613401, Tamil Nadu, India; haribalaji94@gmail.com, balajianand1994@gmail.com, vivekanandan321@gmail.com, nannilamvickky@gmail.com, abhisheksrinivasan007@gmail.com, balamuruganremesh5@gmail.com,panneer@mech.sastra.edu

Abstract

Objectives: To develop a theoretical model to predict the surface Roughness (R_a) of different metallic surfaces using acoustic signals. **Methods:** Acoustic signals are generated with the help of dry friction contact between two metallic surfaces. In this work, Cast iron and Mild Steel Samples from different machining processes are collected and the dry friction contact is made with HSS and Tungsten Carbide Tools to generate the acoustic signals. The acoustic signals obtained through a microphone are processed using MATLAB. Number of Samples versus Amplitude is plotted and then the resulting output is plotted as Time versus Amplitude. Subsequently the external noises from the acoustic signals are removed to get a reliable roughness value. **Findings:** The maximum amplitudes of the samples are tabulated and used for the deriving model for the surface roughness prediction. Theoretical model of HSS with various machining processes samples is $y = 1.6865 \ln(x) + 8.9978$. Theoretical model of Tungsten carbide with various machining processes samples is $y = 6.302 \ln(x) + 27.337$. Both the models are correlating with a trend line of 0.9. **Application:** This theoretical model can be used to predict the surface roughness (R_a) of metallic surfaces. This approach can be implemented in surface finish measuring devices.

Keywords: Acoustic Signals, Amplitude, Microphone, Metallic Surfaces, Surface Roughness

1. Introduction

Surface Roughness is the deviations in the direction of the normal vector of a real surface from its ideal form. Surface roughness determines the amount of friction that will be produced when the machined objects are employed in machineries. Hence, Surface Roughness must be measured properly to ensure the function of the surface. To find the roughness value of any surface, the most widely used Surface Measurement Parameter is R_a[1,2] and hence the R_a value is used in this research work. The surface measurement techniques can be broadly classified as "contact" methods[3,4] and "non-contact" methods[7–9]. Talysurf, Dektak, Rutherford Backscattering Spectroscopy, Nanoindenter are some of the devices which operate on the contact method. In these devices a probe is made to traverse along the surface of the job. The deviation of the probe in very small scale is plotted as a graph, which is used to find the profile of the surface and hence calculate the value of the roughness[5,6]. The disadvantage of contact method is that the sensitive probe wears out and breaks easily if misused or used on a metal with high roughness. The non-contact methods are Optical Microscopy, White Light Interferometry[8], Atomic Force Microscopy, Surface Topography, Confocal Microscopy, Image Processing[11–16] etc. In these methods, a light source, mostly LASER[9] is made to fall on the surface of the job and the profile of the job surface is generated using the light reflected from the surface. The non-contact methods are expensive. Hence the proposed method, though a contact method,

*Author for correspondence

comparatively reduce the cost of measurement of the surface roughness of the metal and predict R_a value in close proximity to a value as obtained by existing contact and non-contact methods and also overcomes the disadvantages of the contact methods. It is also noted here that measurement using dry friction contact can be made in the areas of surfaces which are not functionally critical.

2. Methodology

Surfaces are generated by various machining processes[10] such as Turning, Shaping, Grinding, etc. Sample jobs are prepared by Shaping a Cast Iron Sample and Turning, and Cylindrical Grinding of Mild Steel Samples with High Speed Steel (HSS) and Tungsten Carbide Inserts as cutting tools with pre-set cutting conditions. Three samples were chosen one each from Shaping, Turning, and Cylindrical Grinding because they will have distinctive surface roughness values which will be very useful in correlating the relationship between the amplitude of Acoustic Signals and Surface Roughness. The surface roughness (R_a) values of these samples were measured using a Surface Roughness Testing Machine and the actual R_a values were noted (Table 1 and 2).

To obtain the acoustic signals, an experimental set up was established where the samples were secured horizontally on to a surface plate with a holding and clamping arrangement. To generate sound, the same tools which machined those surfaces were used which were set at an angle of 45° to the sample surface. At this angle, there will be a point contact between the two metals and hence the cutting will be avoided. The sample length of movement was considered within the range of 5 cm – 15 cm. When the tools were making a dry friction contact with the sample surface and moved, sound waves were generated which is captured using a microphone.

