EFFECT OF FEED, SPEED, AND DEPTH OF CUT ON THE DIMENSIONAL ACCURACY OBTAINED FOR A WORKPIECE TURNED ON A LATHE

by

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INTRODUCTION

A basic manufacturing system may be considered to be composed of two major components, the machine tool, and the cutting or manufacturing process.

The purpose of the machine tool is to provide the kinematic means, the mechanical positioning, and the necessary energy to produce the specified accuracy of shape, dimensional accuracy, and surface finish of the components within permissible limits, as far as possible, independently of the skill of the operator.

The cutting process depends on the operational speeds and rates of metal removal provided by the machine. It must satisfy the latest developments in tools and materials to ensure the possibility of high productivity with high quality.

The distortions from the desired cylindrical shape on a lathe may be classified into macrogeometrical and microgeometrical surface deviations (1)*. The macrogeometrical deviations indicate the irregularities on the machined surface, while the microgeometrical deviations indicate the surface roughness.

The macrogeometrical deviations have three forms or orders. First is the shape deviations, first order, Fig. 1. The reason for deviation from roundness is a result of geometrical errors of the machine and the elastic deformation due to the applied cutting forces. Second is the surface waviness, second order, Fig. 2, which results from relative motions between the tool and the workpiece, and is normal to the formed surface. The third order or tool track, Fig. 3, is strongly dependent on the geometrical form

*( ) refers to reference in Bibliography.

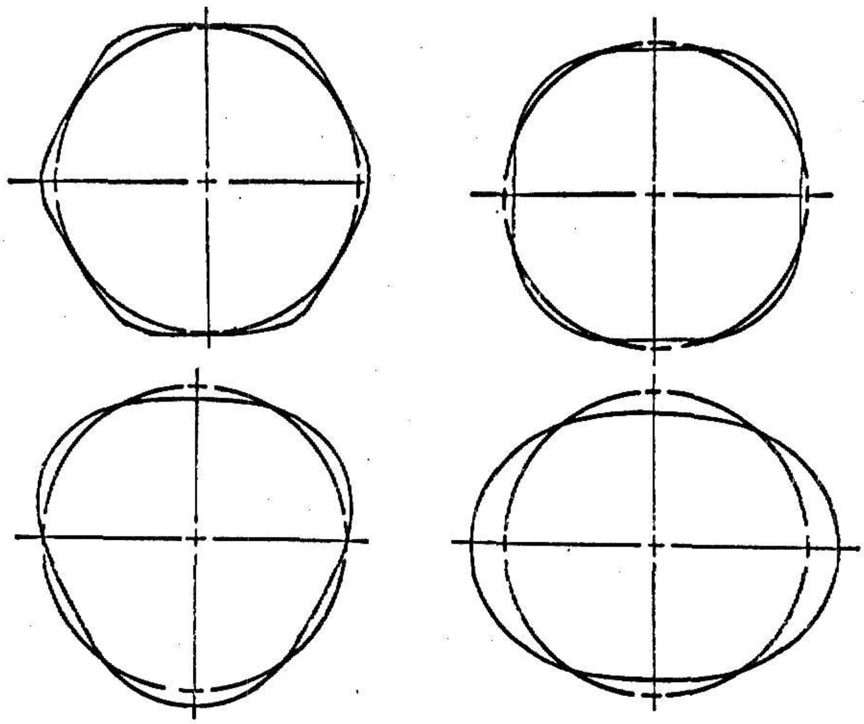

Fig. 1. First-Order Macrogeometrical Error Forms of Turned Surfaces.

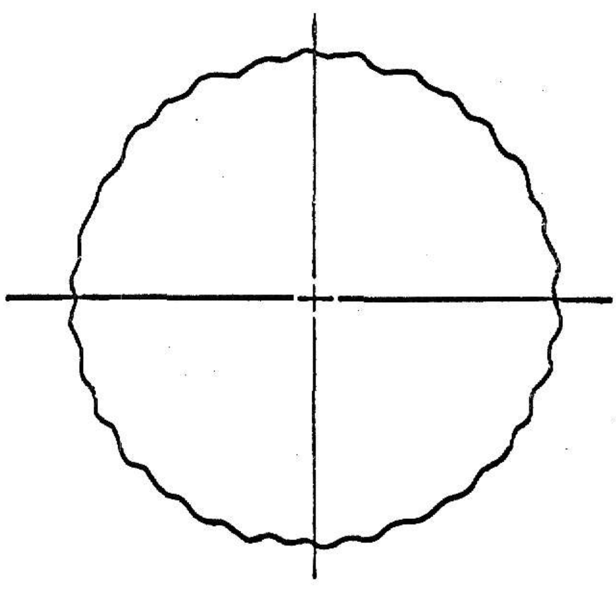

Fig. 2. Second-Order Macrogeometrical Error Forms.

of the cutting tool. The first and second orders of error reflect the static and dynamic behavior of the machine tool.

The microgeometrical deviations have a random frequency content which is superimposed on the various macrogeometrical errors. They are mainly due to the physics of the cutting process, Fig. 4.

The factors affecting the dimensional accuracy and the machining quality as collected by Koenigsberger (2) are:

> Tool and carrier, mainly the tool shape, material, rake angles, and quality of cutting faces, quality of tool clamping, and tool overhang.
>
> The workpiece and its clamping, mainly the machinability** of the material, stiffness of workpiece, clamping fixtures, and accuracy of the centers.
>
> The selecting of cutting conditions, cutting speed, feed rate, and depth of cut.
>
> The changes of working conditions and the relative position between the cutting tool and the workpiece, have a great effect on the produced accuracy. They may occur due to tool wear and crater formation, inaccuracies in the thermal deformations, vibrations, changes in oil film thickness in bearings and slide ways of the machine,..., and operational forces or by temperature changes of the various parts under machining.

