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Application of 2k Factorial on Some Cutting Parameters on the Dimensional Accuracy of Turned Mild Steel Rod

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Abstract: *Machining operation is affected by some factors, either positively or negatively such as coolant, tool geometry, type of tool, tool angle, depth of cut, cutting speed, size chip, cutting rate, type workpiece, etc. This experiment was designed to turn five pieces of mild steels rod of 22mm in diameter to a diameter of 20mm as the targeted final diameter of each work piece. The parameters used for the experiment were coolant, depth of cut, feed rate, and cutting speed, the outcome to be tested were dimensional accuracy. Two values were assigned to each of the parameters except coolant which was maintained at 15cl throughout the experiment and cutting speed has four values. A* 2^k *factorial design with 5 parameters was adopted, of which some of the factors affected the dimensional accuracy seriously. Comparing the tabulated value of* f_o *with the calculated values it was find out that* $f_{0.01, 1, 32} = 7.50$*. So it mean that the* H_o *hypothesis is rejected in the case of B, C, D, E, AC, BE, CE, DE, ABC, ABE, ADE, BCD, BCE, ACDE, and such they have no significant effect on the result since the tabulated value is less than the calculated value. In the case of others the null hypothesis is accepted and so their effect is significant on the result.*

Key words: *dimensional, parameter, factorial, accuracy, mild steel, machining*

I. Introduction

Machining is a vital activity that is carried out for any mechanical manufacturing process. It involves changing the shape of a metallic, wooden, ceramics, plastic, etc, components to a desired shape; reduction of the dimensional sizes of a component, etc. This paper is designed to carry out machining on a steel rod using lathe machine. It intends to find out the effects of some selected factors on the surface finishing of the machined component. Those parameters that were considered are: cutting speed, cutting feed rate, depth of cut, tool angle, and coolant use. Various values were chose for each of the parameters above and the tool life was considered for every cut with the chosen values (Fang and Fang, 2007).

Factors Affecting Surface finishing and Tool Life

The life of tool is affected by many factors such as: cutting speed, depth of cut, chip thickness, tool geometry, material or the cutting fluid and rigidity of machine. Physical and chemical properties of work material influence tool life by affecting form stability and rate of wear of tools. The nose radius tends to affect tool life.

Cutting speed

Cutting speed has the greatest influence on tool life. As the cutting speed increases the temperature also rises. The heat is more concentrated on the tool than on the work and the hardness of the tool matrix changes so the relative increase in the hardness of the work accelerates the abrasive action. The criterion of the wear is dependent on the cutting speed because the predominant wear may be wear for flank or crater if cutting speed is increased.

Feed and depth of cut

The tool life is influenced by the feed rate also. With a fine feed the area of chip passing over the tool face is greater than that of coarse feed for a given volume of swarf removal, but to offset this chip will be greater hence the resultant pressure will nullify the advantage.

Tool Geometry

The tool life is also affected by tool geometry. A tool with large rake angle becomes weak as a large rake reduces the tool cross-section and the amount of metal to absorb the heat.

Tool material

Physical and chemical properties of work material influence tool life by affecting form stability and rate of wear of tool.

Cutting fluid

It reduces the coefficient of friction at the chip tool interface and increases tool life (Fang and Fang, 2007).

Cutting Procedures

The lines drawn are showing some basic concepts of speeds and feeds in the context of lathe work. The angular velocity of the workpiece (rev/min) is called the "spindle speed" by machinists. Its tangential linear equivalent at the tool-cutter interface (m/min or sfm) is called the "cutting speed", "surface speed", or simply the "speed" by machinists. The "feeds" may be for the X-axis or the Z-axis (typically mm/rev or inch/rev for lathe work; sometimes measured as mm/min or inch/min). Notice that as the tool plunges closer to the work piece's center, the same spindle speed will yield a decreasing surface (cutting) speed (because each rev represents a smaller circumferential distance, but takes the same amount of time). Most CNC lathes have CSS to counteract that natural decrease, which speeds up the spindle as the tool plunges in (Tae-Hong, 2007).

According to Altin et al (2007), Cutting speed may be defined as the rate (or speed) that the material moves past the cutting edge of the tool, irrespective of the machining operation used — the surface speed. A cutting speed for mild steel, of 100 ft/min (or approx 30 meters/min) is the same whether it is the speed of the (stationary) cutter passing over the (moving) workpiece, such as in a turning operation, or the speed of the (rotating) cutter moving past a (stationary) workpiece, such as in a milling operation. What will affect the value of this surface speed for mild steel are the cutting conditions.

