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TEXTURAL ANALYSIS OF SHAPED SURFACES USING MACHINE VISION SYSTEM BASED AMPLITUDE PARAMETERS TO ESTIMATE THE CUTTING TOOL CONDITION

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ABSTRACT

Texture of machined surface provides reliable information regarding the extent of the tool wear. A non contact experimental study is presented for accomplishing texture analysis using machine vision system to estimate the condition of cutting tool at various conditions. Machined surface images of different materials by shaping process at different wear conditions cutting tool are grabbed using CCD camera. Machining conditions are kept constant but two different work piece materials and cutting tools are used. This paper, proposes an amplitude parameters based approach for analysis of machined surfaces. Machined surfaces with different wear conditions of the cutting tool i.e., sharp, semi-dull and dull are investigated by surface metrology software Truemap and also with conventional method using stylus instrument for comparative purpose. Through experiments, we found a high degree of correlation between tool wear and surface roughness (surface texture) of the machined surfaces. Effectiveness of this approach is well justified with results.

Keywords: *Machine Vision, Tool Condition Monitoring, Surface Metrology, CCD Camera, Amplitude Parameters.*

1. Introduction

The following section gives an overview of the various methods employed in part for monitoring of the tool condition by the work piece surface texture analysis. There are several methods for measuring the tool condition, developed in last few years. However, considerably less work has been performed on the development of surface texture sensors that provide information on the condition of the tool employed in machining the surface. The following is the brief discussion of these methods. Many approaches have been proposed to accomplish tool condition monitoring and most of the methods essentially involve processing information such as acoustic emission (AE), vibration signature (acceleration signals), cutting force, etc. Even though all these techniques perform reasonably well, the implementation usually requires specially designed equipment that is not suitable or even expensive for industry use. On-line process monitoring has been an active area of research because it is recognized as an essential part of fully automated manufacturing systems. One of the parameters to be controlled in machining is surface finish, which is a vital criterion in the performance and utility of industrial products. The proper functioning of a machined part is in many instances largely dependent on the quality of its surface. Surface finish is an important attribute of quality in any machining operation. Many researchers have studied the influence of various factors that can improve surface finish of a work piece. The simplest procedure is a visual comparison with an established standard. This method is simple and can be realized in real time as it is independent of machining process, machining can be continued as the images of work piece are captured and analyzed. In automated manufacturing system the productivity can be very effectively improved by making use of the machine vision system.

2. Literature Review

The tool condition can be neither measured nor described in any simple way. In Pedersen et al. [1] the tool condition is mainly defined by wear marks on the tool, with a complicated geometry are discussed. In Bradley et al. [2] the degree of tool wear of multi point cutting tool is estimated by extracting the parameters from images of the machined surfaces. In Guangming

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Zhang et al. [3], On-line monitoring of the surface finish which is an active area of machining research is discussed. In Kassim et al. [4] the texture of the machined surface was used to estimate the tool wear and Hough transform was used to process the images of work piece. Lee et al. [5] presents a system for measuring the surface roughness of turned parts using a computer vision system. In Tarng [6] the wear of the grinding wheel was given by using machine vision system. In Ramamoorthy et al. [7] the surface roughness of various machined surfaces are obtained by using machine vision system. Zhong et al. [8] presented the relation between surface roughness with machining parameters like feed rate, nose radius and cutting speed. In Aguiar et al. [9] the thermal damages in grinding processes are monitored by using the acoustic emission signals, which were acquired from a fixed sensor, placed on the work piece holder. In Barber et al. [10] the texture of a machined surface is closely related to the cutting tool condition and the arithmetic average roughness (Ra) of machined surfaces is found to be highly correlated to the tool wear is presented. In Mannan et al. [12] showed that the machined surface texture can be used to estimate tool wear. Nadakatti et al. discussed the knowledge based condition monitoring cost effective technique using the feedback signals like displacements, velocity and acceleration due to vibration. By keeping the above literature review in to consideration, it is clear that the surface texture of the work piece is in good relation with the condition of the tool. The computer vision system provides three dimensional roughness values of the surfaces such as RMS Surface Roughness (Sq), Ten-Point Height (Sz), Skewness (Ssk) and Kurtosis (Sku) etc. Surface texture is an important characteristic for the analysis of many types of images. In Dhanasekar et al. [11] the surface roughness measurement broadly divided into two groups such as contact and non-contact methods. Extensive research has been performed by many earlier researchers on machine vision approaches which have the advantages such as non-contact, faster than contact methods and are capable of measuring an area of the surface rather than a single line which makes it a 3D evaluation. In this paper, a non contact method using machine vision for inspecting surface roughness of machined surfaces produced by varying the work piece and cutting tools combinations for shaping processes is studied to monitor and to measure the cutting tool condition has been presented. This paper also illustrates the application of image amplitude parameters (RMS roughness, Skewness and Kurtosis) in estimating the condition of the cutting tool. Image processing and machine vision technology improves productivity and quality management and provides a competitive advantage to industries that employ this technology. The surface metrology software “TRUEMAP” offers image processing functions, which simplify calculation of amplitude parameters and also plots the machined surfaces in 3D exploded view. With this software, we analyze images of machined work pieces to extract information that relate to the extent of tool wear at various conditions of different work piece and cutting tool combinations at constant machining conditions. Fig. 9 shows the surface textures of different materials produced by various machining operations initiated with a sharp tool and continued with the same tool until it has undergone a substantial amount of wear. It can be seen that the surface textures vary significantly as the tool wears. When the tool is sharp, the surface textures are very regular along the direction of the machining process. However, when the tool becomes dull, the surface texture becomes irregular. In the absence of severe cutting tool vibrations, the cut surface is almost a negative imprint of tool geometry, so that the surface texture reflects the volumetric changes in cutting edge shape. As the tool wears, the general orientation of the line texture can also change, as shown in Fig. 9 (case.1-case.4). It can be seen that, it is easier to analyze the machined surface than to look at certain portions of the cutting tool, which is normally the case with the optical systems for flank wear measurement.

