A Review Paper for Optimization of Surface Roughness and MRR in CNC Milling

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Abstract:
The main purpose of this review paper is to check whether quality lies within desired tolerance level which can be accepted by the customers. So, optimizing surface roughness and metal removal rate using various CNC machining parameters including spindle speed (N), feed rate (f) and depth of cut (d) and insert nose radius (r). By developing a mathematical model in CNC milling on a hard steel specimen. And this mathematical model is developed with the help of the design of Matrix. Also CNC (Computer Numerical Control), in which the instructions are stored as a program in a micro-computer attached to the machine. The computer will also handle much of the control logic of the machine, making it more adaptable than earlier hard-wired controllers. This experimental study aims at response surface methodology has been applied for finding the effect on surface roughness and metal removal rate by various process parameters. And after that we can easily find out that which parameter will be more affect.

Keywords: *CNC milling operation, MRR, RSM, Surface roughness*

1. Introduction

The challenge of modern machining industries is mainly focused on the achievement of high quality, in term of work piece dimensional accuracy, surface finish. Surface texture is concerned with the geometric irregularities of the surface of a solid material which is defined in terms of surface roughness, waviness, lay and flaws. Surface roughness consists of the fine irregularities of the surface texture, including feed marks generated by the machining process.

In manufacturing industries, manufacturers focused on the quality and Productivity of the product. To increase the productivity of the product, computer numerically machine tools have been implemented during the past decades. Surface roughness is one of the most important parameters to determine the quality of product. The mechanism behind the formation of surface roughness is very dynamic, Complicated, and process dependent. Several factors will influence the final surface roughness in a CNC milling operations such as controllable factors (spindle speed, feed rate and depth of cut). Principal surface method is suitable to find the best combination of independent variables which is spindle speed, feed rate, and the depth of cut in order to achieve desired surface roughness.

2. CNC milling process

Milling is the process of machining flat, curved or irregular surface by feeding the work piece against a rotating cutter containing a number of cutting edges. Milling process consists of a motor driven spindle, which mounts and revolves the milling cutter and a reciprocating adjustable worktable, which mounts and feeds the work piece. Milling machine is a machine tool that cuts metal with multiple-tooth cutting tool called a milling cutter. The work piece is fastened to the milling machine table and is fed against the revolving milling cutter. The milling cutter can have cutting teeth on the periphery or side or both.

2.1 Principle Functions of CNC

The principle functions of CNC are as follows:-

- Machine tool control
- In-process compensation
- Improved programming and operating features
- Diagnostics

2.2 CNC System Elements

A typical CNC system consists of the following six elements:-

- Part program
- Program input device
- Machine control unit
- Drive system
- Machine tool
- Feedback system

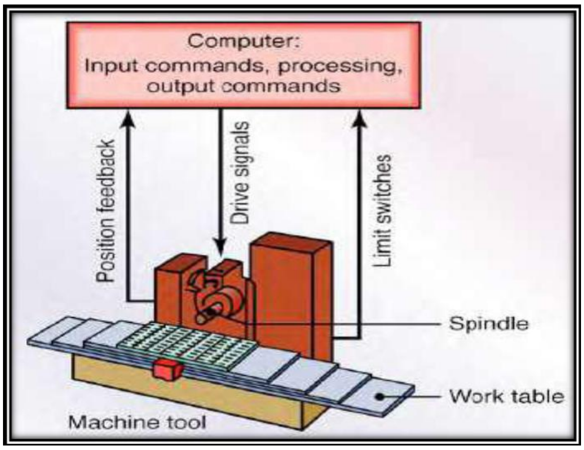

Fig.1 Major components of a numerical control machine tool

3. Adjustable Process Parameters

Cutting Speed: Speed (v) is the peripheral speed of the cutter in m/min.

Cutting speed (V) = πDN/1000

Where D = cutter diameter, mm

N = cutter speed, rpm

The cutting speed in a milling machine depends on work material, cutter diameter and number of cutter teeth, feed, and depth of cut, width of cutter and use of coolant.

Feed: Feed (f) is defined as the movement of work relative to the cutter axis and is the rate at which the work is being fed to the cutter.

Feed in milling operation is expressed in the following three ways:

1. Feed per tooth (f_z), mm per tooth of cutter
2. Feed per revolution (f_{rev}), mm per revolution of cutter
3. Feed per minutes (f_m), mm, per minute

The above three feeds are related as follows:

$f_m = N*f_{rev} = f_z*Z*N$

Where Z = number of teeth in cutter

N = cutter speed, rpm

Depth of Cut: Depth of cut is practically self explanatory. It is the thickness of the layer being removed (in a single pass) from the work piece or the distance from the uncut surface of the work to the cut surface, expressed in mm.