Considering the previous factors, it could be mentioned that the tool material, shape, and type were selected at first to suit as near as possible the material to be cut, the working conditions, and the required surface finish; hence, the tool cannot be considerably changed during machining. The methods of clamping for both tool and workpiece can be controlled to obtain the best requirements. The changes of working conditions are difficult

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**Machinability is the ability of a workpiece to yield to the cutting forces of a tool applied to it under efficient conditions. Under these conditions a maximum removal of material and satisfactory finish on the work are possible in a minimum amount of time during the life of a tool, before renewal of the cutting edge is necessary.

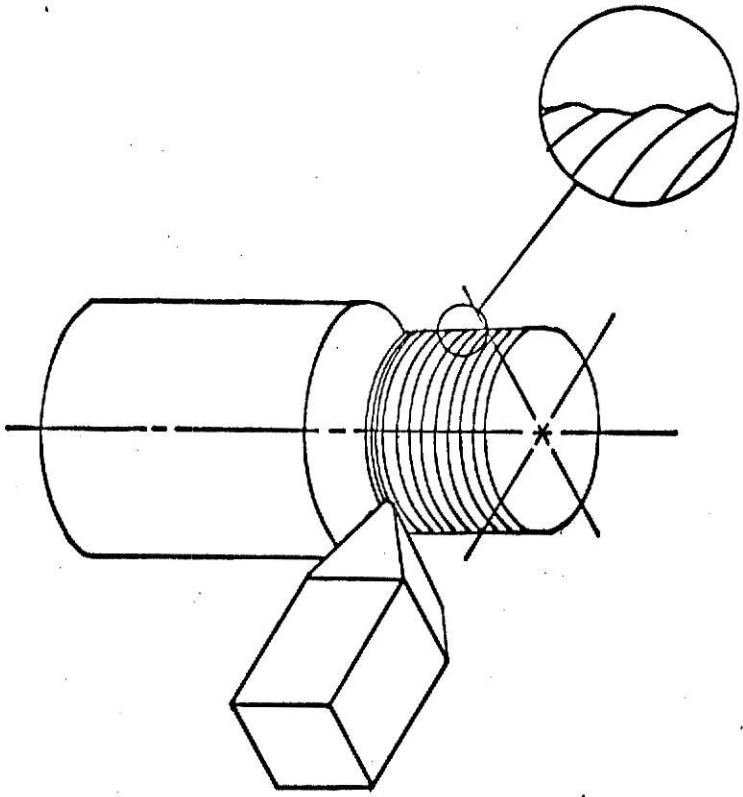


Fig. 3. Third-Order Macrogeometrical Error Forms.

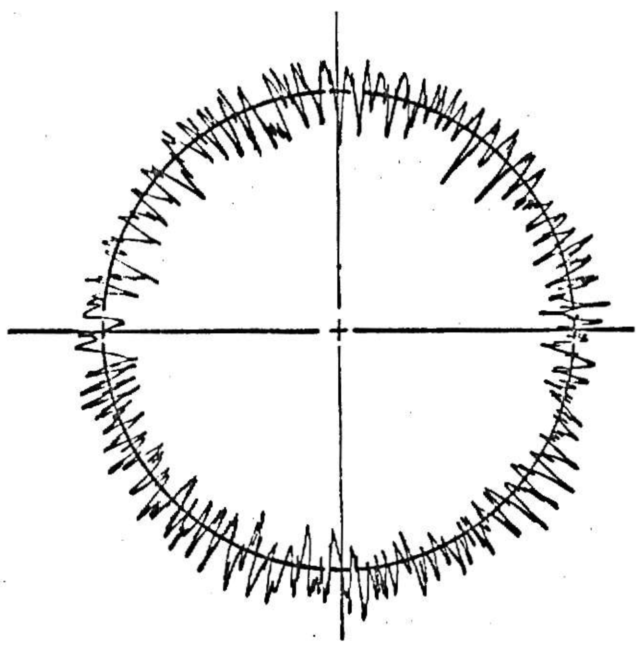


Fig. 4. Microgeometrical Error Forms.

to control or investigate. But the selection of cutting conditions, speed, feed, and depth of cut (d.o.c.), are the items which can be easily changed during operations, and also can be controlled to obtain suitable accuracies and dimensions for the workpiece.

The purpose of this study is to determine the effect of speed, feed, and depth of cut on the dimensional accuracy of a workpiece turned on a lathe. From the obtained results and curves, the optimum values of dimensional accuracy with respect to speed, feed, and depth of cut can be determined. Three different steels were used for the experiments.