3. Surface Texture of a Machined Surface as a Basis for Cutting Tool Monitoring

For a given tool and work piece, many factors can influence the form of this spatial signature, such as the feed rate, spindle speed, machine tool alignment, and tool setup. It is assumed here that the surface features generated by the wear of the tool can be separated from the other factors. The surface texture of a part is indicative of all machine tool performance factors present during machining; examples are, tool wear, machine tool rigidity, bearing wear, chatter, and sideways errors. The objective here is to extract the surface texture signature component, due to tool wear, from the other texture components and employ it as an indicator of the tool condition. This technique is a direct tool condition measurement method. The standard approach [15] of developing an image processing parameter and empirically correlating it with the *Ra* value is adequate for measuring the tool condition. The drop in *Ra* after ten passes is due to heating and ductile surface deformation by the worn tool. Therefore, we considered up to ten passes only. After ten passes *Ra* may not be a reliable tool wear

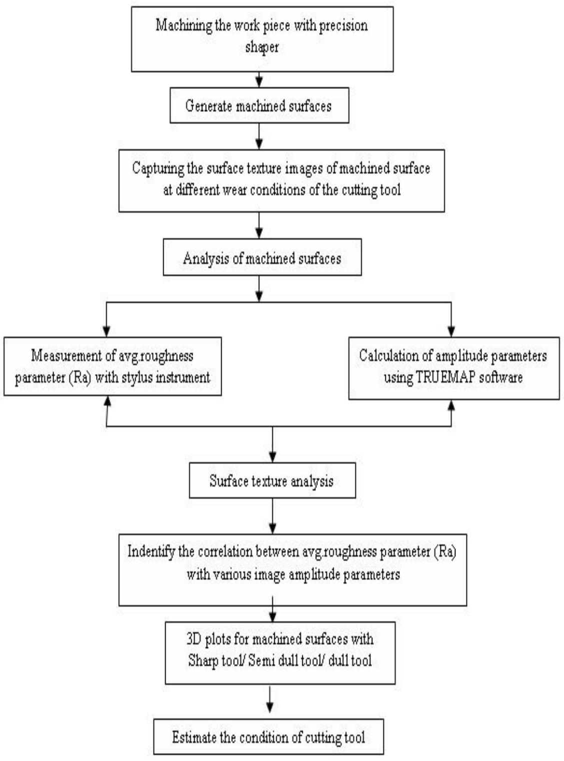


Fig. 1 Procedure Adopted in the Present Work

indicator, even though a stylus profilometer measurement indicates an acceptable *Ra* value.

Researchers have studied the influence of various factors that can improve the surface finish of a work piece but in this work variation in work piece material and variation of cutting tool are included in this experimental investigation. Experimental results indicate that surface roughness increases with decrease in hardness of cutting tool and surface roughness decreases with increase in brittleness of work piece material. In many earlier works, tool wear and condition monitoring were discussed [13, 14].

