PROCESS CAPABILITY ASSESSMENT USING VISION SYSTEM

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Abstract: Surface roughness assessment would help in predicting a component's functionality. This clearly shows the significance of measuring the surface roughness of machined components. Thus, each machined component, depending upon its intended function, requires a certain surface finish. To predict the surface roughness of a machined component, a detailed understanding of the machining parameters is essential. This is because, surface roughness generated on a component, depends upon machining parameters speed, feed, and depth of cut. A stable manufacturing process gives a consistent surface finish on all the manufactured components. Thus, only by having a stable process, consistent quality of manufactured products is possible. The capability of the machine is defined as the capability of the machine to carry out the set process efficiently and effectively to produce parts as per the specification limits. Machining parameters, tools, coolant flow rate, etc. An effort has been made in this research work, to show how by measuring surface roughness of machined components process capability can be assessed. Thus, the method is a novel technique of assessing the process capability of a given process. A capable process would help a manufacturing company in meeting customer expectations. The proposed method is of non-contact type, quick, and industry-friendly.

Key words: Surface Roughness Measurement, Process Capability Assessment, Process Capability, Capability Evaluation

1. INTRODUCTION

Surface roughness evaluation is significant in product manufacturing. Whitehouse [1] and Whitehouse and Archard [2], discuss the different types of filters used for separating roughness from waviness. Many researchers have worked on surface texture assessments [3, 4 and 5]. The texture is formed components such as form, waviness, and roughness. Many researchers have attempted to classify texture according to wavelength range- M-system [6] and E-system [7] came into being. The filters are useful for separating the three components of texture, which is required for further analysis [8, 9].
In 1982, Whitehouse [10] proposed a simulation of M-system filtering mechanism. Research contributions of Whitehouse and Archard [11] are very significant. Up to 1960's researchers were using simple geometric shapes to model machining processes like turning and milling but were not of use while modeling grinding or polishing. Nayak [12] implemented random surface models while assessing surface roughness.
Surface roughness is a quality that has a direct impact on product performance and appearance [13]. Sajjad Ghodrati et al. [14] explored the significance of roughness assessments. The surface finish is difficult to define by a single parameter. Normally surface roughness is characterized by height parameter and wavelength parameter, reported by Inamdar [15]. Makiko Yonehara et al [16] did experiments to explore the effect of roughness on glossiness. In their experiments, they used polished and sandblasted surfaces. Thammarat Somthong and Qingping Yang [17] proposed a method for measuring the surface roughness of workpieces. The method makes use of imaging through stereo-method and coordinate measuring method (CMM).
The capability of the machine to carry out the set process efficiently and effectively to produce parts as per the specification limits. Machining capability would depend on its feed, speed, tools, coolant flow rate, etc. Many researchers [18-22] have focused on considerable theoretical and experimental research work for the betterment of both product quality and process capability (Cp) with the help of statistical techniques. The expression for machine capability is the same as the process capability. But it is denoted by Cm and the corrected machine capability is denoted by Cmk. In 1998, Deleryd defined process capability as – the ability of a manufacturing process to meet the customer's expectations [23]. Instead, problems have aroused due to a lack of knowledge in handling statistical data or misinterpreting it. Along with understanding the definition well, it is essential to know that, computing of Cp is based on two assumptions [24] and they are: (i) Quality characteristics under consideration follow a normal distribution. This assumption is made to have computational advantages. (ii) Process being studied

is under statistical control. If a process is not under control, then Cp will fail in showing the capability of the process. The parameters, such as Cp, Cpk, and Cpm, are extensively used in manufacturing processes to indicate to check product's compliance to specifications [25].

2. METHODOLOGY AND EXPERIMENTATION

Surface roughness is measured by using the steps given below.

1. Installation of charge-coupled device (CCD) camera onto the CNC milling machine: CCD camera is mounted on the work table to capture the surface image of the specimen being machined.

2. Mounting of the specimen onto the CNC machine: Specimen is fixed onto the work table to hold it for machining.

3. Setting up machining parameters to perform machining of the specimen.

4. Machining of the specimen: Specimens made out of aluminium, having dimensions (8 cm x 8cm), are machined, using BFW make vertical machining center, based on the machining parameters set (Table 1), using High-speed steel tool.