REVIEW OF LITERATURE

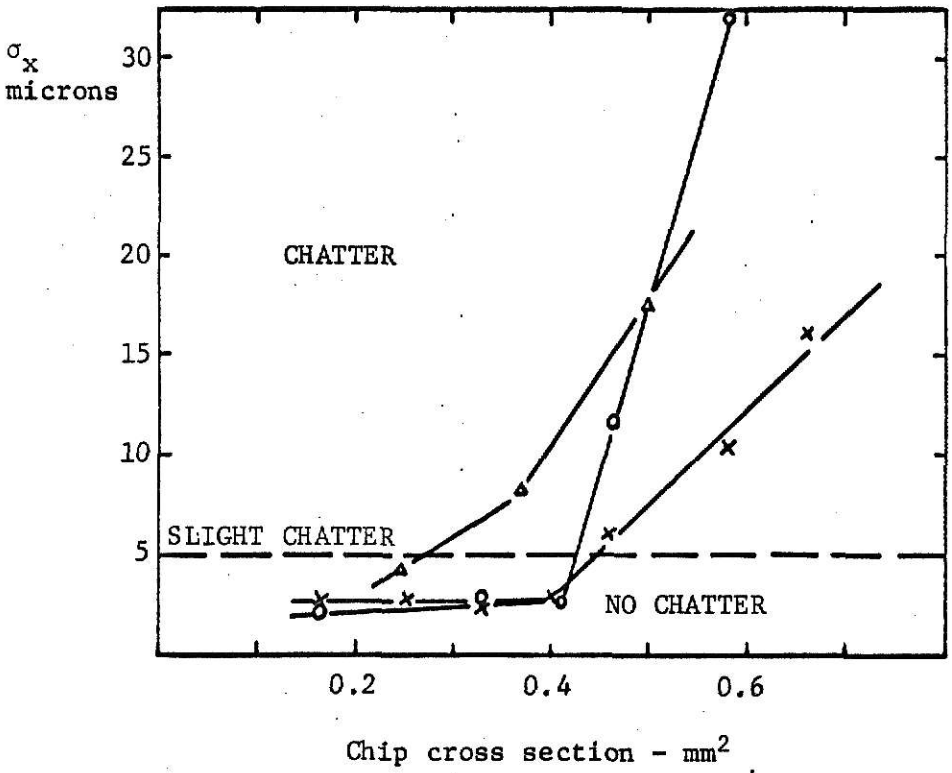
Most of the work in the field of manufacturing research has dealt with the surface finish of the produced surface, tool wear, chip formation, cutting forces, and, to some extent, material deformation and vibration during dynamic cutting.

Some work has been done on the accuracy of dimensions of produced workpieces. J. Peklenik and J. R. Gartner (1) treated the surface accuracies of turned parts produced on a lathe. They got a relation between the chip cross-section area and the standard deviation. Standard deviation is a measure of the magnitude of the overall surface profile variation from its ideal form.

As a result, it was found that for practical recommendations of stable cutting operation, and reasonable surface outputs, the cutting conditions should be selected such that the standard deviation, σ_x, be less than 5 μ [micron, 10^{-3} millimeters], which corresponds to 0.28 square millimeter [mm^2] chip cross section at a speed of 85 meters per minute [m/min], and 0.42 mm^2 chip cross section at speeds over 110 m/min, as indicated in Fig. 5 by the dash line. These results were for mild steel workpieces and carbide tools for fine and semifine turning.

P. W. Harrison (3) found a relation between the accuracy of industrial measurements and size of the workpieces between 0.5 mm and 125 mm [0.02 to 5.0 inches]. His analysis was done for various manufacturing factories. The results show that:

> External measurements are considerably more accurate than internal ones, but both become progressively less accurate with an increase in diameter.
>
> The algebraic mean of industrial errors is similar in shape for external and internal diameters.



△ Vel. 85 m/min

○ Vel. 110 m/min

× Vel. 180 m/min

Fig. 5. Relation of Standard Deviation to Chip Cross Section Area.

The best ranges for both dimensional errors and accuracy are between 2.5 to 7.5 mm [0.1 to 0.3 in.], and 12.5 to 40 mm [0.5 to 1.6 in.].

An analysis of the deformations of a lathe measured under static load with the tool half way between the two centers was represented by Koenigsberger (2) as in Plate I.

An equation of deflection was developed by A. P. Sokolovsky (4) for the machine components and workpiece. This equation is:

Deflection of system = Deflection of (carriage + head stock + tail stock + workpiece)

$$Y_{system} = P_y \; W_c + W_{hs} (\frac{L-x}{L})^2 + W_{ts} (\frac{x}{L})^2 + \frac{0.31 (x-L)^2 \; x^2}{d^4 \; L}$$

where

P_y = the radial force acting on the workpiece (kg)

W_c = compliance of carriage = $\frac{1}{\text{regidity}} = \frac{Y}{P}$ (μ/kg)

W_{hs} = compliance of head stock (μ/kg)

W_{ts} = compliance of tail stock (μ/kg)

d = diameter of workpiece

L = length of workpiece

x = distance from cutting tool to the head stock end (when turning on a lathe between two centers).

In this research, the measurements were taken at a mean distance x = 0.6 L to 0.7 L from the head stock.

This yielded:

at 0.6 L $(\frac{L-x}{L})^2 = 0.16$ $(\frac{x}{L})^2 = 0.36$

at 0.7 L $(\frac{L-x}{L})^2 = 0.09$ $(\frac{x}{L})^2 = 0.49$

For a lathe with height of centers 300 mm

Explanation of Plate I

(a)

a = deflection of center line of spindle.

b = deflection of tail stock sleeve.

d = deflection of center line of workpiece.

c = climbing of the workpiece on the tail stock center.

e = further displacement on workpiece due to c.

h = moving away of the workpiece center from the tool edge.

f = bend of bed shear due to the action of the radial force.

g = total deflection of saddle slide ways due to front shear.

i = deflection of the tool carrier due to backlash in the cross traverse screw and in the slideways.

The tool is removed by a total amount K.