3.1 Estimation of surface roughness

The surface roughness parameter used throughout in this study is the average surface roughness (Ra) as it is the most commonly used surface finish parameters by researchers and in industry as well. It is the arithmetic average of the absolute value of the heights of roughness irregularities from the mean value measured. Surface roughness is the measure of the finer surface irregularities in the surface texture. These are the result of the manufacturing process employed to create the surface. The ability of a manufacturing operation to produce a specific surface roughness depends on many factors. It is given by

$$R_a = \frac{1}{L}\int_o^L |z(x)|dx \qquad (1)$$

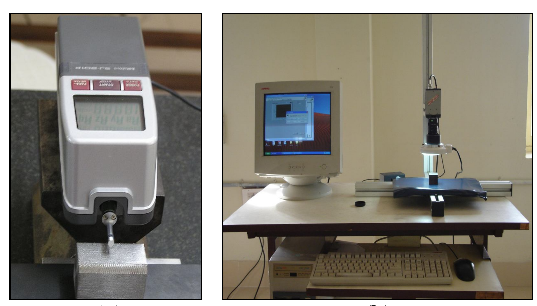
Where Z- average roughness height, X-profile direction and L- sampling length.

3.2 Amplitude parameters used in surface texture analysis

The following surface texture parameters [16] and [17] were computed relative to the mean fit through the surface. They describe amplitude related properties of the machined surface and their significance mentioned in table 1.

4. Experimental Set up and Procedure

Experiments are conducted on precision shaper at constant machining conditions with different workpiece materials and different wear conditions (sharp/semi-dull/dull) of cutting tool combinations and the images of machined work piece are grabbed using CCD camera.



(a) (b)

Fig. 2 Surface Roughness Measurement with Stylus and CCD Set Up for Shaped Surfaces

The roughness parameters were obtained using stylus measuring instrument. Shaping operation is carried out with high carbon steel (HCS) tool and high speed steel (HSS) tools to produce different surface textures. The machining carried on high precision shaper. The tool materials are selected to examine the effect of tool hardness and brittleness in work piece on machined surface roughness. Mild steel (0.15%C-0.45%C) and EN8 (0.35%C-0.45%C) specimens selected for experimental investigation. The above selection is made as carbon percentage is being different the mechanical properties of the two steels will vary so as to examine the variation in results due to differences in strength and hardness can be estimated. Based on the ISO standards three conditions of the tool are considered: Sharp tool (0 mm of tool flank wear), semi-dull tool(0.3mm of tool flank wear), Dull tool (0.6mm of tool flank wear) and tool flank wear is measured with optical projector. The machining was conducted at 24 m/min speed and 1.5 mm feed and the same machining conditions are maintained throughout the experiment. The work piece dimensions were 32mm width and 45mm length are used. Surface texture analysis can be effectively used as good source for to measure the cutting tool condition. Shaping operation initiated with sharp tool continued up to ten passes. Based on experimental results, it was observed that up to six passes machining the surface finish values were found be in allowable range. It was also found that the machined surfaces shows good surface finish up to first 2 passes at this stage the cutting tool maintains its sharpness but during 6 and 8 passes a slight increase in Ra values was found and this state of the tool condition was measured as semi dull based on experimental and software results. The images of the machined surfaces are grabbed using a CCD camera. Fig 2(b) shows the set-up of CCD camera coupled with computer.

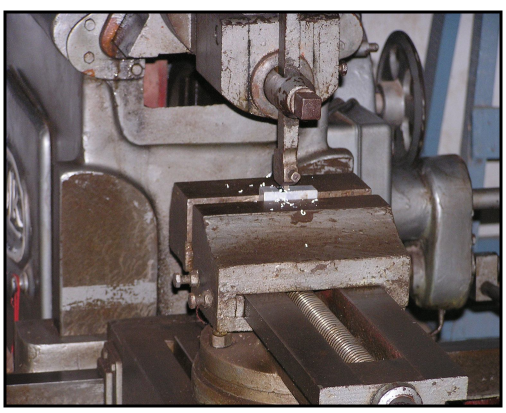


Fig. 3 Set Up for Shaping Operation

The same tool and set up continued until it completes the ten passes during 8 and 10 passes of machining it was clear that surface roughness value (Ra) has increased along with increase in number of passes. Similar trend was observed in the amplitude parameter (Sq) values also. By correlating both experimental values and amplitude parameter values, the condition of tool can be assessed and it was estimated as dull tool. Each specimen is subjected to number of passes 2,4,6,8, up to 10 passes. It is found that the variations are in close relation with the condition of the tool.

