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AN EXPERIMENTAL STUDY OF CUTTING PARAMETERS ON CONCENTRICITY IN CNC TURNING OPERATION USING DESIGN OF EXPERIMENT

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Abstract — *A major channel of machined components is produced by CNC and VMC machines. These machines have got specific capability to produce components meeting both the dimensional and geometric requirements. These requirements are to be met within order to meet the functional requirements by each component as a part of an assembly. This work is an effort in this direction especially in the content of Location control. Here concentricity is taken as response to be study as geometry of part. Greater attention is given to the geometry in addition to the dimensional accuracy and surface characteristics of products by industries these days. In order to produce parts which are more functional and ensure ease of assembly. In this work design of experiment is carried out to investigate the effect of Machining parameters on concentricity. How this concentricity behaves under the different combination of machining parameters is the objective of this work. Experimental work carried out on mild steel (AISI 1020) work piece on CNC turning center. Turning Operation was performed on mild steel round bar. AISI 1020 steel can be largely utilized in all industrial sectors in order to enhance weldability or machinability properties. It is used in a variety of applications due to its cold drawn or turned and polished finish property. The current status and demands is that the specific requirements of geometrical and dimensional relation need to ensure for better functioning of part while assembling. The economic and efficient manufacturing is also required apart from creating product which satisfies the customer more.*

I. INTRODUCTION

Turning operation is one of the most basic machining processes. That is, the part is rotated while a single point cutting tool is moved parallel to the axis of rotation. Turning is a form of machining, a material removal process, which is used to create rotational parts by cutting away unwanted material. The turning process requires a turning machine or lathe, work piece, and cutting tool. Turning is used to produce rotational, typically axi-symmetric, parts that have many features, such as holes, grooves, threads, tapers, various diameter steps, and even contoured surfaces. Geometric requirements that part must possesses after turning process are cylindricity, circularity, circular runout, total runout, concentricity of features etc. within the specified limits of sizes. The process variables like cutting tool geometry, cutting tool material, speed, coolant type, feed, depth of cut etc. are affecting the geometric requirements of parts.

Geometric dimensioning and tolerancing (GD&T) is a system for defining and communicating engineering tolerances pertaining geometric shape of component. Geometric dimensioning and tolerancing (GD&T) is used to define the nominal (theoretically perfect) geometry of parts and assemblies, to define the allowable variation in form and possible size of individual features, and to define the allowable variation between features.

The plus and minus system of dimensioning and tolerancing is insufficient to consistently convey design intent. If one part is made in one geographic location and mating part in another, even though both were made as per drawing specifications, when brought together the parts would not always mate in assembly. ASME Y14.5-2009 is the accepted geometric dimensioning and tolerancing standard superseding ANSI Y14.5M-1994 used within the USAs and ISO 1101-2004 is used outside of the USA. It allows as repeatability of part orientation, interchangeability of part etc. Allows a designer to express his/her thoughts and design requirements in clear, concise manner.

I. LITERATURE REVIEW

So far as work in the study of behavior of geometry of feature as a function of machining parameter is concern we find least amount of literature. Some of the research paper related to the same is discussed below.

In studies Tadvi et el.[1], a Three-factor two-level factorial design was used to determine the effects of the cutting speed, feed and depth of cut on geometric tolerances in CNC turning of Aluminium 6061(size 25mm dia x 100 mm length). A hexagon CMM machine was used to measure the data for circularity. The study shows that the circularity error is minimum at 800 rpm, 0.1 mm/rev. and depth of cut 0.75 mm, for 2^3 Design. From the circularity model feed is most significant parameter and speed is less significant parameter and depth of cut does not affect the circularity.

Mustafa et el. [2], experimental and statistical methods were used. The parameters determined at the experimental design stage and the parameters necessary for improving dimensional precision of the work piece were consistent. Thus, the study was successfully completed. In short, independent variables estimated for the dependent variables solved the problem. The minimum surface roughness value was 0.831 µm. The minimum cutting force was 94 N. The minimum work piece cylindricity error was 0.019 mm.