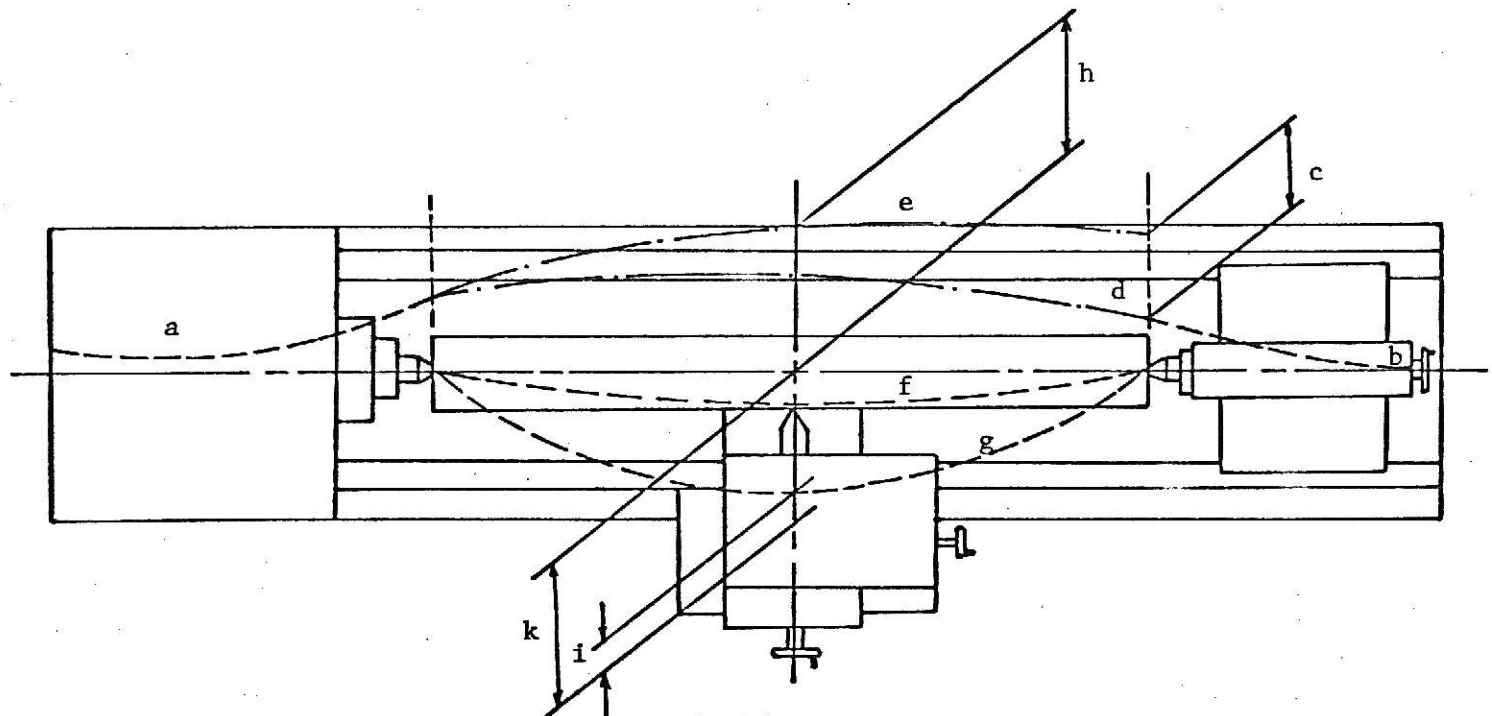
Distance between cutting edge and workpiece = k + h.

Resulting increase in workpiece = d = 2(h + k).

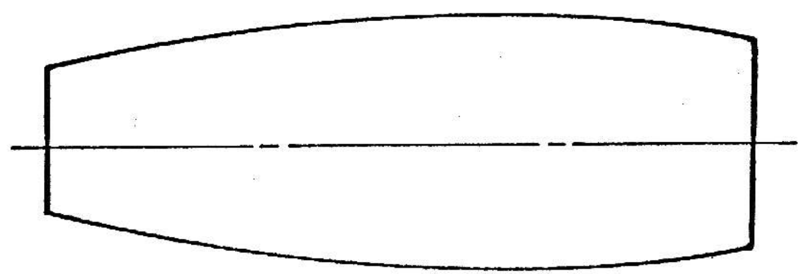
(b)

The resulting shape of the workpiece.

Plate I



(a)



(b)

From tables in (4):

$$W_c = 0.17\ \mu/kg$$

$$W_{ts} = 0.20\ \mu/kg$$

$$W_{hs} = 0.13\ \mu/kg$$

Then for x = 0.6 L

$$Y_{system} = P_y(0.17 + 0.13 \times 0.16 + 0.2 \times 0.36 + 0.01)$$

$$= 0.272\ P_y\ \mu$$

and for x = 0.7 L

$$Y_{system} = 0.29\ P_y\ \mu$$

and the mean value of measurements

$$Y_{system} = 0.28\ P_y\ \mu$$

The cutting forces were found experimentally for different conditions and materials, as in (2).

The cutting force is not constant but pulsating, due to the elasticity of the tool, workpiece, and machine and due to the resulting changes in the depth of cut, effective rake angle, chip formation, and relative velocity between the tool and workpiece.

The magnitude of the cutting force is influenced by the cutting speed, the properties of the workpiece material, the size and shape of the chip section [d.o.c., feed rate], and the shape of the tool edge, mainly the rake angle and to some extent the tool material. For speeds below 95 m/min., the cutting force decreases with increased cutting speed. Above 95 m/min., the force is approximately constant over a wide range. The material gives a parameter called specific cutting resistance, K_s, which is the cutting force per unit chip section [mm^2]. This specific cutting resistance decreases with an increase of chip section. Values of K_s were obtained for values of $\frac{\text{feed}}{\text{d.o.c.}}$ from 2 to 10. The formula of cutting force is:

$$P_1 = (\text{d.o.c.})\ \text{feed}\ K_s$$

$$= a\ F\ K_s$$

TABLE 1

Material \ F mm/rev.	0.07	0.11	0.15	0.23	0.30
St. 40 [SAE 1117]	345	285	255	205	180
St. 70 [SAE 1144]	485	386	340	276	242
SAE 1035	456	366	320	256	221

Values of K_s for experimental materials in k_g/mm^2

A lot of work has been done on surface finish produced for several different conditions, (5), (6), (7), and (8), and can be discussed as follows.