5. Monitoring Surface roughness parameters (Ra, Rq, Rp): CCD camera captures the machined surface image, having a resolution of 512 x 480 pixels, while machining and calculating the surface roughness values. The system is calibrated by measuring known inputs. The device is used for measurement only after calibration.

6. Validation of roughness parameters by using stylus-based (contact) measuring method. Table 1 shows the roughness values obtained from both stylus and vision measurement methods. The stylus method is based on online sampling. Whereas, the Vision method is area-based. That is, the vision method computes the roughness parameters by using a window of 32x32 pixels.

Figure 1 shows the components of a vision system- frame grabber, CCD camera, advanced image processing card, and a MIL software development kit. Figure 2 shows the experimental set-up.
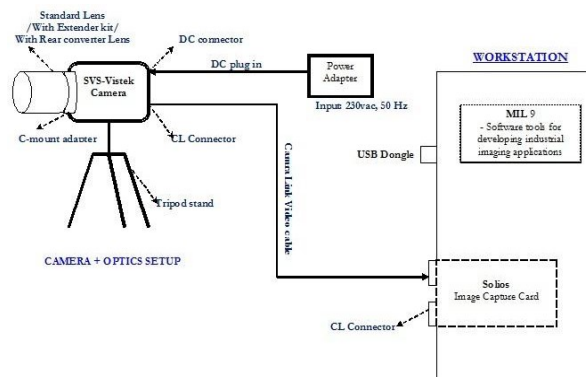
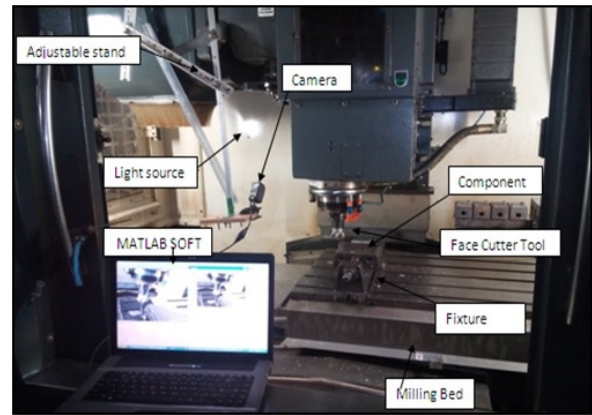Fig. 1. Schematic of basic components of vision system

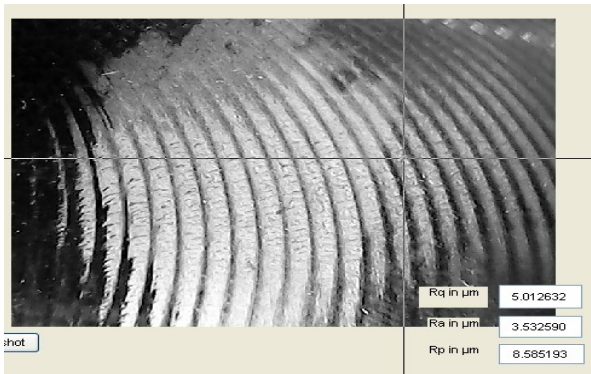Fig. 2. Machine vision system setup attached with the milling machine

Mitutoyo- Surftest SJ-210 stylus instrument is used to evaluate the roughness for the specimens prepared by the milling process using different machining parameters. The surface roughness parameters are measured. These roughness parameters values for all the specimens are shown in Table 1.