II. GEOMETRIC DIMENSIONING AND TOLERANCING

An engineering drawing of a production part conveys information from the designer to the manufacturing and inspection. It must contain all information necessary for the part to be correctly manufactured and inspected. The system of geometric tolerancing offers a precise interpretation of drawing requirements. Geometric dimensioning & tolerancing is an international system of symbolic language, and is simply another tool available to make engineering drawings for communication from design through manufacturing & inspection. It uses a series of internationally recognized symbols rather than words to describe the part shape. These symbols are applied to the features of a part and provide a very concise and clear definition of the design intent. GD&T is a step ahead to produce parts which are functionally better. Geometric tolerancing controls geometric characteristics of part features. [5]

Geometric tolerance characteristics are categorized as form, orientation, profile, runout and location. Different types of geometric characteristic symbols are used to specify the drawing as shown in Table 1. Form contains flatness, straightness, circularity and cylindricity. The form characteristics are always individual (not related to datums). In other words, features that are flat, round, straight or cylindrical are not compared to other features but are compared only to perfect geometric counterparts of themselves. Profile contains profile of a line and profile of a surface. The profile characteristics may, but are not require the use of datums. Orientation contains perpendicularity, parallelism and angularity. They require the use of datums. Runout contains total runout and circular runout. They require the use of datum. Location contains position, symmetry and concentricity. This also requires the use of datums. [5]

ADVANTAGES OF GEOMETRIC DIMENSIONING & TOLERANCING

The system of Geometric Tolerancing offers a precise interpretation of drawing requirements. Following are some advantage of using GD&T Control:

1. Plus and minus system results in a “Square or Rectangular” tolerance zone for hole location. This results in less tolerance being available for hole, which in turn results in higher manufacturing costs for part. Whereas, Geometric tolerancing results in a cylindrical tolerance zone for the hole location. This results in 57% more tolerance for hole location, which translates into lower manufacturing costs for the parts and higher profits.

Table 1: Geometric Controls [5]

Pertainsto	Type of Tolerance	Geometric Characteristics	Symbol
Individual Feature Only	Form	STRAIGHTNESS	—
		FLATNESS	▱
		CIRCULARITY	○
		CYLINDRICITY	⌭
Individual Feature or Related Features	Profile	PROFILE OF A LINE	⌒
		PROFILE OF A SURFACE	⌓
Related Features	Orientation	ANGULARITY	∠
		PERPENDICULARITY	⊥
		PARALLELISM	//
	Location	POSITION	⌖
		CONCENTRICITY	◎
		SYMMETRY	⌯
	Runout	CIRCULAR RUNOUT	↗
		TOTAL RUNOUT	⌰

2. Plus and minus tolerancing always results in a tolerance zone of fixed size. This results in some otherwise functional parts being scrapped during inspection. Due to the higher resulting scrape rate, the operating costs go

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higher. Whereas, Geometric tolerancing allows for the use of MMC modifier, which results in increased tolerance zones under certain conditions. This results in allowing more functional parts being accepted during inspection.

3. Use of G.D. &T. results in improved product designs. Also it takes into consideration the part function at the design stage and makes use of functional dimensioning philosophy to establish part tolerances based upon functional requirements.
4. Use of G.D. &T. results in improved communications, at all levels, by providing a common language to design, manufacturing, and quality control. It enforces uniformity in drawing specifications and interpretation, and results in reduced controversy, guess work and assumptions.
5. Location of part features are more accurately defined from specified datums for Repeatability.
6. Interchangeability of Parts.[6]

III. CONCENTRICITY TOLERANCING

Concentricity is a three dimensional type of location control. It controls opposed points to an axis. Concentricity is the condition where the median points of all diametrically opposed elements of a feature of revolution (or correspondingly located elements of two or more radially disposed features) are congruent with the axis of a datum feature. A median point is the mid-point of a two point measurement. These median points/elements coincide exactly in all their parts with the datum axis. This tolerance zone generated is cylindrical or spherical and coaxial with the datum axis or center point. Concentricity will control location and can have some effect on the form and orientation of the feature. Figure 1 will gives very clear idea about the concentricity control. [5]

