Surface Roughness Optimization Techniques of CNC Milling: A Review

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Abstract*: Surface Roughness is mostly used as an index to determine the surface finish for continuous improvement of quality. A large number of publications by various authors reflect the interest in this technique. Reviews of literature on surface roughness optimization have been done in the past by a few authors. However, considering the contributions in the recent times, a more comprehensive review is attempted here. In this paper, the authors have reviewed the literature in a way that would help researchers, academicians and practitioners to take a closer look at the growth, development and applicability of this technique. The authors have examined various papers and have proposed a different scheme of classification. In addition, certain gaps that would provide hints for further research in this field have been identified.*

INTRODUCTION: With the more precise demands of modern engineering products, the control of surface texture together has become more important. This review studies the various optimization methodologies, which is applied to optimize surface roughness in end milling operations. Conventional machining processes require a lot of time and effort. The accuracy achieved by such processes is not up to the level. With the invention of CNC machines, it becomes easy to do the various machining processes easily and accurately. Out of various machining processes, milling process has the advantage of multi-point cutting tool with high dimensional accuracy. So, it is important to study the various parameters that affect the quality surface

roughness to get the desired accuracy. Further, it is important to study which parameter affects the surface roughness significantly and the various optimization techniques. This can be done after a detailed literature review. Surface finish is important factor in evaluating the quality of products. Decision makers are constantly on the lookout for techniques to enable quality improvement. Surface Roughness Optimization is one such technique that has become popular in the recent times. The term surface finish is well known but the concept is understood more in qualitative terms than in quantitative terms. This is evident from the fact that many industries continue to specify finish as rough, good, smooth, glossy, mirror etc. None of these terms are sufficiently accurate and besides, they tend to convey different meanings to different people. It is in the common interest to adopt a quantitative method of evaluation with appropriate inspection techniques which will eliminate the variable subjective factor.

This paper, besides providing a review of literature on surface roughness optimization, covers the following objectives:

(1) Describing the publications in an orderly manner to enable easy and quick search;
(2) Classification of various techniques that can be used for optimization of surface roughness;
(3) Outcome of publications; and
(4) Identifying gaps and providing hints for further research.

This paper first provides a comparison among the earlier reviews on surface roughness and highlights the outcome in each case. All new techniques have been discussed.

Six papers have been studied in detail to conclude:

- The various optimization techniques that can be used to get an optimal value of surface finish.
- Various parameters that affects the surface roughness.
- Which parameter affects the surface roughness significantly?
- Various surface roughness measuring instruments.
- Different attributes that can affect the quality of a product.
- Gaps in the existing literature.

Detail of papers which have been reviewed in the present paper are:

(1) "Application of response surface methodology in the optimization of cutting conditions for surface roughness", H.Oktem, T.Erzurumlu and H.Kurtaran, 2005, Journal of Materials Processing Technology 170(2005)11-16.

(2)"Milling surface roughness prediction using evolutionary programming methods", Oguz Colak, Cahit Kurbanoglu and M.Cengiz Kayacan, 2007, Journal of Materials & Design 28(2007)657-666.

(3)"Surface Roughness optimization in an end milling operation using Taguchi design method, Julie Z.Zhang, Joseph C.Chen and E.Daniel Kirby, 2007, Journal of Materials Processing Technology184(2007)233-239.

(4) "The effects of cutter path strategies on surface roughness of pocket milling of 1.2738 steel based on Taguchi method", Cevdet Gologlu and Nazim Sakarya, 2008, Journal of Materials Processing Technology 206(2008)7-16.

(5) "Optimization of CNC end milling process parameters using PCA based Taguchi method", Sanjit Moshat et al, 2010, Internatonal Journal of Engineering, Science & Technology (2010)92-102.

(6) "Surface Roughness Prediction for CNC milling process using Artificial Neural Network", M.F.F.Ab.Rashid and M.R.Abdul Lani, 2010, Proceedings of World Congress in Engineering.