Table 1. Actual surface roughness (R_a) versus max amplitude of acoustic signal generated by HSS

NO	Machining Process	Measured Suface Finish(R_a)	Max. Amplitude of Acoustic Signal
1	Shaping	6.15	0.1373
2	Turning	3.97	0.0733
3	Cylindrical Grinding	0.28	0.0053

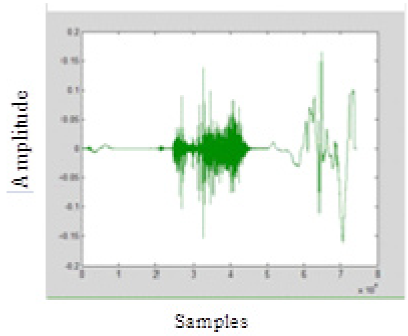
Table 2. Actual surface roughness (R_a) versus max amplitude of acoustic signal generated by Tungsten Carbide

NO	Machining Process	Measured Suface Finish(R_a)	Max. Amplitude of Acoustic Signal
1	Shaping	6.15	0.0303
2	Turning	3.97	0.0284
3	Cylindrical Grinding	0.28	0.0135

The microphone is selected in such a way that it does not attenuate the sound signal. The microphone is fixed at a distance of about 3cm from the metal contact point which is kept constant for all the samples so as to capture the sound with same intensity. The sound recorded by the microphone includes the sound from the surface, surrounding noises and some noise due to the vibrations produced when the two metals are in contact[17]. Hence the entire set up was established in a sound proof environment. To avoid the sound produced by the vibrations due to the movement of the tool over the surface, the sample was isolated from the base while clamping. The sound is recorded in the form of .wma format and is converted into .wav format to make it readable in MATLAB. This .wav file is read in MATLAB and the amplitude of the sound wave is plotted against number of samples initially. The sampling frequency is found to be 44100 samples per second[18,19]. The X-axis is then converted into time (in seconds) and the plot of time vs. amplitude is obtained. The sound file is found to be consisting of audio signals which are not a part of the signals related to surface, but due to the placement of tool over the work piece etc. These portions are removed from the sound wave by observing the time period of the unwanted signals. The default MATLAB function of "max" which returns the maximum value of amplitude from the signal is used for defining the surface roughness.

3. Results

On testing these three samples with the above methodology by dry friction of High Speed Steel and Tungsten Carbide Inserts with the sample surfaces, sound signal were obtained. The signals obtained were converted to plots relating amplitude to time domain and then those signals which are not part of the surface quality are removed. The resulting plots are presented in Figures 1 to 6.



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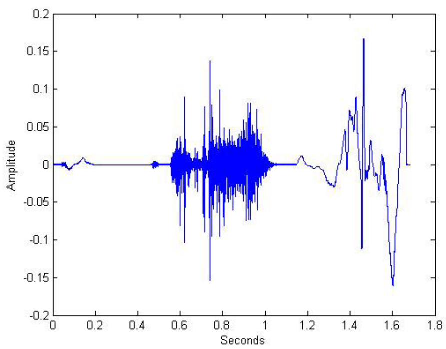

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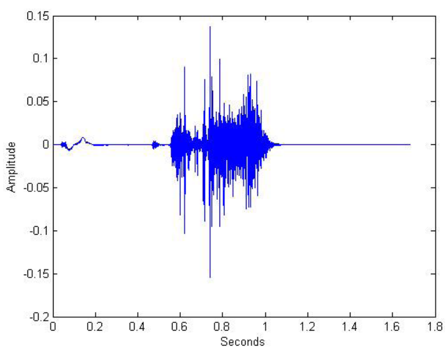


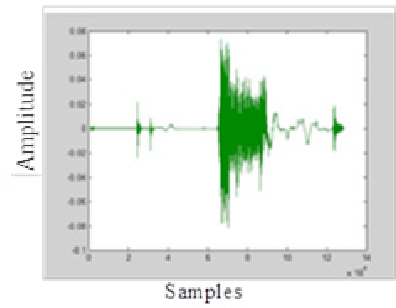
(c)

Figure 1. **(a)** Acoustic signals amplitude vs. samples (HSS on Cast Iron Sample produced in shaper), **(b)** Acoustic signals amplitude vs. time (HSS on Cast Iron Sample produced in shaper) and **(c)** Acoustic signals reflecting the surface roughness (HSS on Cast Iron Sample produced in shaper).