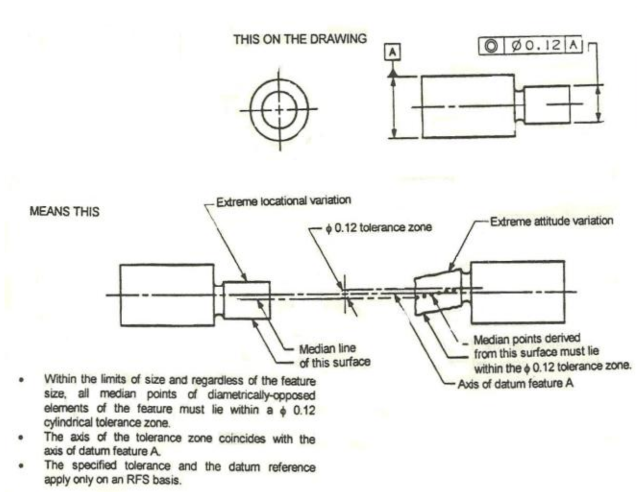

Figure 1: Concentricity definition [5]

Concentricity is applied to circular feature, and the parts which are having operating like turning, drilling, boring etc are required to have concentricity within specified tolerance zone. In industry concentricity control is used in few unique applications, where a primary consideration is precise balance of part, equal wall thickness and another functional requirement that's call equal distribution of mass. [5]

Turning Operation

The process of Turning has been long considered an art due to the tremendous amount of variability and subjectivity involved. The quality of turning differs from operator to operator and the results are highly inconsistent. The surface roughness ,geometric tolerances depend on the proper control of turning parameters such as cutting speed, feed rate, depth of cut, work piece material, coolant type, cutting tool material and geometry etc. To attain the desired outcomes, it is imperative to select proper values for the turning control parameters. Moving the art of turning into a science and quantifying the results can solve many of the above problems. [3]

Table 2: Controllable & Response Parameters [3]

Controllable Parameters	Cutting speed, Feed, Depth of cut, Coolant type, Cutting tool material and geometry, workpiece material, etc.
Uncontrollable Parameters	Geometric tolerances, surface roughness.

Factorial designs have been found to be most efficient for experiments that involve the study of the effects of two or more factors, which is the case here. Thus, in this research, the experiments were designed using factorial design concepts.

Operator's variability and environmental factors may be considered random variations in conducting the experiments or say uncontrollable parameters. And there are some controllable parameters which we can keep constant during process or can vary to study effect of the same. For this study workpiece material, workpiece dimension and cutting material are kept constant during process. As a variable parameter Speed, feed and depth of cut are taken. According to tool material and work piece material following data were taken using reference:

Table 3: Factors and Their levels [3] [4]

Factors/ Levels	Low	Medium	High
Speed(RPM)	2000	2500	3000
Feed(mm/rev)	0.10	0.15	0.20
Depth of Cut (mm)	0.1	0.3	0.5

IV. DESIGN OF EXPERIMENT

Many experiments involve the study of the effects of two or more factors/variables on various responses. In general factorial designs are the most efficient for this type of experiments. The effect of factor is defined to be change in response produced by a change in the level of the factor. This is frequently called main effect because it refers to the primary factor of interest in the experiment. [4]

The advantage of factorial design is that it is more efficient than one factor at a time experiments. It is necessary when interaction may be present to avoid misleading conclusion. Moreover, factorial designs allow the effects of a factor to be estimated at several levels of the other factors, yielding that are valid over a range of experimental conditions. [4]

The 2^3 Design

Suppose that three factor A, B and C, each at two levels, are of interest. The design is called 2^3 factorial designs and the eight treatment combination can now be displayed geometrically as a cube, as shown in fig 4.7. Using the "+" and "_" notation to represent the low and high levels of the factors, we may list the eight runs in the 2^3 design as in fig 4.8. This is sometimes called the design matrix. [4]
There are actually three different notations that are widely used for the runs in the 2^k design. The first is the "+" and "_" notation, often called geometric notation. The second is the use of lowercase letter labels to identify the treatment combinations. The final notation uses 1 and 0 to denote high and low factor levels, respectively, instead of "+" and "_". These different notations in shown in Table 4. [4]