4.1 Analysis of machined surfaces

The present method, being non-contact captures the images of work piece surfaces after designed number of passes of machining with CCD camera and then these images are analyzed to obtain amplitude parameters used for surface roughness estimation of machined surfaces. These experiments were carried out for preparing flat work pieces made by shaping operation. After each pass of cutting, images are captured by texture analysis system at same time average surface roughness (Ra) value measured with stylus instrument. This procedure is continued until the tool becomes dull or fails .Each specimen was subjected to ten number passes. During experiments, it is observed that the cutting tool unable to remove metal after ten passes. A sub image of the original image is used for further processing with image metrology software TRUEMAP.

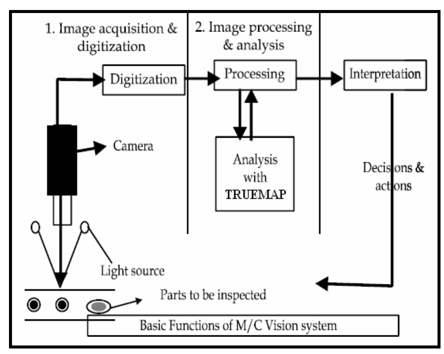


Fig. 4 Basic Steps in Machine Vision System

4.2 Surface roughness measuring techniques - direct measurement [Stylus instrument]

The average roughness 'Ra' of the machined surface is obtained directly by stylus instrument (fig.2a). The surfaces of the work pieces which were machined by different machining processes are subjected to this test. The roughness values thus obtained from this instrument compared with the amplitude parameter values.

4.3 Machine vision system

A machine vision system (Fig.4) analyses images and produces description of what is imaged. Inspection by visual means is a very obvious and potentially highly beneficial application area, which can be used as a powerful tool in automating quality control procedures and in obtaining specific quantitative measurements of important parameters in manufacturing process. Thus the machine vision system is considered elements of a fed back loop that is concerned with sensing.

4.4 Image capturing and analysis

Images were taken using a monochrome 0.5-in format CCD camera fitted with a focal lens with extension tubes to give a magnification of approximately 1.3. Images were captured using a frame-grabber. Image processing can mean both operations, i.e. quality enhancement, coding and analysis and processing, which includes takes from image formation to comprehension. Image analysis implies the description and measurement or image properties. After every two passes and by using surface metrology software TRUEMAP the surface roughness amplitude parameters were calculated. In this paper, the variations are found to be in close relation with the tool condition. The images of the machined surfaces various cutting tool conditions are shown in figure 9. Fig.5 – fig.8, represents the 3D plots for various surfaces and gives the three dimensional view of the surfaces with peaks and valleys of varying heights and depths with tool condition.

5. Results and Discussions

By using "Truemap" software calculate image amplitude parameters like RMS roughness (S_q), Skewness (S_{sk}) and Kurtosis (S_{ku}). The variation of the image amplitude parameters used for assessing surface roughness and Ra value from stylus instrument, with respect to the cutting tool conditions are shown in Table 2 and it was found that, the average surface roughness Ra value is in close relation with tool condition. The results of the images captured for Mild steel and EN8 specimens are analyzed for surface roughness at different work piece material and cutting tool combinations at constant machining condition.

Entire experimental investigation is planned into four different cases and results are analyzed by keeping the following points into consideration.

i. HSS tool- high hardness – less wear- high surface finish
ii. HCS tool- Less hardness– high wear– high surface roughness
iii. Mild steel – ductile work piece– less surface roughness
iv. EN8 – brittle work piece– high surface roughness.

5.1 Case1: Images of the mild steel specimens shaped with high speed steel tool

In this case shaping operation was carried on mild steel with high speed steel tool with sharp, semi dull and dull tool. The images of the surfaces after machining are captured through CCD camera are shown in fig .9 at constant machining condition. Fig 5, 6, 7, 8, represents the 3D plots for various surfaces and gives the three dimensional view of the surfaces with peaks and valleys. Where the height and depth of the peaks and valleys varied with respect to tool condition. From table.2 it was found that, the surface roughness is in close relation with tool condition. As the number of passes increases, a proportionate rise in image amplitude parameter (Sq) was found along with Ra value from stylus instrument. It indicates the correlation between them with respect to cutting tool condition. HSS cutting tool, due its high hardness it posses less wear hence this tool produces the surfaces with relatively lesser values of Ra with respect to state of cutting tool which is an indication for surface with less roughness.