3.1 Details of Plots Generated by Dry Friction of HSS on Three Surfaces Produced by Shaping, Turning and Grinding

The details of the plots of the acoustic signals generated during dry friction of High Speed Steel on Cast Iron Sample shaped using Shaping Machine are presented above in Figure 1a to 1c. The Figure 1a shows the acoustic signals plotted taking amplitude along Y-axis and number of samples along X-axis. The plot converted into amplitude vs. time grid is shown in Figure 1b. The plot showing the signal after removing unwanted signal is shown Figure 1c, As can be observed from Figure 1c the max. amplitude of the signal is 0.1373 (Obtained from MATLAB max. function).

The details of the plots of the acoustic signals generated during dry friction of High Speed Steel on Cylindrical Mild Steel Sample turned using Lathe Machine are presented below in Figure 2a to 2c. The Figure 2a shows the acoustic signals plotted taking amplitude along Y-axis and number of samples along X-axis. The plot converted into amplitude



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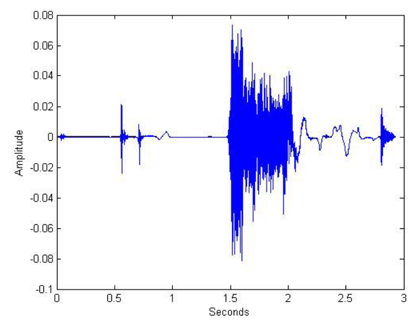

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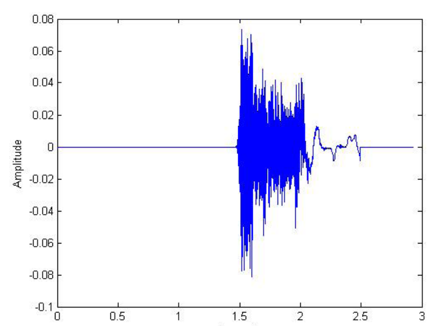

(c)

Figure 2. **(a)** Acoustic signals amplitude vs. samples (HSS on Mild Steel sample produced in Lathe), **(b)** Acoustic signals amplitude vs. time (HSS on Mild Steel sample produced in Lathe) and **(c)** Acoustic signals reflecting the surface roughness (HSS on Mild Steel sample produced in Lathe).

vs. time grid is shown in Figure 2b. The grid showing the signal after removing those signals from the plot which are not part of the intended sound waves and which reflects only the surface roughness is shown Figure 2c. As can be observed from Figure 2c the max. amplitude of the signal is 0.0733, (Obtained from MATLAB max function).

The details of the plots generated during dry friction of High Speed Steel on Cylindrical Mild Steel Sample ground using Grinding Machine are presented below in Figure 3a to 3c. The Figure 3a shows the acoustic signals plotted taking amplitude along Y-axis and number of samples along X-axis. The plot converted into amplitude vs. time grid is shown in Figure 3b. The grid showing the signal after removing those signals from the plot which are not part of the intended sound waves and which reflects only the surface roughness is shown Figure 3c. As can be observed from Figure 3c the max amplitude of the signal is 0.0053 (Obtained from MATLAB max function).