Table 4: 2^3 design [4]

Run	A	B	C	Labels	Run	A	B	C	Labels
1	-	-	-	(1)	5	-	-	+	C
2	+	-	-	A	6	+	-	+	Ac
3	-	+	-	B	7	-	+	+	Bc
4	+	+	-	Ab	8	+	+	+	Abc

There is seven degree of freedom between the eight treatment combinations in the 2^3 design. Three degree of freedom is associated with the main effect of A, B, and C. Four degree of freedom associated with interactions; one each with AB, AC, and BC and one with ABC. [4]

Addition of center points to the 2^k design

There is a method of replicating certain points in a 2^k factorial that will provide protection against curvature from second order effects as well as allow an independent estimate of error to be obtained. The method consists of adding center points to the 2^k design. One important reason for adding the replicate run at the design center points do not affect the usual effect estimates in a 2^k design. When we add center points, we assume that the k factor is quantitative. [4]

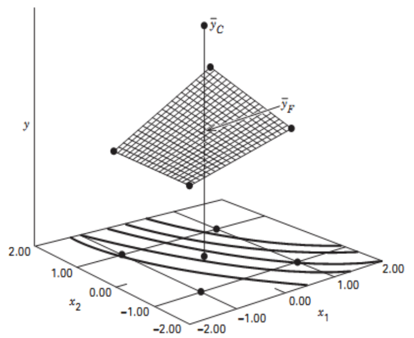

Figure 2: 2^2 design with center points [4]

To illustrate the approach, consider a 2^2 design with one observation at each of the factorial points and n_c observations at the center points (0, 0). Figure 2 illustrates the situation. From Figure 2 if $\overline{yf} - \overline{yc}$ is small then the center points lie on or near the plane passing through the factorial points, and there is no quadratic curvature. On the other hand if

$\overline{yf} - \overline{yc}$ is large, then quadratic curvature is present. Where $\overline{yf}$ is the average of the four runs at the four factorial points and $\overline{yc}$ is an average of the n_c runs at the center points. [4]

DOE for Turning

The surface roughness, geometric tolerances depend on the proper control of turning parameters such as cutting speed, feed rate, depth of cut, work piece material, coolant type, cutting tool material and geometry etc. To attain the desired outcomes, it is imperative to select proper values for the turning control parameters. Moving the art of turning into a science and quantifying the results can solve many of the above problems. [3] [4]

Table 5: 2^3 Design for concentricity control [3] [4]

Sr. No.	Speed (RPM)	Feed (mm/rev)	Depth of Cut(mm)	Sr. No.	Speed (RPM)	Feed (mm/rev)	Depth of Cut(mm)
1	2000	0.10	0.1	7	2000	0.20	0.5
2	3000	0.10	0.1	8	3000	0.20	0.5
3	2000	0.20	0.1	9	2500	0.15	0.3
4	3000	0.20	0.1	10	2500	0.15	0.3
5	2000	0.10	0.5	11	2500	0.15	0.3
6	3000	0.10	0.5	12	2500	0.15	0.3

V. EXPERIMENTATION WORK

In experimentation work turning operation was carried out on AISI 1020 material. Figure 3 shows turning operation.