A complete detail of each paper is required for describing all the aspects so that a new researcher can easily locate them, download them so that one can enhance his skills. This can be achieved by describing fully the paper. The papers are arranged in ascending order of their year of publication. These selected papers are studied in detail so that every aspect starting from the work piece, selection of machine, parameters to be taken for optimization, instrument to be used for measurement of surface roughness so that surface roughness at various locations of the work piece can be determined. Then, the various optimization technique that can be used for optimization by describing both single response optimization technique and multi optimization techniques so that value of various parameters like cutting speed, depth of cut and feed rate can be determined for optimization of surface roughness. For surface roughness smaller the better can be used because it will yield greater surface

finish. It is in the common interest to adopt a quantitative method of evaluation with appropriate inspection techniques which will eliminate the variable subjective factor. When different surfaces are compared, it is possible to distinguish them in terms of reflectivity (dull or shiny appearances), smoothness, the presence of chatter marks, or the visual scratch pattern. Table 1 shows the title , year of publication and the name of concerned journal.

S.NO	Title of Paper	Year of Publication	Name of Journal
1.	Application of response surface methodology in the optimization of cutting conditions for surface roughness.	2005	Journal of Materials Processing Technology.
2.	Milling surface roughness prediction using evolutionary programming methods.	2007	Journal of Materials & Design.
3.	Surface Roughness optimization in an end milling operation using Taguchi design method.	2007	Journal of Materials Processing Technology.
4.	The effects of cutter path strategies on surface roughness of pocket milling of 1.2738 steel based on Taguchi method.	2008	Journal of Materials Processing Technology.
5.	Optimization of CNC end milling process parameters using PCA based Taguchi method.	2010	International Journal of Engineering, Science&Technology.
6.	Surface Roughness Prediction for CNC milling process using Artificial Neural Network.	2010	Proceedings of World Congress in Engineering.

Table No. 1 title of papers along with year & journal in which published

These selected papers are then studied in detail so that every aspect of the work done by the researcher can be framed in a better way. Outcomes of the reviews are shown in Table 2. Further, a comparison among the earlier attempts to review literature is made using certain attributes.

S.NO	TITLE OF PAPER	OUTCOME
1.	**Application of response surface methodology in the optimization of cutting conditions for surface roughness.**	RSM is utilized to create an efficient model for surface roughness in terms of cutting parameters feed, cutting speed, axial & radial depth and machining tolerances. A number of experiments is done and GA technique is used for surface roughness optimization. The accuracy of model is verified experimentally.
2.	**Milling surface roughness prediction using evolutionary programming methods.**	Gene expression programming is used for predicting surface roughness. The algorithm is evaluated with the help of C++ language. The evaluated C++ function gives the relation between cutting parameters and surface roughness in a high accuracy, as a rate of 91 percent.GEP is coming from its ability to generate mathematical equations that can be easily programmed.

3.	**Surface Roughness optimization in an end milling operation using Taguchi design method.**	Taguchi design application is used to optimize surface quality in a CNC milling operation.L9 orthogonal array is used for array selection.ANOVA and S/N ratio are calculated for an optimum value of surface roughness. Confirmation tests verified that the Taguchi design was successful in optimizing parameters.
4.	**The effects of cutter path strategies on surface roughness of pocket milling of 1.2738 steel based on Taguchi method.**	The cutting parameters evaluated are cutting velocity, feed rate, depth of cut and their aim is to identify the effects of cutter path strategies in milling. These aim will be addressed by means of using Taguchi parameter design.
5.	**Optimization of CNC end milling process parameters using PCA based Taguchi method.**	This method is useful to built up a bridge between quality and productivity means it provide good surface finish and high metal removal rate. Also this methodology has been found fruitful in the cases where simultaneous optimization of huge number of responses is required.
6.	**Surface Roughness Prediction for CNC milling process using Artificial Neural Network.**	The main purpose of this research is to provide an effective and accurate way to predict surface roughness in CNC end milling. The result of average percentage error is 13.3%, showing that the prediction accuracy is about 86.7%.

Table No. 2 showing Outcomes of the different reviews

Surface roughness refers to deviation from the normal surface. Order of deviation is defined in international standards. First- and second-order deviations refer to forms, i.e. flatness, circularity, etc. and to waviness, respectively, and are due to machine tool errors, deformation of the work piece, erroneous setups and clamping, vibration and work piece material in homogeneity. Third and fourth-order deviations refer to periodic grooves and to cracks which are connected to the shape and condition of the cutting edges, chip formation and process kinematics. Fifth- and sixth-order deviations refer to work piece material structure, which is connected to physical–chemical mechanisms (slip, diffusion, oxidation, residual stress, etc.). Different order deviations are superimposed and form the surface roughness profile, as in Fig. 2.