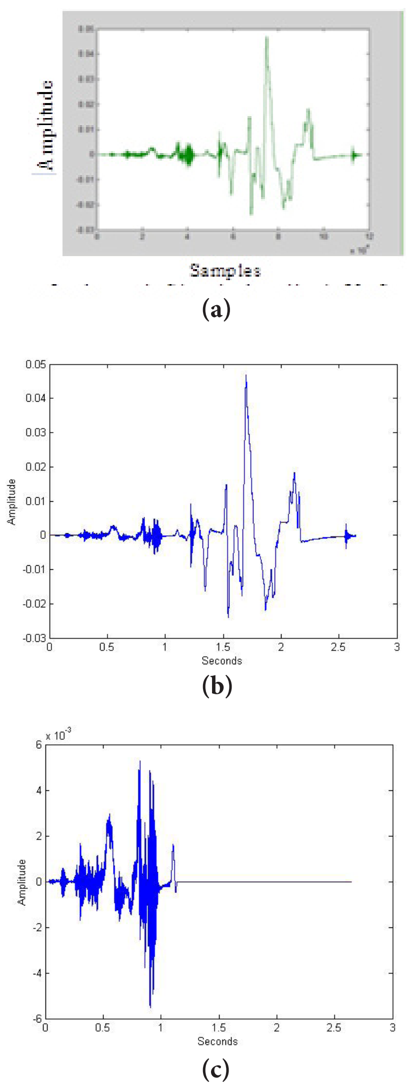

Figure 3. **(a)** Acoustic signals amplitude vs. samples (HSS on Mild Steel Sample produced in Grinding Machine). **(b)** Acoustic signals amplitude vs. time (HSS on Mild Steel Sample produced in Grinding Machine). **(c)** Acoustic signals reflecting the surface roughness (HSS on Mild Steel Sample produced in Grinding Machine).

3.2 Details of Plots Generated by Dry Friction of Tungsten Carbide on Three Samples produced by Shaping, Turning and Grinding

The details of the plots generated during dry friction of Tungsten Carbide on Cast Iron Sample Shaped using Shaping Machine are presented below in Figure 4a to 4c. The Figure 4a shows the acoustic signals plotted taking amplitude along Y-axis and number of samples along X-axis. The plot converted into amplitude vs. time grid is shown in Figure 4b. The plot showing the signal after removing those signals which are not part of the intended sound waves and which reflects only the surface roughness is shown Figure 1c. As can be observed from Figure 4c the max amplitude of the signal is 0.0303 (Obtained from MATLAB max function).

The details of the plots generated during dry friction of Tungsten Carbide on Cylindrical Mild Steel Sample turned using Lathe Machine are presented below in Figure 5a to 5c. The Figure 5a shows the acoustic signals plotted taking amplitude along Y-axis and number of samples along X-axis. The plot converted into amplitude vs. time grid is shown in Figure 5b. The grid showing the signal after removing those signals from the plot which are not part of the intended sound waves and which reflects only the surface roughness is shown Figure 5c. As can be observed from Figure 5c the max amplitude of the signal is 0.0284 (Obtained from MATLAB max function).

The details of the plots generated during dry friction of Tungsten Carbide on Cylindrical Mild Steel Sample ground using Grinding Machine are presented below in Figure 6a to 6c. The Figure 6a shows the acoustic signals plotted taking amplitude along Y-axis and number of samples along X-axis. The plot converted into amplitude vs. time grid is shown in Figure 6b. The grid showing the signal after removing those signals from the plot which are not part of the intended sound waves and which reflects only the surface roughness is shown Figure 6c. As can be observed from Figure 6c the max amplitude of the signal is 0.0135 (Obtained from MATLAB max function).

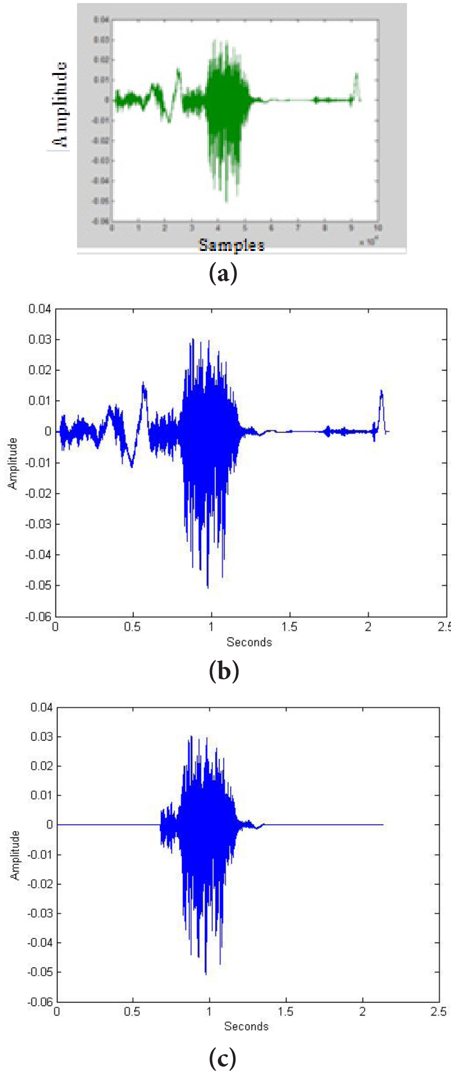

Figure 4. **(a)** Acoustic signals amplitude vs. samples (Tungsten Carbide on Cast Iron Sample produced in shaper), **(b)** Acoustic signals amplitude vs. time (Tungsten Carbide on Cast Iron Sample produced in shaper) and **(c)** Acoustic signals reflecting the surface roughness (Tungsten Carbide on Cast Iron Sample produced in shaper).