The milling process is considered for the process capability experiment. The milled specimens are prepared by varying machining parameters are shown in Table 1. Surface roughness parameters are evaluated by employing the surface roughness tester (make: Mitutoyo, series: surftest-210). Table 1 shows the surface roughness values obtained through the profilometer for different specimens. The image of each specimen is captured using the CCD camera. The images are processed using MATLAB. The digital image is represented by a rectangular matrix with elements corresponding to the brightness. The basic image data is fed to the algorithms developed using MATLAB. Then vision system surface roughness 2D parameters are evaluated in MATLAB. The processing capability of the milling process is shown in Table 2.
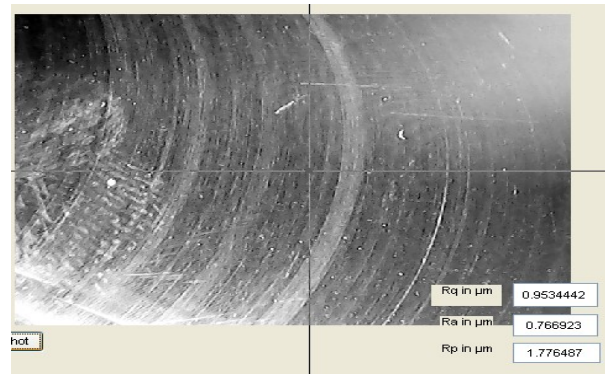
2.1. In Process Surface Roughness Evaluation
Figure 2 shows the experimental setup for surface roughness evaluation by the in-process method. Machining parameters are varied for each specimen and machining is carried out in a CNC milling machine, images are captured using a computer vision system of the specimen being machined. These images are analyzed and quality of the image is improved and surface roughness parameters are measured.
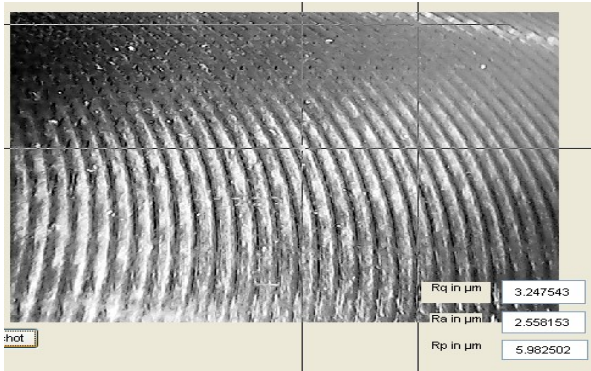
Figure 3 shows details of different specimens. The image resolution is 512x480 pixels. Figure 3 shows the directions of the predominant surface pattern (lay). This is characteristic of a particular machining process. Milled specimens are characterized by lays shown in Figure 3. In the process measured surface roughness values are tabulated in Table 1.
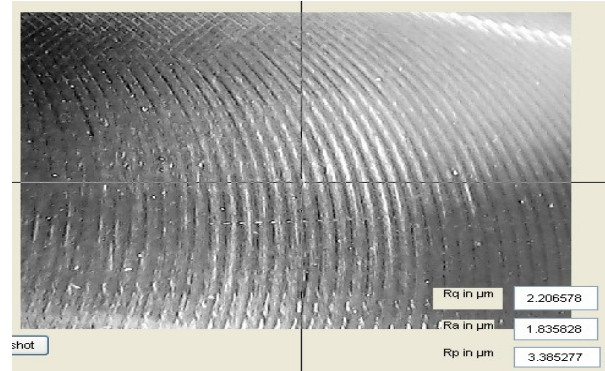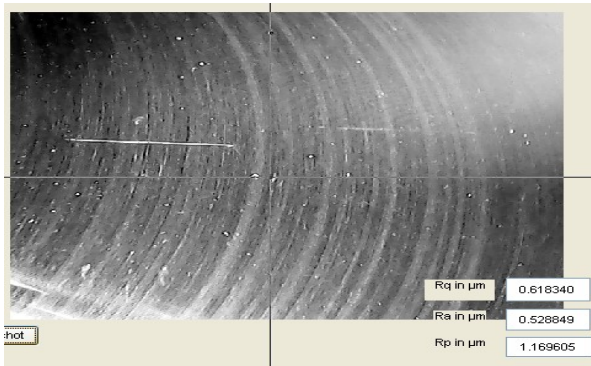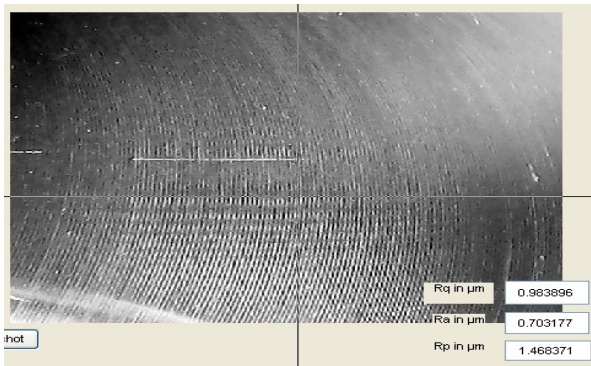
Specimen 1- Speed 300 revolution/minutes