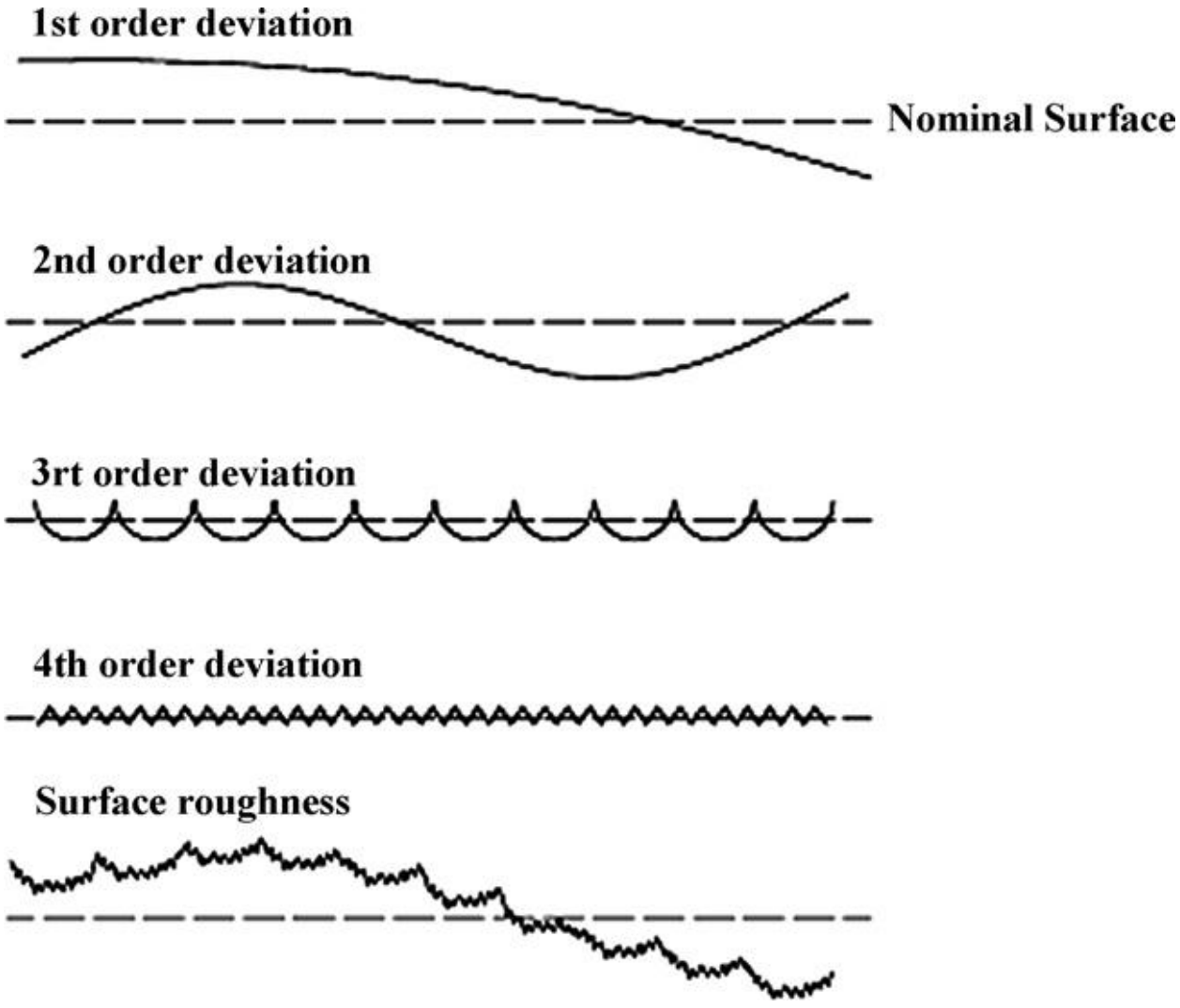

Fig No. 2 Different order deviations

Selection of process parameters is based on literature review and researchers take these parameters with the help of cause and effect diagram. Surface finish depends on a number of factors shown by cause and effect diagram as shown in fig 3.Out of these parameters, machining parameters need to be studied in a detailed manner so that the surface roughness of a surface can be worked out and possibly be minimized from the engineering point of view.