Depth Of Cut = D – d

Depth of cut = mm Here, *D and d* represent initial and final thickness (in mm) of the job respectively.

4. Response Surface Method

Response surface methodology (RSM) is a collection of mathematical and statistical techniques for empirical model building. By careful design of *experiments*, the objective is to optimize a *response* (output variable) which is influenced by several *independent variables* (input variables). An experiment is a series of tests, called *runs*, in which changes are made in the input variables in order to identify the reasons for changes in the output response.

Originally, RSM was developed to model experimental responses, and then migrated into the modeling of numerical experiments. The difference is in the type of error generated by the response. In physical experiments, inaccuracy can be due, for example, to measurement errors while, in computer experiments, numerical noise is a result of incomplete convergence of iterative processes, round-off errors or the discrete representation of continuous physical phenomena. In RSM, the errors are assumed to be random.

The design procedure of response surface methodology is as follows:-

1. Designing of a series of experiments for adequate and reliable measurement of the response of interest.
2. Developing a mathematical model of the second order response surface with the best fittings.
3. Finding the optimal set of experimental parameters that produce a maximum or minimum value of response.
4. Representing the direct and interactive effects of process parameters through two and three dimensional plots.

5. Literature Survey

In manufacturing industries, manufacturers focused on the quality of the product. **P.G. Benardos, Greece [1]** found that a neural network modeling approach is presented for the prediction of surface roughness (Ra) in CNC face milling. The data used for the training and checking of the networks' performance derived from experiments conducted on a CNC milling machine according to the principles of Taguchi design of experiments. The factors considered in the experiment were the depth of cut, the feed rate per tooth, the cutting speed, the engagement and wear of the cutting tool, the use of cutting fluid and the three components of the cutting force. Using feed forward ANN trained with the Levenberg – Marquardt algorithm was able to predict the surface roughness with a mean squared error equal to 1.86% and to be consistent throughout the entire range of values.

P. Franco[2] was developed Influence of radial and axial run outs on surface roughness in face milling with round insert cutting tools**.** In this work, a numerical model for predicting the surface profile and surface roughness as a function of these factors is presented, incorporating a random values generation algorithm that makes it possible to determine the variation in surface roughness from the values that can be adopted by tool errors. The results that correspond to a number of teeth equal to 4, insert diameter of 12 mm, depth of cut of 0.5 mm, cutting speed of 120 m/min and feed of 0.4–1.4 mm/rev are analyzed.

Kurbanoglub et al [3] carried out Milling surface roughness prediction using evolutionary programming methods. CNC milling has become one of the most competent, productive and flexible manufacturing methods, for complicated or sculptured surfaces. In order to design, optimize, built up to sophisticated, multi-axis milling centers, their expected manufacturing output is at least beneficial. In this study gene expression programming method is used for predicting surface roughness of milling surface with related to cutting parameters. Cutting speed, feed and depth of cut of end milling operations are collected for predicting surface roughness.

Babur, Mahmut[4] from Turkey worked on the statistical modeling of surface roughness in high-speed flat end milling. Surface roughness is one of the most important requirements in machining process. The surface roughness value is a result of the tool wear. This paper presents the development of a statistical model for surface roughness estimation in a high-speed flat end milling process under wet cutting conditions, using machining variables such as spindle speed, feed rate, depth of cut, and step over. First- and second order models were developed using experimental results of a rotatable central composite design, and assessed by means of various statistical tests. The highest coefficient of correlation (Radj 2) (88%) was obtained with a 10-parameter second-order model. Thus, in order to enhance the estimation capability of the model, another independent variable was included into the model to account for the effect of the tool wear, and the total operating time of the tool was selected as the most suitable variable for this purpose. By inserting this new variable as a linear term into the model, Radj 2 was increased to 94% and a good fit was observed between the model predictions and supplementary experimental data.

Julie et al [5] in USA has found Surface roughness optimization in an end milling operation using the Taguchi design method. This paper presents a study of the Taguchi design application to optimize surface quality in a CNC face milling operation. Maintaining good surface quality usually involves additional manufacturing cost or loss of productivity. This study included feed rate, spindle speed and depth of cut as control factors, and the noise factors were the operating chamber temperature and the usage of different tool inserts in the same specification, which introduced tool condition and dimensional variability. An orthogonal array of L9(34) was used; ANOVA analyses were carried out to identify the significant factors affecting surface roughness, and the optimal cutting combination was determined by seeking the best surface roughness (response) and signal-to-noise ratio.