The surface finish in machining operations depends on the type of chip formation, the cutting tool profile, and the process geometry or deflections. The chip formation depends on the cutting conditions and the workpiece material. Discontinuous-chip formation or continuous-chip with built up edge [b.u.e.] can cause cracks to extend into the finished work surface and create force fluctuations which deflect the tool and initiate vibrations. All affect the surface finish. As the b.u.e. projects downwards into the workpiece, and the further the extension of the b.u.e. projects, the worse the surface becomes. The continuous-chip with no b.u.e. is the most desirable condition if it can be achieved. If the continuous-chip form is obtained, the tool profile will be produced on the workpiece surface in the form of feed marks

(5). Hence for an ideal cut, the ideal surface finish equation can be derived from the geometry of the tool and process, but in practice these are true for the first few cuts on the workpiece, where the satisfactory cutting conditions can be achieved, Appendix I, (6).

At very low cutting speeds, tensile rupture and discontinuous-chip formation cause poor surface finish. The finish can be improved by increasing speed up to about 4.6 m/min., where continuous-chip formation is obtained. Further increase of speed results in b.u.e. formation and the surface finish deteriorates. The poorest surface finish is obtained at about 25 to 35 m/min. As the speed is increased, the b.u.e. decreases, and the surface finish improves and approaches the ideal surface finish after a speed of about 185 m/min., (7).

Experiments showed that the surface roughness increases with feed, but with low speeds the surface finish is far from the ideal values.

A larger shear plane would tend to give rise to tensile stress near the tool tip, accompanied by high shear strain. Hence, at an increased chip thickness a crack is formed near the tool tip and causes poor surface finish.

Thus, the conclusions of various cutting parameters can be summarized as in (8).

Increase in cutting speed	Improves greatly the surface finish
Increase in feed	Deteriorates greatly the surface finish
Increase in depth of cut	Deteriorates slightly the surface finish
Increase in nose radius	Improves greatly the surface finish

Increase in true rake angle	Improves greatly the surface finish
Increase in trail angle	Deteriorates greatly the surface finish

The built up edge formation was treated widely in many researches, and can be summarized as follows. When the coefficient of friction between the tool face and chip exceeds a certain minimum value, the stress in the shear plane in the chip becomes equal to the shear strength of the chip material; this will cause failure in the shear plane leaving a rectangular portion adhered to the tool face, in the form of a b.u.e. This b.u.e. formation has a great influence on both vibration and surface finish. For any given condition there will be a critical size to which the b.u.e. will grow before the applied forces are sufficient to cause its removal. The growth rate of the b.u.e. is approximately constant. Thus, there will be a natural frequency for b.u.e. formation which will cause cyclic forcing on the machine system. This mechanism is repeated with a frequency of the order of several cycles a second.

The properties of material play a considerable part in determining the b.u.e. formation. A ductile material is generally more adhesive and shows a greater tendency for form a b.u.e.

Cutting conditions which increase the normal load on the rake face of the tool increase the probability of a b.u.e. Thus, increasing the d.o.c. or reducing the rake angles both tend to increase b.u.e.

Heginbotham (9) worked on two steels of 0.16% and 0.29% carbon content. He found the effect of different cutting speeds and feeds on the formation and size of b.u.e. using carbide tools. He found that the speed has a considerable effect on the form of b.u.e. By changing the speed, various phases of b.u.e. were formed, Fig. 6, which change the effective cutting geometry.

Positive wedge b.u.e. occurs at speed range of 5 to 30 m/min. Rectangular b.u.e. occurs at speeds between 30 and 45 m/min. Negative wedge b.u.e. happens for speed ranges of 45 to 90 m/min. And layer type b.u.e. is found for speeds over 90 m/min. The effective rake angle is large at low speeds, 20 to 25°. It decreases for increasing speed due to the change of b.u.e. phase approaching the true rake angle of the tool.

The size of the b.u.e. is measured as the average length of its base in contact with the tool face. The size of the b.u.e. is directly related to the surface roughness. The size increases with increasing speed, and reaches a maximum value at speed 30 m/min, then decreases for further increase in speed.

The size of b.u.e. increases continuously with increasing feed for speeds up to 45 m/min. For speeds of 60 m/min and over the b.u.e. reaches a maximum at feeds up to 0.15 to 0.20 mm/rev. As the feed decreases, the beginning of stable b.u.e. formation appears to be postponed to higher cutting speeds.

Hoshi (10) deduced an equation for the difference between actual and apparent depths of cut, Fig. 7, due to the changes in actual rake angle, this makes over cut of actual d.o.c. larger than the apparent depth of cut.

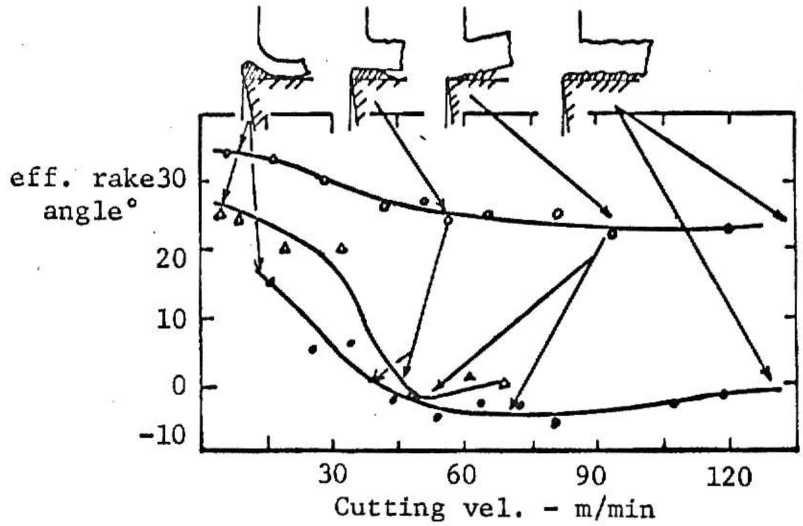
$$t_1' - t_1 = c'\, t_1 \frac{\sin \phi_o'}{\sin B'} [\cos(B' - \phi_o') + \cot \phi_o' \sin(B'-\phi_o') - \operatorname{cosec}\phi_o']$$

where

t' = actual d.o.c.

t_1 = apparent d.o.c.