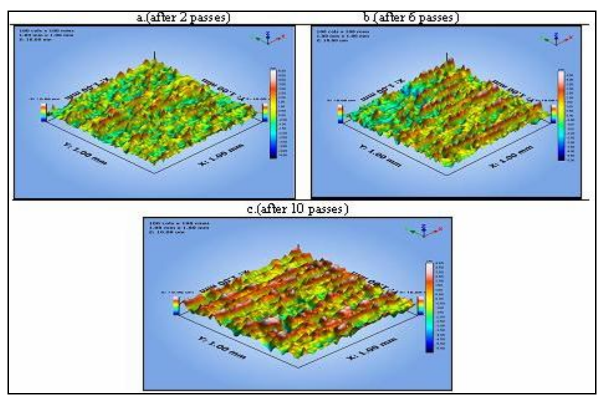


Fig. 5 3D Plot of Machined Surfaces (Shaping of MS with High Speed Steel Tool)

This trend is ably justified by the results tabulated in table 2. It is observed that, irrespective of machining conditions surface roughness of any machined surface steadily increases with increase in number of passes. Figure 5 (case 1) shows the images of machined surfaces. Up to six passes surface finish values are in acceptable range. But after eight passes of machining it is observed a significant growth in the values Ra and this is ably justified with image amplitude parameters also. It is observed that, up to first two passes of machining, the cutting tool results a machined surface with lesser values of Ra. Lesser values of average surface roughness (Ra) value clearly suggest that, up to first two passes the condition of the tool is sharp. Fig 5(a) shows 3D plot for a machined surface shows a machined surface with less number of peaks and also shows the symmetrical distribution which is a standard for good surface finish. It was also observed that, green color in 3D plot indication for a surface with good surface finish. As the machining continued with the same set up, after six passes a notable but acceptable variation in the surface roughness value was found and the same variations were also found in the values of the image amplitude parameters. It is observed that, the values of Skewness parameter still positive even though significant decrease in their values and values of Kurtosis parameter still greater than three even after six passes of machining. These results states that, the cutting tool has performed reasonably up to six passes but results clearly shows a definite decrease in surface finish after 2 passes. By keeping the values of skewness and kurtosis under consideration, the condition of the tool can be estimated. Based on trend in the values of skewness and kurtosis, tool may be inferred to be semi dull. The same set up was continued for further machining and the process repeated up to ten passes. But results show that, after eight passes of machining the variations were found to be very significant. At this stage it was observed that there is a notable change in the values of skewness and kurtosis parameters. After eight passes, skewness parameter was observed to be negative and the values of kurtosis were found to be below three. These two parameters are very important in assessing the surface roughness of a machined surface. Negative ness in skewness is increased after ten passes of machining and it indicates increase in surface roughness due to the presence of the large number of peaks. This change in skew ness parameter also indicates effect of cutting tool hardness on machined surface roughness. The values of kurtosis parameter after eight passes were less than three. Results shows that the surface roughness value (Ra) increases along with decrease in kurtosis value. The values of Skewness (-ve) and Kurtosis (<3) strongly suggest the cutting tool can not be used further machining because bluntness of the cutting tool has increased. According to US patent decrease in kurtosis is clear indication for bluntness. Hence it is can concluded that the cutting tool has reached dull condition.

5.2 Case 2: Images of the mild steel specimens shaped with HCS tool

In this case mild steel specimen machined with high carbon steel tool at constant machining condition. HCS tool due its less hardness it posses high wear hence it produces the machined surfaces with higher values of Ra after every pass of the machining. In both, case1 and case.2 the mild steel specimen is machined with two different (HSS & HCS) cutting tools to generate machined surfaces. Figure 6 represents the case.2. In this case, surface roughness parameter (Ra) values are relatively higher, because HCS tool is less hard so it posses high wear when compared with HSS tool hence it results relatively higher values of Ra after each pass of machining. This trend in Ra and correlation of this Sq with image amplitude parameter observed through out the experiment. The values of kurtosis and skewness also indicate the same as per the table.1. After 8 passes and 10 passes of machining the values of skewness parameter clearly justifies the effect of hardness in cutting tool on machined surface roughness.