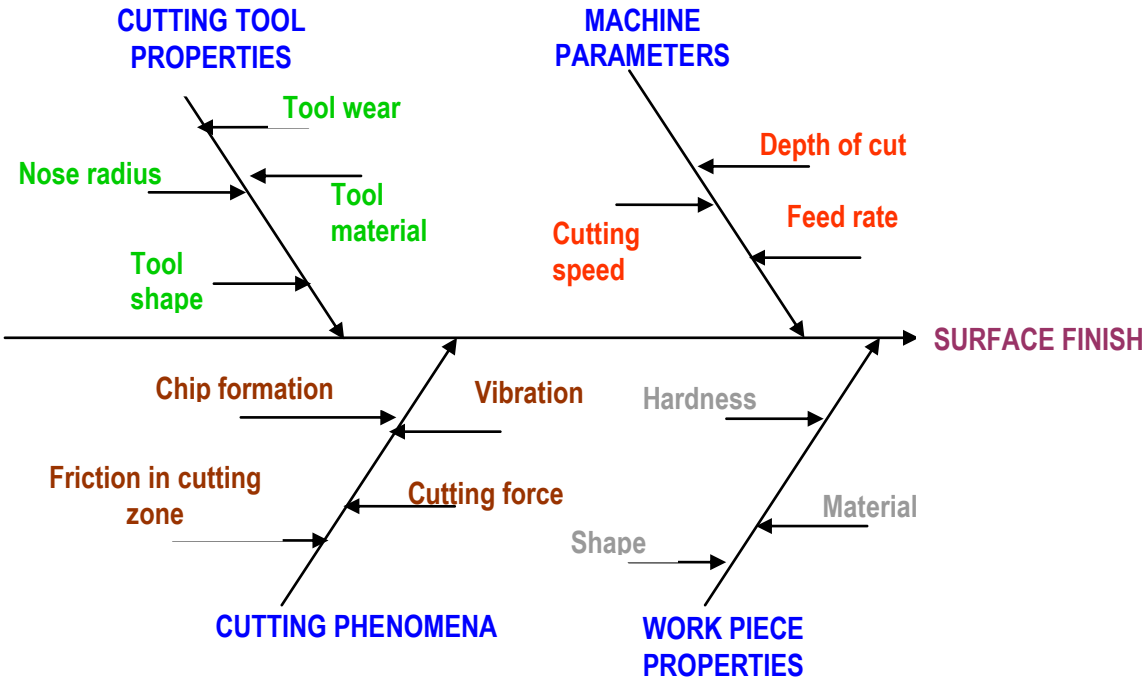

Fig No. 3 Cause & Effect Diagram

Classification of affecting factors:

SNo	Classification	Affecting Factors
1	Machining Parameters	Cutting speed, depth of cut ,feed rate
2	Properties of tool	Tool material,wear,nose radius, tool deflection
3	Work piece properties	Hardness,toughness,material
4	Machining equipment	Vibration,chatter,cutting forces
5	Environmental conditions	Temperature

Table No. 3 Classification of affecting factors

Now, we discuss how surface roughness measurement depends on a number of factors and how it can be measured.

It depends on:

- Instrument to be used for measurement.
- Techniques that can be used for measurement.
- Parameters that have a significant effect on surface roughness.
- Noise factors consideration.

Various instruments that can be used for measurement of surface roughness are:

- Image Processing.
- Microscope.
- Stylus type of instrument.
- Profile tracing instrument.

Image processing instrument shown in figure 4 can be used to detect surface roughness of a surface.