For a given material there will be an optimum cutting speed for a certain set of machining conditions, and from this speed the spindle speed (RPM) can be calculated. Factors affecting the calculation of cutting speed are (Karpat and Ozel, 2008):

- The material being machined (steel, brass, tool steel, plastic, wood) (see table below)
- The material the cutter is made from (Carbon steel, high speed steel (HSS), carbide, ceramics)
- The economical life of the cutter (the cost to regrind or purchase new, compared to the quantity of parts produced).

Cutting speeds are calculated on the assumption that optimum cutting conditions exist, these include (Altin et al, 2007):

- Metal removal rate (finishing cuts that remove a small amount of material may be run at increased speeds)
- Full and constant flow of cutting fluid (adequate cooling and chip flushing)
- Rigidity of the machine and tooling setup (reduction in vibration or chatter)
- Continuity of cut (as compared to an interrupted cut, such as machining square section material in a lathe)
- Condition of material (mill scale, hard spots due to white cast iron forming in castings).

The cutting speed is given as a set of constants that are available from the material manufacturer or supplier, the most common materials are available in reference books, or charts but will always be subject to adjustment depending on the cutting conditions. The following table gives the cutting speeds for a selection of common materials under one set of conditions. The conditions are a tool life of 1 hour, dry cutting (no coolant) and at medium feeds so they may appear to be incorrect depending on circumstances. These cutting speeds may change if, for instance, adequate coolant is available or an improved grade of HSS is used (such as one that includes cobalt) (Altin et al, 2007).

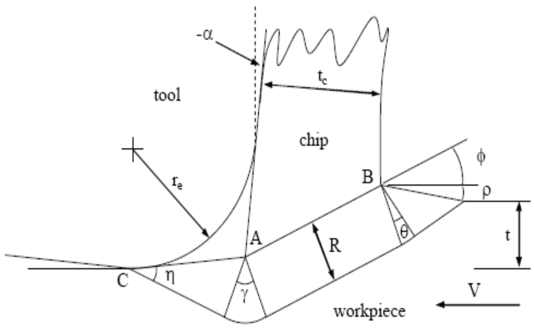

Fig 1: Schematic sketch for turning indicating various angles
Source: (Dogra et al, 2011)

The model developed by Waldorf is used to predict the plowing forces due to tool edge roundness. Waldorf used a slip-line model developed for predicting plowing forces in orthogonal cutting (Joel, 2005;

Hughes, 2006). The model incorporated a small, stable built-up edge of material adhered to the cutting tool. A brief description of the model is provided below (Poulacho et al, 2001). In Figure 1 is the edge radius α is the rake angle, f is the shear angle, and t is the uncut chip thickness. The fan field angles q, g and h are found from geometric and friction relationships. Details for computing the values are available in the equations below. R is the radius of the circular fan field centered at A. If the flow stress k of the material is known along with the shear angle f, the plowing forces can determined from Equation (1). Pcut is the plowing force in the cutting direction, Pthrust is the plowing force normal to the newly generated surface, and w is the width of cut (Thiele et al, 2000; Poulacho et al, 2001).

P_{cut} =[cos(2η) cos(φ-γ+η) + (1+2θ + 2γ + sin(2η) sin(φ-γ+η)] CA Eqn1

P_{thrust} = [(1+2θ + 2γ + sin(2η) cos(φ-γ+η) – cos(2η) sin(φ-γ+η)] CA Eqn 2

Source: Dogra et al (2011)

Spindle speed calculations

Most metalworking books have nomograms or tables of spindle speeds and feed rates for different cutters and workpiece materials; similar tables are also likely available from the manufacturer of the cutter used (Altin et al, 2007).

The spindle speeds may be calculated for all machining operations once the SFM or MPM is known. In most cases we are dealing with a cylindrical object such as a milling cutter or a workpiece turning in a lathe so we need to determine the speed at the periphery of this round object. This speed at the periphery (of a point on the circumference, moving past a stationary point) will depend on the rotational speed (RPM) and diameter of the object (Dogra et al, 2011).

One analogy would be a skateboard rider and a bicycle rider travelling side by side along the road. For a given surface speed (the speed of this pair along the road) the rotational speed (RPM) of their wheels (large for the skater and small for the bicycle rider) will be different. This rotational speed (RPM) is what we are calculating, given a fixed surface speed (speed along the road) and known values for their wheel sizes (cutter or workpiece) (Altin et al, 2007).