Tian-Syung Lan [6] study on virtual CNC milling and implementation of optimum mmr with tool life control. The modeling of dynamic material removal rate (*MRR*) control and the optimum solution with tool life determination through Calculus of Variations to minimize the machining cost of an individual cutting tool under expected machining quantity are introduced in this paper. By introducing the real-world *CNC* (computerized numerical control) machining case from AirTAC into the virtual system, the simulated cutting forces are shown to promise the feasible applicability of the optimum *MRR* control. Additionally, the implementation of the dynamic solution is experimentally performed on our proposed digital PC-based lathe system. The surface roughness of all machined work-pieces is found to not only stabilize as the tool consumed, but also accomplish the recognized standard for finish turning. This study not only provides the economical solution of virtual machining prior to realization for the optimum *MRR*, but also advances the realistic implementation through digital PC-based lathe system to the *CNC* machining industry with profound insight.

M.F.F. Ab. Rashid and M.R. Abdul Lani [7] worked on Surface Roughness Prediction for CNC Milling Process using Artificial Neural Network. The purpose for this research is to develop mathematical model using multiple regression and artificial neural network model for artificial intelligent method. Spindle speed, feed rate, and depth of cut have been chosen as predictors in order to predict surface roughness. 27 samples were run by using FANUC CNC Milling. The experiment is executed by using full factorial design. Analysis of variances shows that the most significant parameter is feed rate followed by spindle speed and lastly depth of cut. After the predicted surface roughness has been obtained by using both methods, average percentage error is calculated. The mathematical model developed by using multiple regression method shows the accuracy of 86.7% which is reliable to be used in surface roughness prediction. On the other hand, artificial neural network technique shows the accuracy of 93.58% which is feasible and applicable in prediction of surface roughness. The result from this research is useful to be implemented in industry to reduce time and cost in surface roughness prediction.

K. Schutzer, et al [8] carried out Improvement of surface accuracy and shop floor feed rate smoothing through open CNC monitoring system and cutting simulation. In the milling process of complex workpiece shapes the feed rate normally becomes instable due to the high degree of surface curvature that requires high acceleration and deceleration of the interpolated axes. This condition impacts on process time and on the surface accuracy regarding the manufactured part form and texture. The challenge to simulate the real machine and control behavior requires accurate models with a set of experiments to tune and dimension the model to the respective machine tool. The aim is to improve the HSC milling process of complex surfaces before removing any material. In this paper experiments show that the surface form accuracy and texture can be optimized through an automatic feed rate smoothing of the finishing operation directly on the machine tool. The axis positions and spindle speeds monitored through the open CNC are used as input for a geometric cutting simulation, thus enabling to predict and optimize the surface quality.

Toshihiko et al [9] in Japan study Surface Roughness Control Based on Digital Copy Milling Concept to Achieve Autonomous Milling Operation. In order to develop an autonomous and intelligent machine tool, a system named Digital Copy Milling (DCM) was developed in our previous studies. The DCM generates tool paths in real time based on the principle of copy milling. In the DCM, the cutting tool is controlled dynamically to follow the surface of CAD model corresponding to the machined shape without any NC program. In this study, surface roughness control of finished surface is performed as an enhanced function of DCM. From rough-cut to semi-finish-cut and finish-cut operations, the DCM selects cutting conditions and generates tool paths dynamically to satisfy instructed surface roughness Ra. The experimental verification was performed successfully.

As per the above study I am also interested to work on the optimization of surface roughness and metal removal rate in CNC end milling using response surface methodology

6. Material Selection

- Stainless steel (SS-304)
- Dimension for material is 100*50*20 mm metal plate.

Table 1 Chemical Composition

Cr	Mn	Ph	S	Si	C	Ni	N	I
18.00 – 20.00	2.00	0.045	0.030	0.75	0.08	8.0 – 10.5	0.10	Bal

Table 2 Mechanical Properties

Properties	Values
Proof Stress	85Mpa
Hardness	80RB
Tensile Strength	655Mpa
Elongation	55 pert.

Table 3 Physical Properties

Properties	Values
Yield strength	241Mpa
Density	$7.9 * 10^3$ Kg/m^3
Thermal Expansion	$17 * 10^{-6}$/K
Modulus Of Elasticity	200Gpa
Thermal Conductivity	16.2 W/m.K

7. Conclusion

In this study the optimal cutting condition for face milling was selected by varying adjustable cutting parameters. With the L_9 orthogonal array, experimental runs and determining suitable optimal cutting parameters for surface finish. The surface finish achievement of the confirmation runs under the optimal cutting parameters indicated that of the parameter settings used. In this study, response surface methodology will apply to produce the best surface roughness in this milling operation. Also, RSM is an efficient and effective method for optimizing surface roughness in a milling.

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