5.3 Case 3: Images of EN8 specimens using HSS tool

In this case, EN8 material is machined with High speed steel tool to investigate the effect of brittleness in work piece material on machined surface roughness. Due to high percentage of carbon EN8 (0.35%C to 0.45%C) material posses high brittle ness and hence it generates surfaces with high roughness. Results in table 2 also indicate the same trend. The points discussed in previous cases hold good for this case also. From the results table 2 it can be concluded that work piece material definitely influences the surface roughness machined surface texture. Throughout the experiment the surface roughness values are found to be relatively high when compared with case 1.

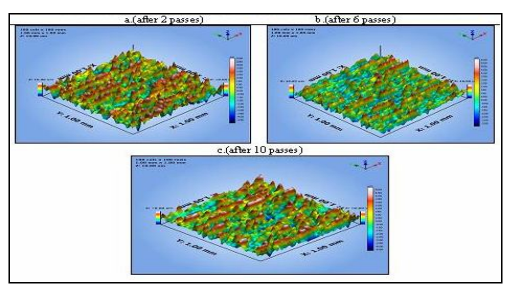


Fig. 6 3D Plots of Machined Surfaces (Shaping of MS with High Carbon Steel Tool)

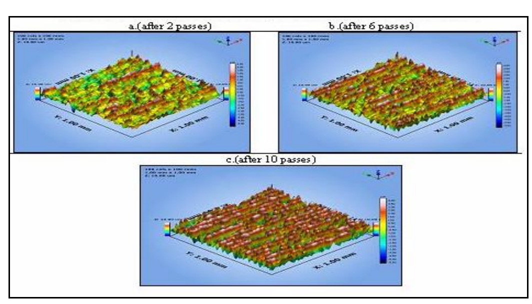


Fig. 7 3D Plot of Machined Surfaces (Shaping of EN8 with High Speed Steel Tool)

5.4 Case 4: Images of the EN8 specimens shaped with high carbon steel tool

In this case, EN8 and High carbon steel tool is selected for experimental study to examine the machined EN8 material surface by change in cutting tool. In this case, after 10 passes of machining discontinue chip was found it means we can not carry out machining any further. Reasons for this are brittleness in EN8 and also due to hardness of HCS cutting tool. HCS tool posses relatively less hardness and hence it generates surfaces with high roughness. The experimental results are also justifies the same. In results table.2, the values of kurtosis parameter is falling below three after 8 passes of machining in every case in entire experimentation. In this case highest negative ness in skewness and smallest value of kurtosis parameter are found. In this case the values of kurtosis parameter started falling below three even after 4 passes of machining. Skewness and kurtosis parameters values are very critical in estimating the condition of the cutting tool. When the tool reaches the dull state the predominant deep valleys displayed in 3D plot with a change in color (brown). This is very simple and clear indication in estimating the state of dull tool but this change in color can not be taken as basis for estimation of the cutting tool.

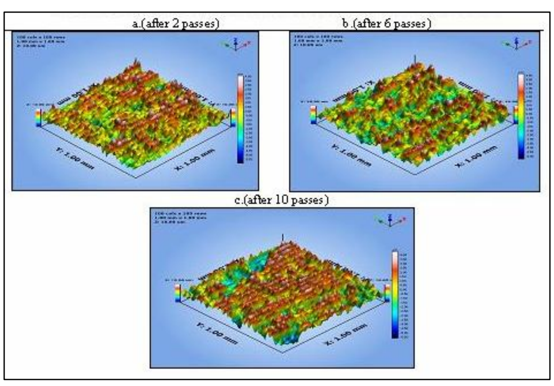


Fig. 8 3D Plot of Machined Surfaces (Shaping of EN8 with High Carbon Steel Tool)

The values of surface roughness parameters (RMS roughness, Ssk, Sku, Sz and Ra from stylus instrument for different work piece and cutting tool combinations were plotted against ‘ number of passes’. The surface roughness parameters were taken on Y-axis and the numbers of passes are taken on X-axis. In figure 10(a) the ‘Ra’ from stylus was plotted against number of passes. Figure 10(b) shows the variation of RMS roughness (Sq) with respect to number of passes. Figure 10(c) shows the variation of Ssk with respect to number of passes. Figure 10(d) shows the variation of Kurtosis with respect to number of passes. In all above mentioned graphs, it was clear that the surface roughness varies with respect to the condition of the cutting tool.