Feed rate

Feed rate is the velocity at which the cutter is fed, that is, advanced against the workpiece. It is expressed in units of distance per revolution for turning and boring (typically inches per revolution [ipr] or millimeters per revolution). It can be expressed thus for milling also, but it is often expressed in units of distance per time for milling (typically inches per minute [ipm] or millimeters per minute), with considerations of how many teeth (or flutes) the cutter has then determining what that means for each tooth (Groover, 2007).

Feed rate is dependent on the (Altin et al, 2007)**:**

- Type of tool (a small drill or a large drill, high speed or carbide, a boxtool or recess, a thin form tool or wide form tool, a slide knurl or a turret straddle knurl).
- Surface finish desired.
- Power available at the spindle (to prevent stalling of the cutter or workpiece).
- Rigidity of the machine and tooling setup (ability to withstand vibration or chatter).
- Strength of the workpiece (high feed rates will collapse thin wall tubing)
- Characteristics of the material being cut, chip flow depends on material type and feed rate. The ideal chip shape is small and breaks free early, carrying heat away from the tool and work.
- Threads per inch (TPI) for taps, die heads and threading tools.

When deciding what feed rate to use for a certain cutting operation, the calculation is fairly straightforward for single-point cutting tools, because all of the cutting work is done at one point (done by "one tooth", as it were). With a milling machine or jointer, where multi-tipped/multi-fluted cutting tools are involved, then the desirable feed rate becomes dependent on the number of teeth on the cutter, as well as the desired amount of material per tooth to cut (expressed as chip load). The greater the number of cutting edges, the higher the feed rate permissible: for a cutting edge to work efficiently it must remove sufficient material to cut rather than rub; it also must do its fair share of work.

The ratio of the spindle speed and the feed rate controls how aggressive the cut is, and the nature of the swarf formed (Groover, 2007).

II. Design of experiment

A full 2^5 (2^k with k = 5 variables) factorial experimental design was adopted to study the effects of cutting parameters on the resulting surface dimensional accuracy. The cutting parameters used in the turning

trials for mild steel are shown in Table 2. A HSS cutting tool was used in the machining trials. In particular, a 22mm diameter by 200mm length mild steel rod was used for the trial, to be turned to 20mm diameter and between 6° and 25° rake angles were used utilized for
the trial. The cutting parameters are shown in the table2 below.

1. H_o: $\alpha_1 = \alpha_2 = \ldots = \alpha_{32} = 0$ (no main effect of factor A)
H_1: at least one $\alpha_i \neq 0$
2. H_o : $\beta_1 = \beta_2 = \ldots = \beta_{32} = 0$ (no main effect of factor B)
H_1: at least one $\beta_i \neq 0$
3. H_o : $\gamma_1 = \gamma_2 = \ldots = \gamma_{32} = 0$ (no main effect of factor C)
H_1: at least one $\gamma_i \neq 0$
4. H_o : $\delta_1 = \delta_2 = \ldots = \delta_{32} = 0$ (no main effect of factor D)
H_1 : at least on $\delta_i \neq 0$
5. H_o : $\eta_1 = \eta_2 = .. = \eta_{32} = 0$ (no main effect of factor E)
H_1 at least one $\eta_i \neq 0$; and so on.

III. Results, Calculation and Discussion

Table 2 on the appendices displays the result of the machining carried out on the five pieces of mild steel rods using varied factors. The dimensional accuracy for each measured value is obtained from the relations: $1/(d_1 - d_2)$, where d_1 is the targeted turned diameter and d_2 is the measured diameter.

From the table 2 above, those data will be used to calculate values for the sum of squares, degree of freedom, mean square and f_0, which are displayed on the table below, for the analysis of variance. The graph representing the above data is shown on figure 2 below, showing the variations of the dimensional accuracies with treatment combinations

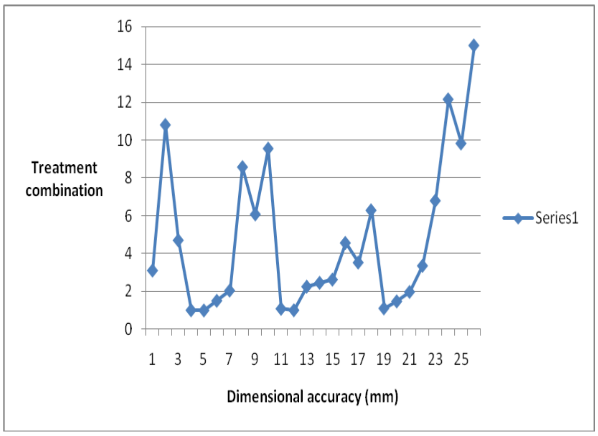

Fig 2: Dimensional accuracy of the various specimen in various treatment combination