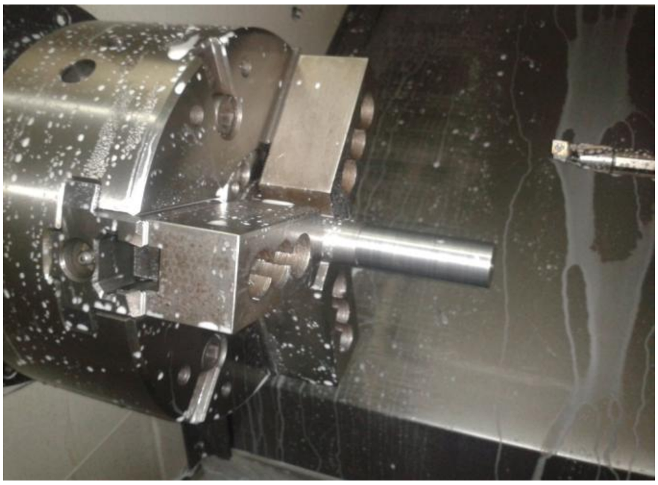

Figure 3: Step Making Operation Holding Datum in Chuck

Turing operation gives following component. Concentricity of this component was measured. Here bigger diameter step is function as datum because same we have hold in chuck, with respect to it we have to measure the concentricity of smaller diameter step.

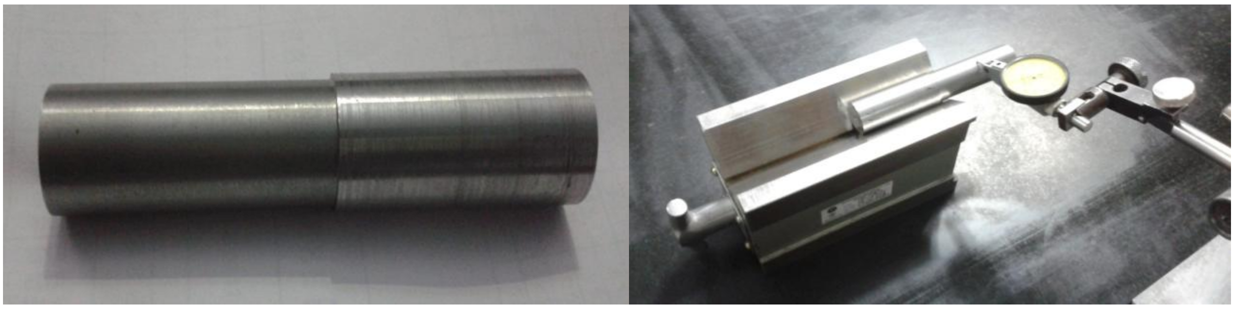

Figure 4: Final Workpiece ready to measure Concentricity

Measurement of Concentricity was carried out at Microflat Datums Pvt. Ltd. using high precision concentricity measuring set up. Here it is visible that datum is rotational axis created by the V– block and the larger diameter. Concentricity of smaller diameter is measured with respect to datum. Figure 4 shows the same. Concentricity value was measured at 5 different cross section in the length of small diameter step and average of the same was taken as concentricity value for that component for the choosen combination of process parameters.

Table 7: Experimental Results

Sr. No.	Factors			Treatment Combination	Response
	Speed RPM	Feed mm/rev	Depth of Cut mm		Concentricity (mm)
1	2000	0.10	0.1	(1)	0.0162
2	3000	0.10	0.1	A	0.0226
3	2000	0.20	0.1	B	0.0239
4	3000	0.20	0.1	Ab	0.0333
5	2000	0.10	0.5	c	0.0178
6	3000	0.10	0.5	Ac	0.0353
7	2000	0.20	0.5	Bc	0.0319
8	3000	0.20	0.5	Abc	0.0421
9	2500	0.15	0.3	-	0.0298
10	2500	0.15	0.3	-	0.0319
11	2500	0.15	0.3	-	0.0293
12	2500	0.15	0.3	-	0.0325

Table 8: Analysis of Variance

Source of Variation	Sum of Square	Degree of Freedom	Mean Square	F	p-value	Coefficient
A	0.00023653	1	0.000236531	30.39	0.0005	0.005437
B	0.00019306	1	0.000193061	24.81	0.0080	0.004912
C	0.00012090	1	0.000120901	15.54	0.0017	0.003888
AB	0.00000231	1	0.000002311	0.30	0.615	-0.000537
AC	0.00001770	1	0.000017701	2.27	0.206	0.001488
BC	0.00000078	1	0.000000781	0.10	0.767	0.000312
ABC	0.00001326	1	0.000013261	1.70	0.262	-0.001287
Curva-ture	0.00002380	1	0.000023800	9.74	0.052	-
Pure Error	0.00000733	3	0.000002443	-	-	-
Resid-ual Error	0.00003113	4	0.000007783	-	-	-
Total	0.00061568	11	-	-	-	-

The 2^3 design with four center points and one replicate with measured response is given in Table 7. The analysis of variance for the same is shown in Table 8. The percentage contribution of each process parameters can be found out.