6. Conclusions

The images of the machined surfaces analyzed with image metrology software TRUEMAP various amplitude parameters have been derived. It this work, it was shown that application of machine vision techniques for effectively estimating the condition of the tool by analyzing the machined surfaces to monitor the cutting tool. With this method it is possible to estimate the condition of the tool without inspecting the cutting tool. The results obtained in each case indicates that, the methodology explained in this research, is able to estimate the condition of the cutting tool by inspecting surface texture of machined surface with the help of amplitude parameters derived form the images of a machined surface. The results show a close relation between the cutting tool condition and the surface roughness of the machined surface and also show a high degree of correlation between average roughness parameter, Ra (stylus) and amplitude parameters. In this work, image of machined surface was used in experimental investigation for measuring the condition of the tool instead of capturing directly the image of the cutting tool and hence this feature saves a lot of time. Even though the present work carried in offline mode but it can be used for online implementation as machining process is not interrupted for measurements provide a machine vision system attached to the machine. Experiments results prove that machine vision system is independent of the machining process and can be adopted to any kind of surface roughness investigation. The encouraging results of this research work pave the way for the development of a real-time, low-cost, and reliable tool-condition-monitoring system. A new approach has been established, for estimating the condition of cutting tool using surface texture as basis and amplitude parameters for analysis.

6.1 Future work

In the present work amplitude parameters are used to analyze the surface texture of the work piece (machined surface). This can be extended to spatial parameters like texture aspect ratio, texture direction, auto correlation etc. Besides the spatial parameters, the functional parameters and hybrid parameters can also be used for this analysis. In the present work experiments were conducted with single point cutting tool. This can also be extended to multi-point cutting tools.

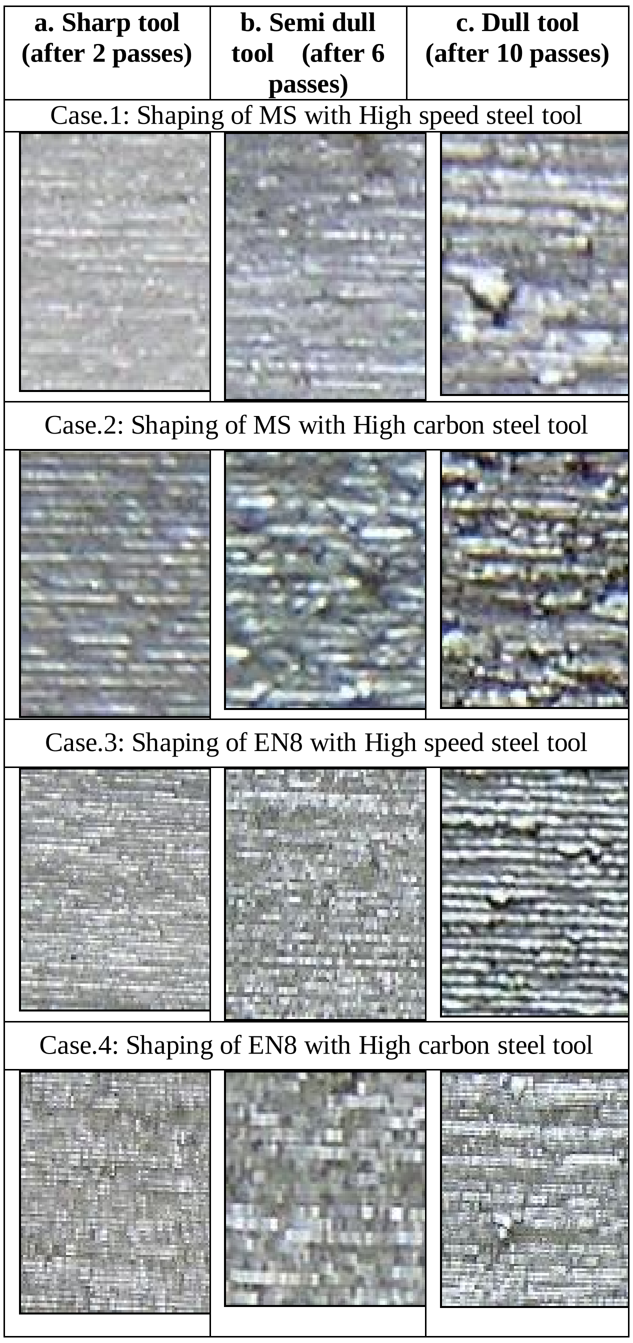


Fig. 9 Images of Machined Surfaces at Different Machining Conditions

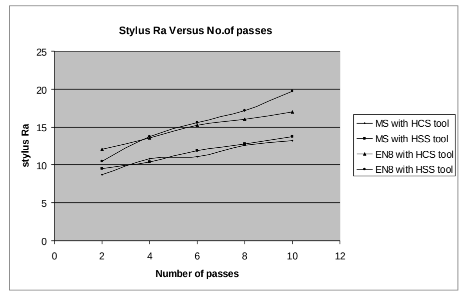


Fig. 10 (a)