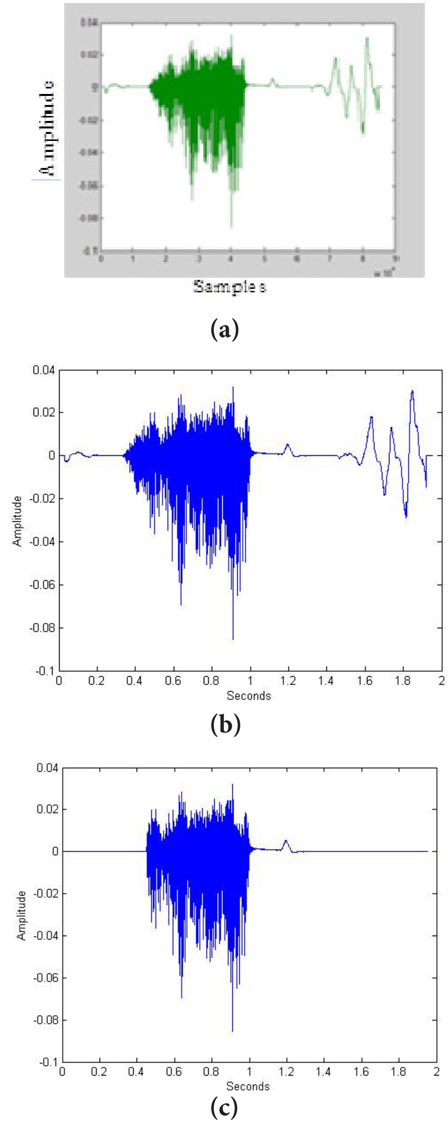

Figure 5. **(a)** Acoustic Signals Amplitude vs. samples (Tungsten Carbide on Mild Steel sample produced in Lathe), **(b)** Acoustic Signals Amplitude vs. Time (Tungsten Carbide on Mild Steel sample produced in Lathe) and **(c)** Acoustic Signals reflecting the surface roughness (Tungsten Carbide on Mild Steel sample produced in Lathe).

4. Summary and Results

The values of maximum amplitudes were tabulated against the corresponding actually measured R_a value. Table 1 presents the details of the amplitudes generated by HSS on different samples against the actually measured surface finish and Table 2 presents the details of amplitudes generated by Tungsten Carbide on different samples against the actually measured surface finish.

As can be observed from Table 1 and 2 there is a good correlation between the variance in the measured surface roughness and the amplitudes of signals. This correlation can be effectively used to develop a theoretical model to predict surface roughness from the acoustic signals.

5. Theoretical Model

To develop a theoretical model relating the surface roughness and the observed amplitude, a logarithmic trend line[20,21] was formed with Maximum Amplitude in X-axis