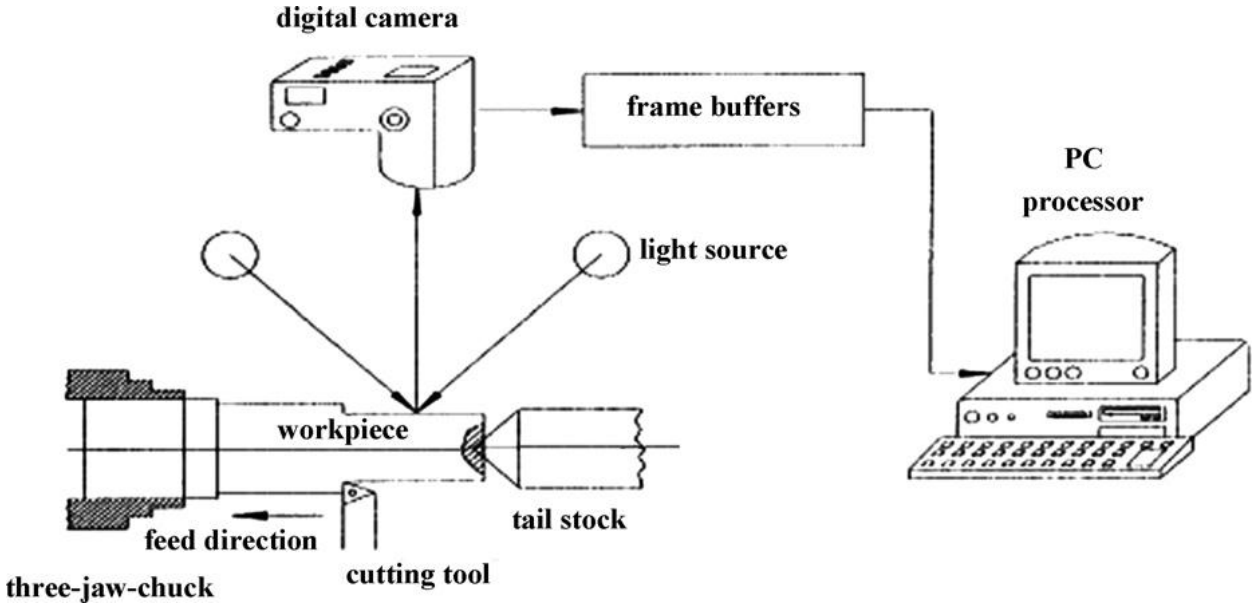

Fig No. 4 Image processing apparatus

Stylus instruments:

The Surftest SJ-201P (Mitutoyo) is a shop–floor type surface-roughness measuring instrument, which traces the surface of various machined parts and calculates the surface roughness based on roughness standards, and displays the results. The work piece is attached to the detector unit of the SJ-201P will trace the minute irregularities of the work piece surface. The vertical stylus displacement during the tracing is processed and value is digitally

displayed on the liquid crystal display of the SJ-201P.The apparatus is shown in figure 5.

Fig No. 5 Mitutoyo Surftest SJ-201P Instrument

Mathematical techniques can also be used like:

Some of the popular parameters of surface finish specification are described as follows:

1 Roughness average (Ra)

This parameter is also known as the arithmetic mean roughness value, AA (arithmetic average) or CLA (center line average). Ra is universally recognized and the most used international parameter of roughness. Therefore,

$$R_a = \frac{1}{L}\int_0^L |Y(x)|dx \qquad (1)$$

Where,

Ra = the arithmetic average deviation from the mean line

L = the sampling length

y = the ordinate of the profile curve

It is the arithmetic mean of the departure of the roughness profile from the mean line.

2 Root-mean-square (RMS) roughnesses (Rq)

This is the root-mean-square parameter corresponding to Ra:

$$R_q = \sqrt{[\frac{1}{L}\int_0^L (Y(x))^2 dx]} \qquad (2)$$

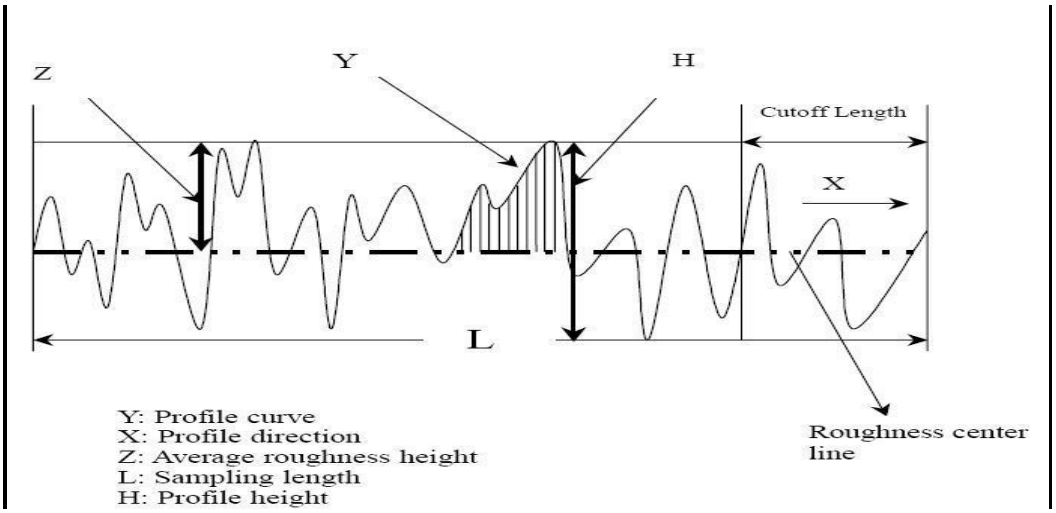

Fig No. 6 Variation of Surface Roughness

3 Maximum peak-to-valley roughness heights (Rmax)

This is the distance between two lines parallel to the mean line that contacts the extreme upper and lower points on the profile within the roughness sampling length. Since Ra and Rq are the most widely used surface parameters in industry, Ra was selected to express the surface roughness in this study.

The next step is to determine the various optimization techniques to calculate surface roughness:

A number of optimization techniques can be used:

- Taguchi method
- PCA(Principle Component Analysis) based Taguchi method
- RSM (Response Surface Methodology)
- Artificial Neural Networks
- Average Roughness Technique
- ANOVAs Approach

These techniques can be explained in detail with the help of table 4.

S.NO.	TECHNIQUE NAME	DETAIL
1.	**PCA-based Taguchi method**	Taguchi's Orthogonal Array (OA) provides a set of well-balanced experiments (with less number of experimental runs), and Taguchi's signal-to-noise ratios (S/N), which are logarithmic functions of desired output. Principal Component Analysis (PCA) is a way of identifying patterns in the correlated data, and expressing the data in such a way so as to highlight their similarities and differences. The main advantage of PCA is that once the Patterns in data have been identified; the data can be compressed, i.e. by reducing the number of dimensions, without much loss of information. The methods involved in PCA are discussed below: 1. Getting some data 2. Normalization of data 3. Calculation of covariance matrix. 4. Interpretation of covariance matrix.
2.	**Artificial Neural Network**	Artificial Neural Network is an adaptable system that can learn relationships through repeated presentation of data and is capable of generalizing to new, previously unseen data. For this study, the network is given a set of inputs and corresponding desired outputs, and the network tries to learn the input-output relationship by adapting its free parameters. First, a training input pattern is presented to the network input layer. The network then propagates the input pattern from layer to layer until the output pattern is Generated by the output layer. If this pattern is different from the desired output, an error is calculated and then

		propagated backwards through the network from the output layer to the Input layer.
3.	**Roughness average technique(Ra)**	Roughness average (Ra): This parameter is also known as the arithmetic mean roughness value, AA (arithmetic average) or CLA (center line average). Ra is universally recognized and the most used international parameter Of roughness.
4.	**Taguchi and ANOVA technique**	ANOVA can be useful for determining influence of any given input parameter for series of experimental. Result by design of exp. For machining process and it can be to interpret experimental data. While performing ANOVA degrees of freedom should also be considered together with each sum of square. In ANOVA studies with certain test error, error variance determination is very Important.
5.	**RSM**	These techniques select orders of polynomial model, analysis of points, conduct analysis and model fitting.

Table No. 4 Detailed Description of Techniques

Now, we consider the machining parameters that can have a significant effect on surface roughness. So, we have to design a table showing factors, technique and software used in each paper. This is done in table 5 to explain the status of each parameter in each of the selected papers.

Parameters or factors	Title of papers					
	Title 1	Title 2	Title 3	Title 4	Title 5	Title 6
Cutting speed	YES	YES	YES	YES	YES	YES
Feed Rate	YES	YES	YES	YES	YES	YES
Depth of Cut	YES	YES	YES	YES	YES	YES
Cutting Force	NO	YES	NO	YES	NO	NO
Temperature	NO	NO	YES	NO	NO	NO
Tool wear	NO	NO	YES	YES	NO	NO
Software used	C language	C++ language	MINITAB	MINITAB	SPSS	MATLAB 2008
Technique used	RSM& GA	GEP	Taguchi Method	Taguchi Method	PCA based Taguchi Method	ANN

Table No. 5 showing status of parameters

Most important parameter is feed rate followed by cutting speed and depth of cut. These have a significant effect on the surface roughness. Language tools are being used along with statistical tools for determination of surface roughness.