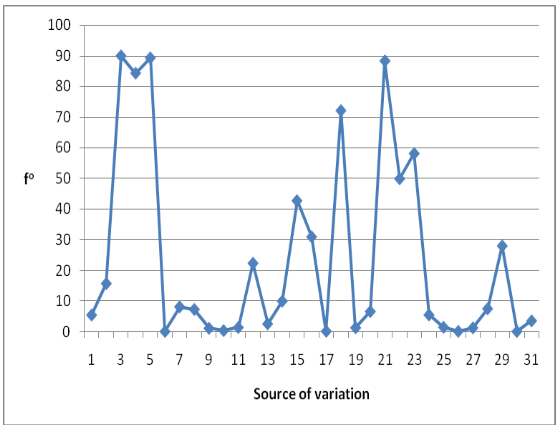

Fig 3: f_o of the reaction of the various factors in relation to the error.

From the graph on fig3, it is shown that the dimensional accuracy varies irregularly with the treatment combinations, with treatment combination abcde having the highest accuracy value (15.00). Treatment combinations (I) and bc have the least accuracy values of 0.99 each bringing the value of the range of the accuracy values to 14.01.

IV. Discussions

Comparing the tabulated value of f_o with the calculated values we find out that $f_{0.01,\ 1,\ 32}$ = 7.50. So it mean that the H_o hypothesis is rejected in the case of B, C, D, E, AC, BE, CE, DE, ABC, ABE, ADE, BCD, BCE, ACDE, and such they have no significant effect on the result since the tabulated value is less than the calculated value. In the case of others the null hypothesis is accepted and so their effect is significant on the result. The graph above gives more information about the values of f_o for the various sources of error, where C is the highest follow by E and then ADE, the least been is AB follow by BCDE and then ABCD.

V. Conclusions

The 2^K factorial design is an effective design of experimental procedures, both in experimental research, field studies research and survey research. In this 2^k factorial experimental designs it was observed that the factors B, C, D, E, BE, DE, ABC, ABE, BCD, BCE, ADE, ACDE are general very significant.

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Appendices

Below are the tables of the research:

Table 1: The Cutting Parameters used for the experiment

Parameter	Chosen values			
Depth of cut (mm)	7	12		
Speed of cut (m/min)	30	32	34	36
Feed rate (mm/sec)	9	15		
Tool angle (degree)	15	20		
Coolant use (cl)	15			

Table 2: Experimental readings of the effects of the factors on dimensional accuracy, with reference target of 20mm diameter

		(A) Coolant (cl)			
		15cl			
		(B) Depth of cut (mm)			
		7		12	
(D)Feed rate (mm/sec)	(E)Cutting speed (RPM)	(C)Cutting angle			
		15°	20°	15°	20°
		Measured diameters (mm)			
9	30	19.03 18.95	19.14 19.00	18.82 18.90	19.05 19.13
9	32	19.25 19.55	18.95 19.05	18.96 19.04	19.28 19.35
15	30	19.60 19.58	19.56 19.53	19.04 18.92	19.46 19.52
15	32	19.60 19.62	19.56 19.62	19.25 19.40	19.68 19.72

9	34	19.72 19.77	19.80 19.69	19.52 19.50	19.83 19.87
9	36	19.80 19.76	19.77 19.79	19.90 19.86	19.93 19.90
15	34	19.65 19.70	19.73 19.70	19.80 19.86	19.88 19.92
15	36	19.89 19.92	19.85 19.83	19.90 19.89	19.90 19.95