Percentage Contribution:

Percentage contributions of factors are given below:

- Speed (A) = (0.000236531/0.000615679) × 100 =34.41%
  Feed (B) = (0.00019361/0.000615649) × 100 =31.35%
  Depth of Cut (C) = (0.000120901/0.000615649) × 100 = 19.63 %

It is clearly understood that, Speed has contribution of 34.41%, Feed is affecting 31.35% and Contribution of Depth of Cut is 19.63%.

Effect plot:

The plots of main effects are shown in figure 5.

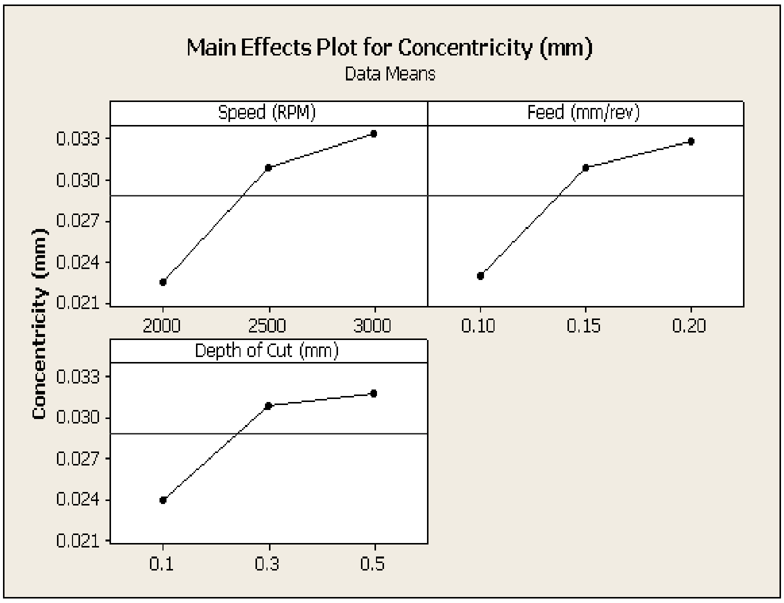

Figure 5: Main Effect plot of Concentricity vs Speed, Feed & Depth of Cut

Regression Model

2^3 Design model for concentricity control

The model for Concentricity control could be written as

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_1 x_2 + \beta_5 x_1 x_3 + \beta_6 x_2 x_3 + \beta_7 x_1 x_2 x_3$$

Where y = Function of Model,

x_1, x_2, x_3= Speed, Feed and Depth of Cut respectively.

$\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6, \beta_7$ = Coefficient

x_1x_2, x_1x_3, x_2x_3 = Interaction between Speed and Feed, Speed and Depth of cut, feed,

$x_1x_2x_3$ = Interaction between Speed, Feed and Depth of Cut

The estimation of β's given below:

$$\beta_0 = \frac{\sum_{i=1}^{a}\sum_{j=1}^{b}\sum_{k=1}^{c} y_{ijk}}{abcn} = \frac{+0.0162+0.0226+0.0239+0.0333+0.0178+0.0353+0.0319+0.0421}{2x2x2x1} = 0.0278875$$

Concentricity model is given by equation,

$y = 0.027887 + 0.005437 x_1 + 0.004912 x_2 + 0.003888 x_3 - 0.000537\, x_1 x_2 + 0.001488\, x_1 x_3 + 0.000312\, x_2 x_3 - 0.001287\, x_1 x_2 x_3$

Surface Plots for Concentricity Control:

Surface plot for concentricity are shown in figure:

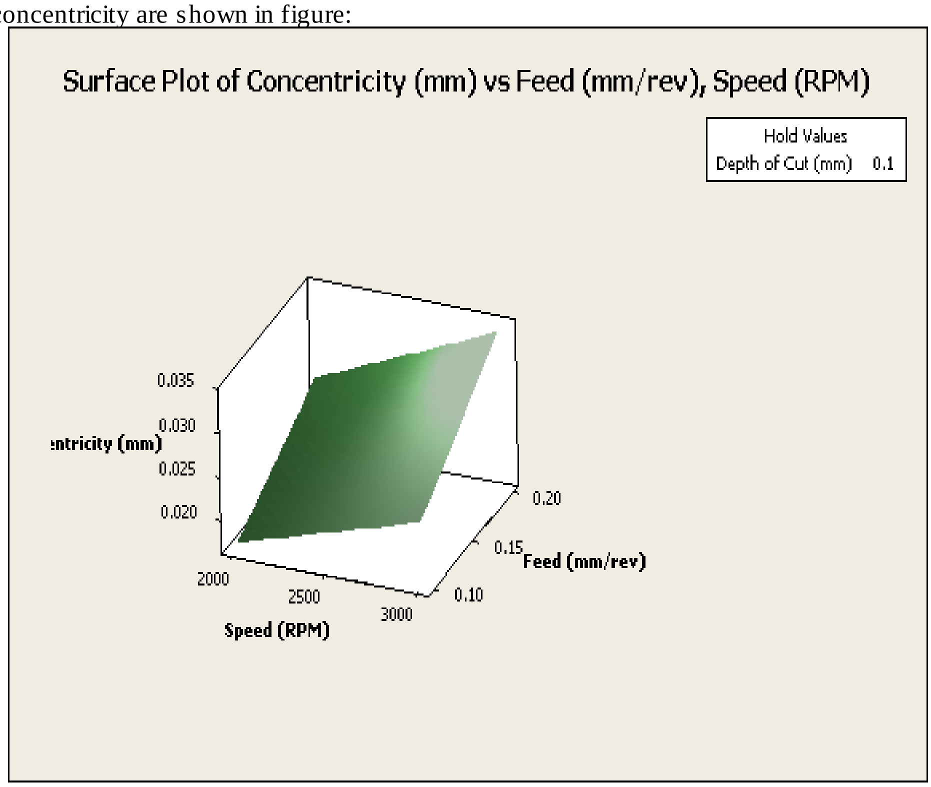

Figure 6: Surface plot for concentricity vs speed & feed

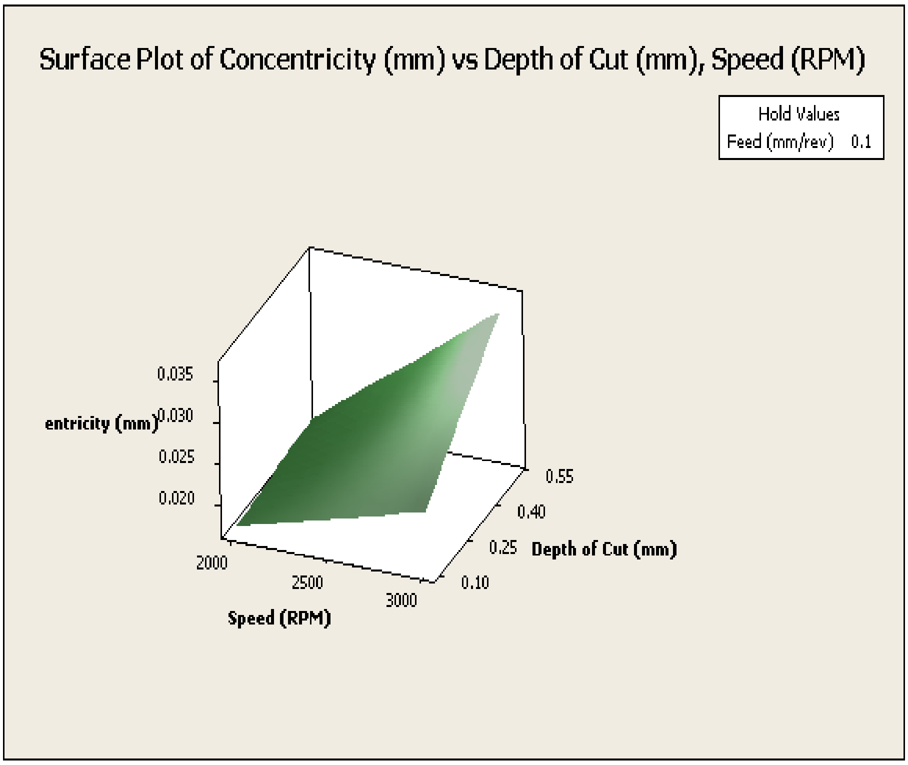

Figure 7: Surface plot for concentricity vs speed & depth of cut

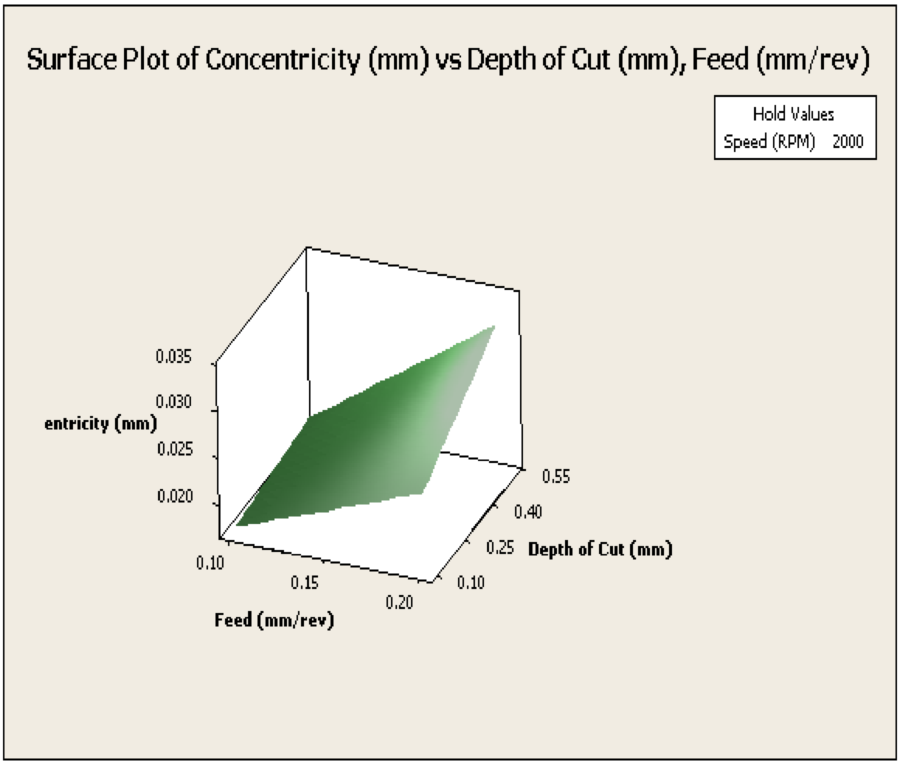

Figure 8: Surface plot for concentricity vs feed & depth of cut

VI. CONCLUSION

This work is meant to evaluate the effects of different machining parameters in turning operation where in concentricity is the major concern. From figure 5 (Main effect plot of concentricity vs. speed, feed & depth of cut 2^3 design) it is understood that for the concentricity, error increase with increase in the speed, feed as well as depth of cut. From this three process variable percentage contribution of the speed is more to the concentricity error and it followed by feed and depth of cut. From Table 8 (Analysis of Variance) also we can conclude that the p-value for speed, feed and depth of cut is less than the confidence level (i.e. 95%). And from p-value concept also we can say that the more significant parameter affecting the concentricity is speed having p-value of 0.0005.

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