B' = friction angle



○ Rake angle 25° 0.16% carbon St.

● Rake angle 0° 0.16% carbon St.

△ Rake angle 0° 0.29% carbon St.

Fig. 6. Effect of Various Classes of b.u.e. on Effective Cutting Geometry.

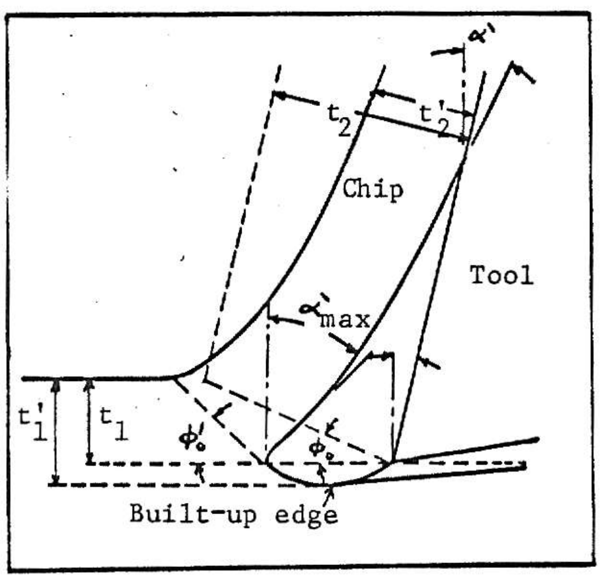


Fig. 7. Cutting Model with Built-up Edge

ϕ'_o = shear angle

c' = constant

These values can be found in the literature.

R. N. Arnold (11) was the first to work in the field of vibration in metal cutting. He obtained basic results for further work on self-induced and forced vibrations in metal cutting.

The self-induced vibration is due to small fluctuations in the forces existing between the tool and the metal. In practice, the forces cannot be exactly constant, and any small fluctuation starts vibrations. The initiation of vibration starts from the second revolution where the acting force of the tool is the result of two actions: Shearing the new material and cutting through a portion of metal undercut of undulating profile produced during the previous revolution. The first causes self-induced vibration, while the second produces a periodic force on the tool. Hence, forced vibration can occur for cuts where the feed is less than the width of cut.

The cutting force on the tool may vary due to variations in d.o.c. produced by the movement of the tool point with respect to the workpiece. Second is the variation of top rake resulting from the change of shape, on which the b.u.e. has great effect. Third is the variation of speed of tool relative to work; and last is the influence of flat at tool point.

Variations are rarely observed at low cutting speeds, though the surface contour is better than at high speeds where the amplitude of tool point is larger than that of low speed, provided that the effect of b.u.e. is eliminated because of its reverse effect. The effect of tool overhang was combined with that of speed in one curve to show the stability region of tool vibration, Fig. 8. The depth of cut does not have much effect on the tool vibration.

Albrecht (12) found that chip-thickness variation also is a result of the shear angle fluctuation. The shape of the chip-thickness variation has been constructed as it occurs due to the variation of shear angle; it resembles a saw tooth wave shape. As the shear angle increases comparatively slowly, the back side of the tooth wave is generated. As the shear angle attains its maximum value, it drops back to its lowest value in an extremely short time, this restarting the cycle and causing forced vibration, Fig. 9.

The tool is the weakest part in the machining operation. The tool wear has a great influence on vibration of cutting. Arnold (11) found that for a carbide tool at 168 m/min cutting speed, the maximum severety of vibration is reached after 3 minutes of cutting with a wear of 0.1 mm. For normal operating conditions of cutting, 0.5 mm wear is allowed on carbide tools before regrinding.

Pekelharing (13) found that the angles of the tool affect life of tools considerably. An increase of clearance angle decreases tool life. The increase of wedge angle increases the life. The life increases to a maximum value as the back rake angle increases to plus 3°, and then is constant to plus 6° back rake.

Bisacre and Bisacre (14) deduced a formula for the tool-life duration of carbide tools. The standard tool-life duration is measured for velocity of cutting for which the tool-life duration is 60 minutes before regrinding [V60].

The formula of tool life is:

$$T\ V^6\ F^4\ D\ \sin^3\theta = (34.77)^6\ \pm 13\%$$

where

T = tool life, minutes

V = cutting speed, f.p.m.

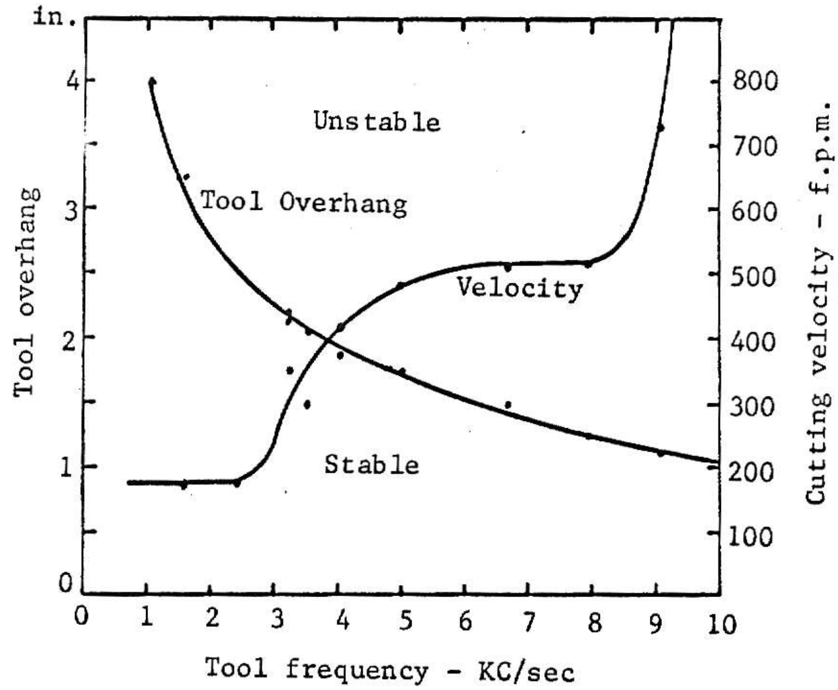


Fig. 8. Stability of Tool Vibration.