Table 3: Algebraic signs for calculating effects in the 2^5 Factorial Designs

Treatment Combination	Design factors						Measured Diameters (mm)		Dimensional accuracy		Dimensionl accuracy	DimensionlAccuracy
	I	A	B	C	D	E	Run1	Run2	Run1	Run2	Total	Average
(1)	+	-	-	-	-	-	19.03	18.95	1.03	0.95	1.98	0.99
A	+	+	-	-	-	-	19.25	19.55	1.33	2.22	3.55	1.78
B	+	-	+	-	-	-	19.60	19.58	2.50	2.38	4.88	2.44
C	+	-	-	+	-	-	19.60	19.62	2.50	2.63	5.13	2.57
D	+	-	-	-	+	-	19.72	19.77	3.57	4.35	7.92	3.96
E	+	-	-	-	-	+	19.80	19.76	5.00	4.17	9.17	4.59
Ab	+	+	+	-	-	-	19.65	19.70	2.86	3.33	6.19	3.10
Ac	+	+	-	+	-	-	19.89	19.92	9.09	12.50	21.59	10.80
Ad	+	+	-	-	+	-	18.82	18.90	8.48	0.91	9.39	4.70
Ae	+	+	-	-	-	+	18.96	19.04	0.96	1.04	2.00	1.00
Bc	+	-	+	+	-	-	19.04	18.92	1.04	0.93	1.97	0.99
Bd	+	-	+	-	+	-	19.25	19.40	1.33	1.67	3.00	1.50
Be	+	-	+	-	+	-	19.52	19.50	2.08	2.00	4.08	2.04
Cd	+	-	-	+	+	-	19.90	19.86	10.00	7.14	17.14	8.57
Ce	+	-	-	+	-	+	19.80	19.86	5.00	7.14	12.14	6.07
De	+	-	-	-	+	+	19.90	19.89	10.00	9.09	19.09	9.55
Abc	+	+	+	+	-	-	19.14	19.00	1.16	1.00	2.16	1.08
Abd	+	+	+	-	+	-	18.95	19.05	0.95	1.05	2.00	1.00
Abe	+	+	+	-	-	+	19.56	19.53	2.27	2.13	4.50	2.25
Bcd	+	-	+	+	+	-	19.56	19.62	2.27	2.63	4.90	2.45
Bce	+	-	+	+	-	+	19.50	19.69	2.00	3.23	5.23	2.62
Cde	+	-	-	+	+	+	19.77	19.79	4.35	4.76	9.11	4.56
Bde	+	-	+	-	+	+	19.73	19.70	3.70	3.33	7.03	3.52
Ade	+	+	-	-	+	+	19,85	19.83	6.67	5.88	12.55	6.28
Ace	+	+	-	+	-	+	19.05	19.13	1.05	1.15	2.20	1.10
Acd	+	+	-	+	+	-	19.28	19.35	1.39	1.54	2.93	1.47
Abcd	+	+	+	+	+	-	19.46	19.52	1.85	2.08	3.93	1.97
Bcde	+	-	+	+	+	+	19.68	19.72	3.13	3.57	6.70	3.35
Abde	+	+	+	-	+	+	19.83	19.87	5.88	7.69	13.57	6.79
Abce	+	+	+	+	-	+	19.93	19.90	14.29	10.00	24.29	12.15
Acde	+	+	-	+	+	+	19.86	19.92	7.14	12.50	19.64	9.82
Abcde	+	+	+	+	+	+	19.90	19.95	10.00	20.00	30.00	15.00

Table 4: Analysis of Variance for the dimensional accuracy

Source of variation	Sum of square	Degree of freedom	Mean square	f_o
A	5.22	1	5.22	5.38
B	15.17	1	15.17	15.64
C	87.20	1	87.20	89.90
D	81.72	1	81.72	84.25
E	86.58	1	86.58	89.26
AB	0.01	1	0.01	0.01
AC	7.76	1	7.76	8.00
AD	6.99	1	6.99	7.21
AE	1.02	1	1.02	1.05

BC	**0.31**	**1**	**0.31**	**0.32**
BD	**1.34**	**1**	**1.34**	**1.38**
BE	**21.61**	**1**	**21.61**	**22.28**
CD	**2.43**	**1**	**2.43**	**2.51**
CE	**9.63**	**1**	**9.63**	**9.93**
DE	**41.39**	**1**	**41.39**	**42.67**
ABC	**29.96**	**1**	**29.96**	**30.89**
ABD	**0.08**	**1**	**0.08**	**0.08**
ABE	**69.91**	**1**	**69.91**	**72.07**
ACD	**1.20**	**1**	**1.20**	**1.24**
ACE	**6.33**	**1**	**6.33**	**6.53**
ADE	**85.61**	**1**	**85.61**	**88.26**
BCD	**48.32**	**1**	**48.32**	**49.81**
BCE	**56.31**	**1**	**56.31**	**58.05**
BDE	**5.26**	**1**	**5.26**	**5.42**
CDE	**1.35**	**1**	**1.35**	**1.39**
ABCD	**0.05**	**1**	**0.05**	**0.05**
ABCE	**1.16**	**1**	**1.16**	**1.20**
ABDE	**7.22**	**1**	**7.22**	**7.44**
ACDE	**27.08**	**1**	**27.08**	**27.92**
BCDE	**0.02**	**1**	**0.02**	**0.02**
ABCDE	**3.37**	**1**	**3.37**	**3.47**
Error	**31.05**	**32**	**0.97**	
Total	**741.32**	**63**		