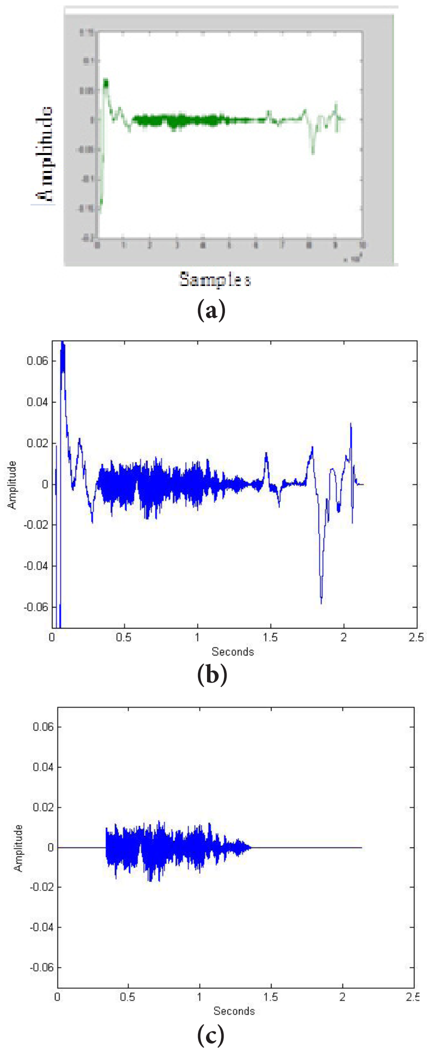

Figure 6. (a) Acoustic Signals Amplitude vs. samples Carbide on Mild Steel ground in Grinding Machine), **(b)** Acoustic Signals Amplitude vs. Time (Carbide on Mild Steel ground in Grinding Machine) and **(c)** Acoustic Signals reflecting the surface roughness (Carbide on Mild Steel ground in Grinding Machine).

and Surface Roughness in Y-axis (Figure 7). When such a trend line was formed using the appropriate feature in Excel for the combination of High Speed Steel versus various samples, the equation relating them was found to be,

$$y = 1.6865 \ln(x) + 8.9978 \quad (1)$$

Where x represents the maximum amplitude and y represents the surface roughness. Similarly another trend line was formed for the combination of Tungsten Carbide versus various samples (Figure 8); the equation relating them was found to be

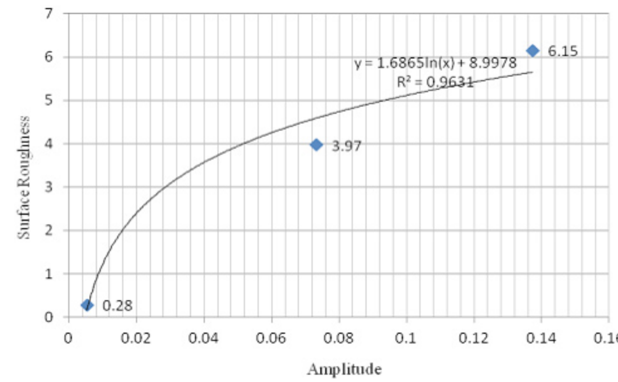

Figure 7. Trend Line - Log Surface Finish vs. Amplitude (For HSS versus various samples).

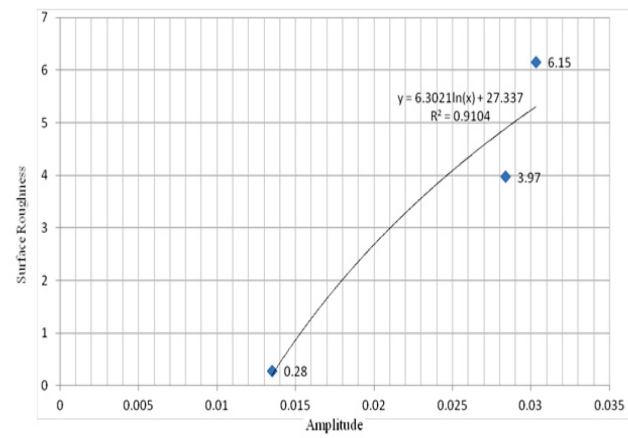

Figure 8. Trend Line - Log Surface Finish vs. Amplitude (For Tungsten Carbide versus various samples).

$$y = 6.302 \ln(x) + 27.337 \quad (2)$$

Based on the above logarithmic trend line equations, the surface roughness of a machined surface can be predicted according to the type of combinations of material being used to make the dry friction.

6. Conclusion

The above results show that the acoustic signals produced by the pair of HSS with other metals and pair of Tungsten Carbide with other metals vary in frequency and correlations.

The maximum value of the amplitude is taken and correlated to get the corresponding equations from which the surface roughness of the material can be predicted.

Two different equations are obtained for HSS and Tungsten Carbide which can be used for prediction of the surface roughness of any material pair, provided one material in the pair is HSS or Carbide.

Thus, this method can be implemented on any material pair to find the corresponding equation for the selected materials to predict surface roughness of the materials.

This method is a simple and a cheaper method to predict surface roughness compared to other costlier methods and instruments.

This method's limitations are that it needs sound proof environment, other disturbances may influence the signal and we need to identify and filter the intended signal from other unwanted signal.

7. Acknowledgement

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8. References

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