Rq in µm	5.012632
Ra in µm	3.532590
Rp in µm	8.585193

Specimen 2- Speed 400 revolution/minutes

Rq in µm	3.247543
Ra in µm	2.558153
Rp in µm	5.982502

Specimen 3 - Feed 100 mm/minutes

Rq in µm	0.618340
Ra in µm	0.528849
Rp in µm	1.169605

Specimen 4 - Feed 200 mm/minutes

Rq in µm	0.983896
Ra in µm	0.703177
Rp in µm	1.468371

Specimen 5 - DOC 0.3 milli meter.

Rq in µm	0.9534442
Ra in µm	0.766923
Rp in µm	1.776487

Specimen 6 - DOC 1 milli meter.

Fig. 3. Machined surface images along with surface roughness parameters

Rq in µm	2.206578
Ra in µm	1.835828
Rp in µm	3.385277

2.2. Process capability evaluation

The following steps are followed for evaluating the process capability:

1. Specimen preparation;
2. Roughness evaluation using vision system- Vision roughness parameter was measured for the different specimens. Table 1 shows the details.
3. Computing process capability. Table 2 shows the details of process capability.

3. RESULTS AND DISCUSSION

The experimental data obtained from the experiments conducted are analyzed and discussed. Machining parameters are varied for each specimen and machining is carried out in CNC milling machine, images are captured using a computer vision system of the specimen being processed. These images are analyzed and the quality of the image is improved by using filters and surface roughness parameters are measured. The processing capability of the milling process is analyzed by surface roughness of machined specimens.

Table 1. Comparison of roughness values measured by stylus and proposed techniques

Sample No.	Speed rpm	Feed mm/ min	Depth mm	Stylus Ra μm	Vision Ra μm	Error %	Stylus Rq μm	Vision Rq μm	Error %	Stylus Rp μm	Vision Rp μm	Error %
1	300	500	0.5	2.888	2.750	4.7	3.247	3.216	0.9	5.982	5.976	0.1
2	400	500	0.5	2.558	2.423	2.4	2.918	2.733	6.3	5.892	5.706	3.1
3	500	500	0.5	1.673	1.583	5.3	2.009	2.156	7.3	4.761	4.612	3.1
4	1600	500	0.5	1.068	1.126	5.4	1.304	1.188	8.8	2.695	2.883	6.9
5	1700	500	0.5	0.817	0.903	9.5	1.021	1.116	9.3	2.392	2.568	8.1
6	1800	500	0.5	0.797	0.824	3.3	1.000	0.998	0.2	2.352	2.478	5.3
7	3500	500	0.5	0.727	0.766	5.3	0.896	0.903	0.7	2.018	2.167	7.3
8	3600	500	0.5	0.686	0.732	6.7	0.829	0.883	6.5	1.726	1.832	6.1
9	3700	500	0.5	0.542	0.587	8.3	0.679	0.722	6.3	1.527	1.664	8.9
10	1000	100	0.5	0.547	0.556	1.6	0.672	0.694	3.2	1.377	1.475	7.1
11	1000	150	0.5	0.642	0.673	4.8	0.830	0.763	8.0	1.472	1.376	6.5
12	1000	200	0.5	0.745	0.815	9.3	0.929	0.871	6.2	2.055	1.943	5.4
13	1000	250	0.5	0.863	0.889	3.0	1.067	0.952	10.7	2.263	2.112	6.6
14	1000	300	0.5	0.955	1.010	5.7	1.233	1.144	7.2	2.546	2.375	6.7
15	1000	350	0.5	1.062	1.154	8.6	1.241	1.236	0.4	2.695	2.502	7.1
16	1000	400	0.5	1.336	1.288	3.5	1.624	1.577	2.8	2.915	2.865	1.7
17	1000	450	0.5	1.412	1.376	2.5	1.738	1.694	2.5	3.385	3.188	5.8
18	1000	500	0.5	1.667	1.536	7.8	1.864	1.779	4.5	3.407	3.325	2.4
19	1000	500	0.2	0.766	0.773	0.9	0.953	1.003	5.2	1.776	1.897	6.8
20	1000	500	0.3	0.817	0.828	1.3	1.013	1.118	10.3	1.962	1.987	1.2
21	1000	500	0.4	0.926	0.998	7.7	1.138	1.188	4.3	2.085	2.132	2.2
22	1000	500	0.5	0.998	1.016	1.8	1.225	1.306	6.6	2.393	2.464	2.9
23	1000	500	0.6	1.102	1.166	5.8	1.318	1.391	5.5	2.585	2.676	3.5
24	1000	500	0.7	1.218	1.327	8.9	1.435	1.448	0.9	2.758	2.967	7.5
25	1000	500	0.8	1.386	1.466	5.7	1.648	1.596	3.1	3.051	3.113	2.0
26	1000	500	0.9	1.616	1.524	5.6	2.039	1.981	2.8	3.219	3.193	0.8
27	1000	500	1	1.835	1.758	4.1	2.206	2.003	9.2	3.835	3.756	2.0