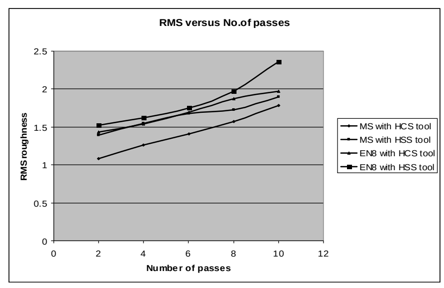


Fig. 10 (b)

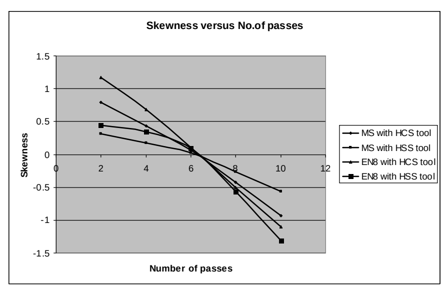


Fig. 10(c)

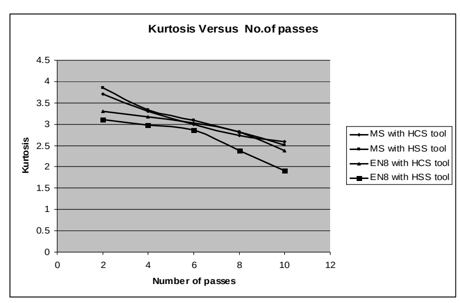


Fig. 10 (d)

Table 1: Amplitude Parameters Considered for Surface Textural Analysis

Skewness (Ssk)	Kurtosis (Sku)	RMS roughness(Sq)	Result	Reason
Positive (+ve)	High value(>3)	Low value	Good surface finish	a) Few number of peaks than valleys in 3D view plots. b) Very close distribution
Negative(-ve)	Low value(<3)	High value	High surface roughness	a) More number of peaks than valleys in 3D view plots. b)Well spread distribution

Table 2: Results of both Stylus and Amplitude Parameters for each Combination

Case 1: Shaping of MS with High Speed Steel Tool

S.No	Surface Parameters (µm)	Number of passes 2	4	6	8	10
1	RMS Roughness	1.080	1.260	1.410	1.570	1.780
2	Skewness	0.793	0.436	0.069	-0.420	-0.930
3	Kurtosis	3.703	3.302	3.002	2.742	2.583
4	Stylus Ra	8.730	10.850	11.050	12.600	13.200

Case 2: Shaping of MS with High Carbon Steel Tool

S.No	Surface Parameters (µm)	Number of passes 2	4	6	8	10
1	RMS Roughness	1.390	1.550	1.680	1.730	1.900
2	Skewness	0.315	0.175	0.024	-0.260	-0.560
3	Kurtosis	3.848	3.327	3.096	2.821	2.511
4	Stylus Ra	9.520	10.370	11.850	12.800	13.730

Case 3: Shaping of EN8 with High Speed Steel Tool

S.No	Surface Parameters (µm)	Number of passes 2	4	6	8	10
1	RMS Roughness	1.430	1.540	1.690	1.870	1.970
2	Skewness	1.169	0.680	0.100	-0.504	-1.100
3	Kurtosis	3.297	3.171	3.027	2.810	2.375
4	Stylus Ra	12.100	13.600	15.200	16.020	16.950

Case 4: Shaping of EN8 with High Carbon Steel Tool

S.No	Surface Parameters (µm)	Number of passes 2	4	6	8	10
1	RMS Roughness	1.520	1.620	1.750	1.970	2.360
2	Skewness	0.447	0.342	0.098	-0.560	-1.310
3	Kurtosis	3.104	2.984	2.864	2.385	1.906
4	Stylus Ra	10.500	13.750	15.600	17.200	19.740

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