Three major categories were created to classify the selected papers: These are:

(i) Approaches that are based on machining theory to develop analytical models and/or computer algorithms to represent the machined surface;

(ii) Approaches that examine the effects of various factors through the execution of experiments and the analysis of the results;

(iii) Approaches that use designed experiments;

(i) It includes approaches that place emphasis on certain aspects from the theory of machining such as

process kinematics, cutting tool properties, chip formation mechanism etc. Computer-aided design (CAD) methods and tools are utilized so as to achieve the goal of building a model that will be able to simulate the creation of the machined surface profile, thus visualizing surface topography and assessing surface roughness. In general, geometric model development forms the basis of the approach through rigorous mathematical equations. This model is then implemented by a computer algorithm in order to handle the complex calculations. The vibration frequency ratio (FR), which was defined as the ratio of vibration frequency (in Hz) over spindle rotational speed (in rps), was thought to influence the period of the surface waviness along the axial direction. It was also found that the effects of the radial direction vibrations on the surface roughness measures were much more significant than those of either the tangential direction vibrations or the axial direction vibrations as would be expected.

(ii) The experimental approach may be thought of as the most 'obvious' method: experiments with the factors that are considered to be the most important are conducted and the obtained results are used to investigate the effect of each factor as well as the influencing mechanism on the observed quality characteristic. Regression analysis is often employed in order to build models based on the experimental data. The researcher's intuition and insight play a great role in this approach but a high understanding of the examined phenomenon is also necessary for the experiment to yield any meaningful results. The experimental approach is mainly adopted in cases where there can be no analytical formulation of the cause and effect relationships between the various factors. The experimental study included accurate characterization of the edge geometry so as to measure edge features, experimentation on a rigid machine tool with good spindle accuracy to minimize vibration and analysis of variance to establish the statistical significance of the

parameters. The findings revealed the significant effects of the edge hone radius and the work piece hardness to surface roughness and cutting forces.

(iii)

The reason why designed experiments were classified under a different category from the previous approaches is because they constitute a systematic method concerning the planning of experiments, collection and analysis of data with near-optimum use of available resources.

Gaps in existing Literature:

- Most of the researchers have investigated only limited number of process parameters of CNC milling.
- Multi - response optimization of parameters of CNC milling is another area where less attention has been paid in the past.
- The optimization techniques have not been completely explained.
- A limited work is done on modeling of parameters.
- A large number of materials are yet to be verified by experimentation.
- Difference between single response optimization and multi response optimization is not completely explained.

Conclusion:

- Range of the process parameters can be established with the help of review done on surface roughness optimization.
- Effect of process parameters like cutting speed, feed rate, lubrication pressure, depth of cut on surface roughness were studied.
- Taguchi Technique can be used for optimization of parameters for surface roughness.
- Response Surface Methodology (RSM) can be used for developing mathematical models in the form of regression equations.
- For single- response optimization, desirability function can be used in combination with RSM.
- For multi-response optimization utility concept can be used along with Taguchi Technique.
- Surface Roughness can be compared both experimentally and mathematically.
- Some papers with more number of parameters can be selected.

- Difference between single response optimization and multi response optimization can be worked out.
- Experimental methods are preferred as compare to analytical methods for analysis.
- Various techniques like Graph theories can be explored.

References:

- H.Oktem, H.Kurtaran, (2005) "Application of response surface methodology in the optimization of cutting conditions for surface roughness", Journal of Material Processing Technology 170, Pp. 11–16.
- Julie Zhang, Joseph Chen (2007) "Surface Roughness optimization in an end milling operation using Taguchi design method", Journal of Material Processing Technology 184, 233-239.
- Oguz Colak, Cahit Kurbanoglu (2007) "Milling Surface Roughness using evolutionary programming methods", Journal of Materials & Design 28, 657-666.
- Cevdut Gologlu, Nazim Sakarya (2008) "The effects of cutter path strategies on surface roughness of pocket milling of 1.2738 steel based on Taguchi method", Journal of Material Processing Technology 206, 7-16.
- Sanjit Moshat et al (2010) "Optimization of Cnc end milling process parameters using PCA based Taguchi Method", International Journal of Engineering, Science & Technology, 92-102.
- M.F.F.Ab.Rashid et al (2010) "Surface Roughness Prediction for CNC milling process using Artificial Neural Network", Proceedings of World Congress in Engineering.