Note: the stylus is stylus measurement and Vision is vision measurement

Table 2. Surface roughness parameters for milling, speed, feed, depth of cut, and vision system Ra with LCL and UCL

Sl. No.	Speed (rpm)	Feed (mm /min)	DOC (mm)	Vision system Ra μm (X_i)	Vision system Ra μm (X_i, Mean)	Vision system Ra μm (X_i-X_{mean})	Vision system Ra μm Sq .(X_i-X_{mean})	LCL	UCL
1	1000	500	0.5	1.435	1.3492	0.0858	0.0073	1	1.6
2	1000	500	0.5	1.423	1.3492	0.0738	0.0054	1	1.6
3	1000	500	0.5	1.513	1.3492	0.1638	0.0268	1	1.6
4	1000	500	0.5	1.326	1.3492	-0.0232	0.0005	1	1.6
5	1000	500	0.5	1.128	1.3492	-0.2212	0.0489	1	1.6
6	1000	500	0.5	1.424	1.3492	0.0748	0.0055	1	1.6
7	1000	500	0.5	1.393	1.3492	0.0438	0.0019	1	1.6
8	1000	500	0.5	1.426	1.3492	0.0768	0.0058	1	1.6
9	1000	500	0.5	1.397	1.3492	0.0478	0.0022	1	1.6
10	1000	500	0.5	1.483	1.3492	0.1338	0.0179	1	1.6
11	1000	500	0.5	1.364	1.3492	0.0148	0.0002	1	1.6
12	1000	500	0.5	1.295	1.3492	-0.0542	0.0029	1	1.6
13	1000	500	0.5	1.129	1.3492	-0.2202	0.0484	1	1.6
14	1000	500	0.5	1.113	1.3492	-0.2362	0.0557	1	1.6
15	1000	500	0.5	1.354	1.3492	0.0048	0.0002	1	1.6
16	1000	500	0.5	1.288	1.3492	-0.0612	0.0037	1	1.6
17	1000	500	0.5	1.376	1.3492	0.0268	0.0007	1	1.6
18	1000	500	0.5	1.536	1.3492	0.1868	0.0348	1	1.6
19	1000	500	0.5	1.423	1.3492	0.0738	0.0054	1	1.6
20	1000	500	0.5	1.31	1.3492	-0.0392	0.0015	1	1.6

Sl. No.	Speed (rpm)	Feed (mm /min)	DOC (mm)	Vision system Ra μm (Xi)	Vision system Ra μm (Xi, Mean)	Vision system Ra μm (Xi-X$_{mean}$)	Vision system Ra μm Sq .(Xi-X$_{mean}$)	L C L	U C L
21	1000	500	0.5	1.186	1.3492	-0.1632	0.0266	1	1.6
22	1000	500	0.5	1.141	1.3492	-0.2082	0.0433	1	1.6
23	1000	500	0.5	1.366	1.3492	0.0168	0.0002	1	1.6
24	1000	500	0.5	1.372	1.3492	0.0228	0.0005	1	1.6
25	1000	500	0.5	1.366	1.3492	0.0168	0.0002	1	1.6
26	1000	500	0.5	1.424	1.3492	0.0748	0.0055	1	1.6
27	1000	500	0.5	1.438	1.3492	0.0888	0.0078	1	1.6

Table 1 shows the machining parameters used while preparing milled specimens. Figures 5 and 6 show an excellent correlation in the roughness readings obtained from both vision and stylus methods. Thus, the vision method can be used for the roughness assessment of milled surfaces.