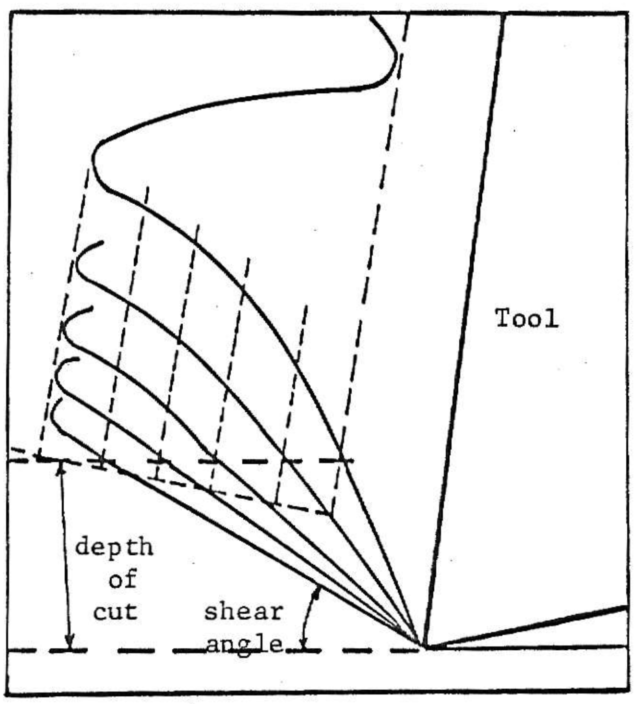


Fig. 9. Shear Angle Variation

F = feed, inches

D = depth of cut, inches

θ = cutting plane angle of tool, measured from direction of feed

The conditions for life duration of carbide tool machining medium carbon steel for 60 minutes are:

V60	= 100 m/min	[330 f.p.m.]
F	= 0.625 mm/rev	[0.025 in/rev]
d.o.c.	= 1.56 mm	[0.0625 in]
θ	= 50°	

EXPERIMENT

In general, a machine tool is designed for a range of cutting speeds and feeds. For rough cutting operations, it is necessary for the machine to provide sufficiently high metal removal; but for fine cutting operations, it is required to provide adequate workpiece accuracy. These rough and fine cutting operations require different cutting conditions.

This paper considers the fine cutting operations. The chosen cutting conditions were selected to suit economically realistic cutting conditions and to provide stable cutting operations, as far as possible.

Equipment and Materials

Equipment was selected to minimize deflection and measuring errors.

The first machine was a new medium sized lathe with rigid construction and had the specifications indicated in Appendix II.

The second machine was a used medium sized lathe, Appendix II.

A carbide tip tool was used for finish and semifinish turning on medium carbon steels. It had the geometry shown in Appendix II, which is the normal shape for cutting steels, and was fixed in a tool post.

The first measuring machine was a horizontal meteroscope, Appendix II. The workpiece was held between two centers on a floating table. The fixed anvil was circular with 5 mm diameter, and the movable anvil was V-shaped with straight edge of width 2 mm. The second piece of measuring equipment was an electrical comparator, Appendix II.

Materials used were three different steels:

1. Steel 40, hot rolled - cold drawn. It is comparable to SAE 1117.

   Ultimate tensile strength = 40 kg/mm^2 [56,000 psi]

Brinell Hardness No. [B.H.N.] = 140 - 145

2. Steel 70, hot rolled - cold drawn. It is comparable to SAE 1144.

Ultimate tensile strength = 70 kg/mm^2 [98,000 psi]

Brinell Hardness No. [B.H.N.] = 215 - 218

3. Steel SAE 1035, hot rolled.

Ultimate tensile strength = 57 kg/mm^2 [80,000 psi]

Brenell Hardness No. [.B.H.N.] = 180

Working Conditions and Measurement

Dry cutting with the following conditions:

Range of speeds	40 - 130	m/min
	130 - 425	f.p.m.
Range of feeds	0.07 - 0.3	mm/rev
	0.00275 - 0.012	in/rev
Range of d.o.c.	0.1 - 1.2	mm
	0.004 - 0.048	in

All of the cross-section areas of cut were within the stable region of Fig. 5.

The workpieces had rigid dimensions, i.e. $\frac{L}{D} \leq 3$, Fig. 10, to minimize deflection.

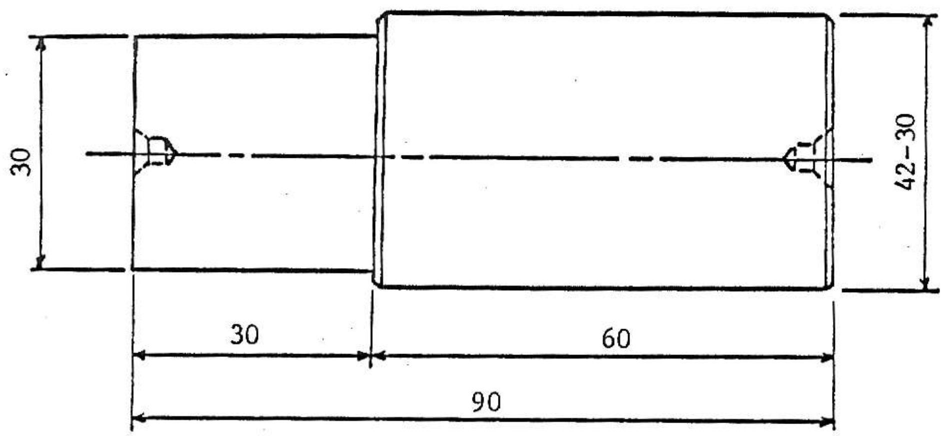
The tool overhang was 35 to 40 mm [1.4 - 1.6 in.] to work in the stable region for tool vibration, as in Fig. 8.