Excellent correlation between standard (stylus method) and the proposed method is obtained with a correlation coefficient of 0.98.
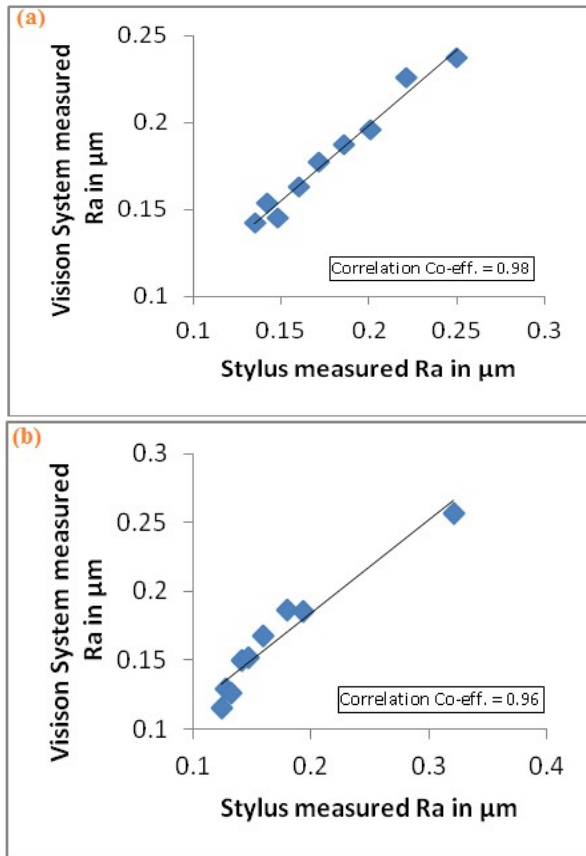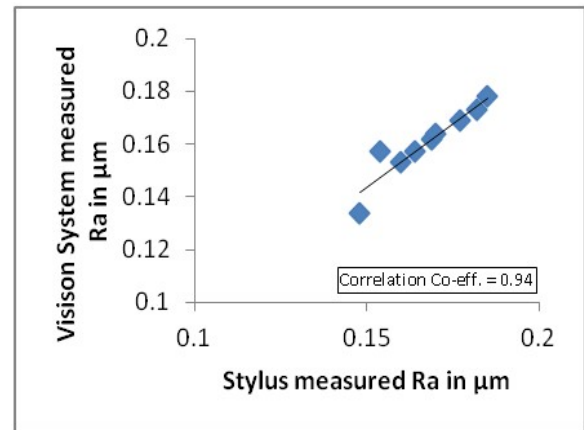

Fig. 6. Correlation curves at varying depth of cut

3.1. Graphical representation for Aluminum specimen for varying parameters

Figure 7 indicates a good correlation was obtained between the two methods within the speed range of 1800 to 3600 rpm. And correlation was not good for the specimens made outside this range. Figure 8 from these experimental results shown in the graph, surface roughness of the material is increased as feed increases. Figure 9 from these experimental results shown in the graph, surface roughness of the material is increased as the depth of cut increases.

Fig. 5. Correlation curves at varying (a) speed (b) feed
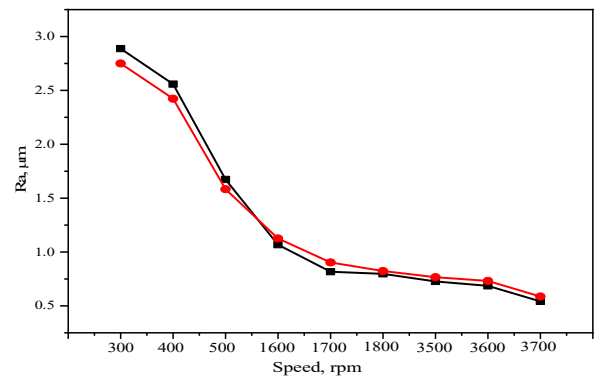

Fig. 7. Graph showing roughness values (stylus and vision system) measurements V/s varying speed
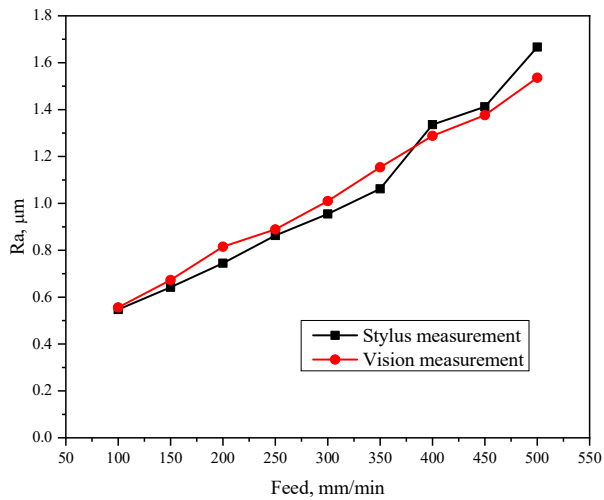
Fig. 8. Graph showing roughness values (stylus and vision system) measurements V/s varying feed
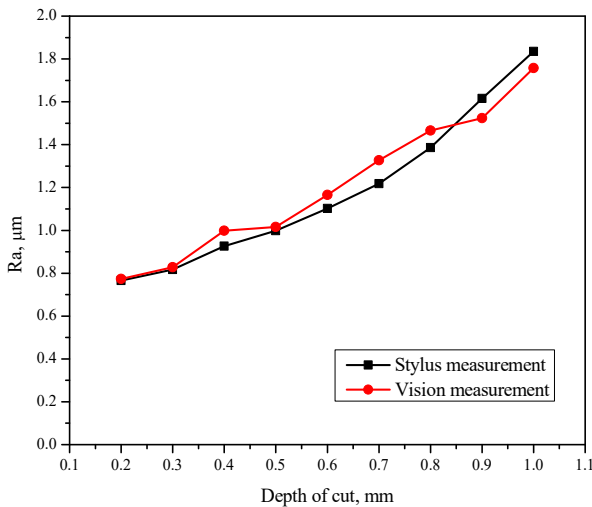

Fig. 9. Graphical representation of roughness values (stylus and vision system) measurements V/s varying depth of cut

3.2. Process capability

The following paragraphs show the effect of machining parameters on the process capability of the milling process. Figure 10 represents the characteristic curves for process capability with varied process parameters.

Fig. 10 shows a relationship between vision surface roughness (Ra) and the number of samples in the region 1 to 1.57 μm. Thus, this method of milling process can be used for predicting the process capability within the specified region.
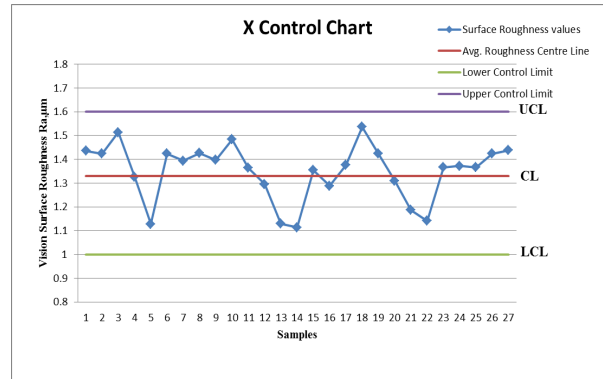

Fig. 10. Graphical representation of process variation as observed for machined samples wrt. varying speed, feed, and depth of cut

4. CONCLUSIONS

Present research work proposes a novel technique for determining the process capability of a manufactured process. The major advantage of the proposed method is that it is the non-contact way of measuring the process capability and is amenable for automation. Measuring process capability ensures manufacturing of the consistent quality product, for fulfilling customer expectations. For the research work, aluminium components were made by milling process on a CNC milling machine. The specimens are prepared by using different machining parameters. Roughness parameters were measured while performing milling, by fitting a camera sensor to the CNC Milling machine, connected to the vision system. C++ software developed in-house is used for computing surface roughness parameters. The maximum deviation between the two techniques is 9.5 %, 10.7 %, and 8.1 %, for Ra, Rq, and Rp respectively.

Capability analysis helps in determining whether the manufactured component lies in between tolerance limits and engineering specifications. It was demonstrated from the current research that; surface roughness can be used for determining the process capability of a manufacturing process.

5. REFERENCES

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