To minimize the effect of tool wear on tool vibration, the tools were sharpened at a fractional period of the life duration of the tool (14), about 15 minutes before regrinding.

Tool life for worst conditions

Speed = 425 f.p.m. feed = 0.012 in/rev

d.o.c. = 0.048 in. θ = 68°



Dimensions in mm.

Fig. 10. Workpiece

$$\text{Tool life} = \frac{(34.77)^6}{(425)^6} \times \frac{1}{(0.012)^4} \times \frac{1}{0.048} \times \frac{1}{0.8}$$

$$= (8.18)^6 \quad \frac{1}{10^{12}} \times \frac{10^8}{(1.2)^4} \times \frac{1}{0.048} \times \frac{1}{0.8}$$

$$= (540)^2 \times \frac{1}{10^4} \times \frac{1}{2.078} \times \frac{1}{0.0384}$$

$$= 365 \text{ min.}$$

$$= 6 \text{ hrs.}$$

To minimize the systematic errors of setting, four or five workpieces were used for each condition of cutting.

To minimize the effect of the centers deflection and taper error, measures were taken at the midsection, for a 20 mm wide strip.

To minimize the effect of random errors due to surface imperfections and measuring sensitivity, 20 random readings were taken on each workpiece. Readings were taken at five intervals, 5 mm apart, with four random readings at each interval. The total reading obtained for one point on each curve was 100 [20 × 5].

All the experiments were measured in the Metric system, except experiments Nos. 25, 26, and 27 which were done in the English system and the data converted to the Metric system.

Experimental Technique

It is required to find relations between deviations of the obtained diameter from the required diameter, $\bar{x}$, and precision of the obtained measurements, σ, i.e. variation of the obtained measurements, with changes of feed, speed, and depth of cut [d.o.c.].

To plot a curve for one relation, five points give adequate range for the varying parameters. For each point, five workpieces are required. The minimum number of workpieces for a curve was 25, increased to 30 for unexpected errors.

Steel SAE 1035 was turned on the second machine using a carbide tipped tool of shank size 5/8 in. × 5/8 in. clamped in a tool holder.

Procedure

The 30 workpieces were turned to the required diameter plus the depth of cut to be turned later, using feed of 0.07 mm/rev [0.00275 in/rev] and velocity of 80 m/min [262 f.p.m.], and d.o.c. of 0.25 mm [0.01 in] maximum. The variations in the workpieces diameters were within ±0.01 mm [±0.0004 in].

One specimen was turned to the required diameter exactly, and was used as a reference for adjusting the tool for the required depth of cut. The machine and tool were set to the required conditions. The reference specimen was put between the centers and the tool was adjusted to just touch it, then the cross slide was locked.

One of the workpieces was put between centers in place of the reference piece. The tool was then fed with the required depth of cut. The cutting operation was performed for this workpiece; the workpiece was then removed and assigned a number. The reference piece was inserted again between the centers to check the tool set for the required depth of cut.

Then the sequence was repeated for each workpiece, and the conditions were changed for every five pieces with respect to the values of the variables in operation. All five pieces machined at the same conditions were given the same number to avoid confusion.

During the turning of the pieces, the tool was changed two or three times, to provide sharp edge cutting. Only 25 pieces were used for measurements.

The workpieces were measured as mentioned before with a total of 100 reading for every point on each curve. By statistical treatment of the obtained measurements (15), example in Appendix III, the mean difference of the obtained diameters from the required diameters, $\bar{x}$, was obtained, as well as the standard deviations, σ, which indicated the variations in dimensions of the obtained diameters.

$\bar{x}$ indicates the accuracy of dimensions

σ indicates the precision of dimensions.

Accuracy of Experiments

The setting error of workpieces on the machine was ±0.005 mm [5 μ, 0.0002 in].

The error of touching the tool with workpieces was ±0.005 m [±0.002 in]. For both, the totalsetting error was ±0.01 [0.004 in].

The effect of the setting error between workpieces on $\bar{x}$ trend was not significant, while it had a considerable effect on σ trend. σ could not be used precisely for the variations within the points. But σ could indicate the trend of precision of the whole field of the tested conditions.

A new parameter was introduced to indicate the precision of the process within the points. This parameter, relative precision index [R.P.I.], is the ratio of the permissible tolerance, T, for the workpieces, to the mean range of dimensions of the five workpieces, $\bar{w}$, i.e. R.P.I. = $\frac{T}{\bar{w}}$ dimensionless.

The tolerance, T, for center lathe turning on diameters ranging from 30 to 50 mm [1.2 to 2 in] is 39μ [1.54 microinches].

High values of R.P.I. mean precise operations. By using R.P.I., the setting errors were eliminated and the obtained deviations will be mainly due to the work conditions.

Presentation of Data

The data obtained were used to plot curves showing accuracy of dimensions, $\bar{x}$, as affected by velocity, feed, and depth of cut. The relative precision index is also given for the same experimental parameters.

The data are in Appendix V, and the curves are on the following pages.

For steel SAE 1035, only one curve is obtained for each parameter to compare the trend with those obtained for steels 40 and 70.

Explanation of Plate II

Effect of Feed on Accuracy of Dimensions

St. 70

vel. = 58 m/min

vel. = 83 m/min

vel. = 106 m/min

St. 40

vel. = 60 m/min

vel. = 80 m/min

vel. = 100 m/min

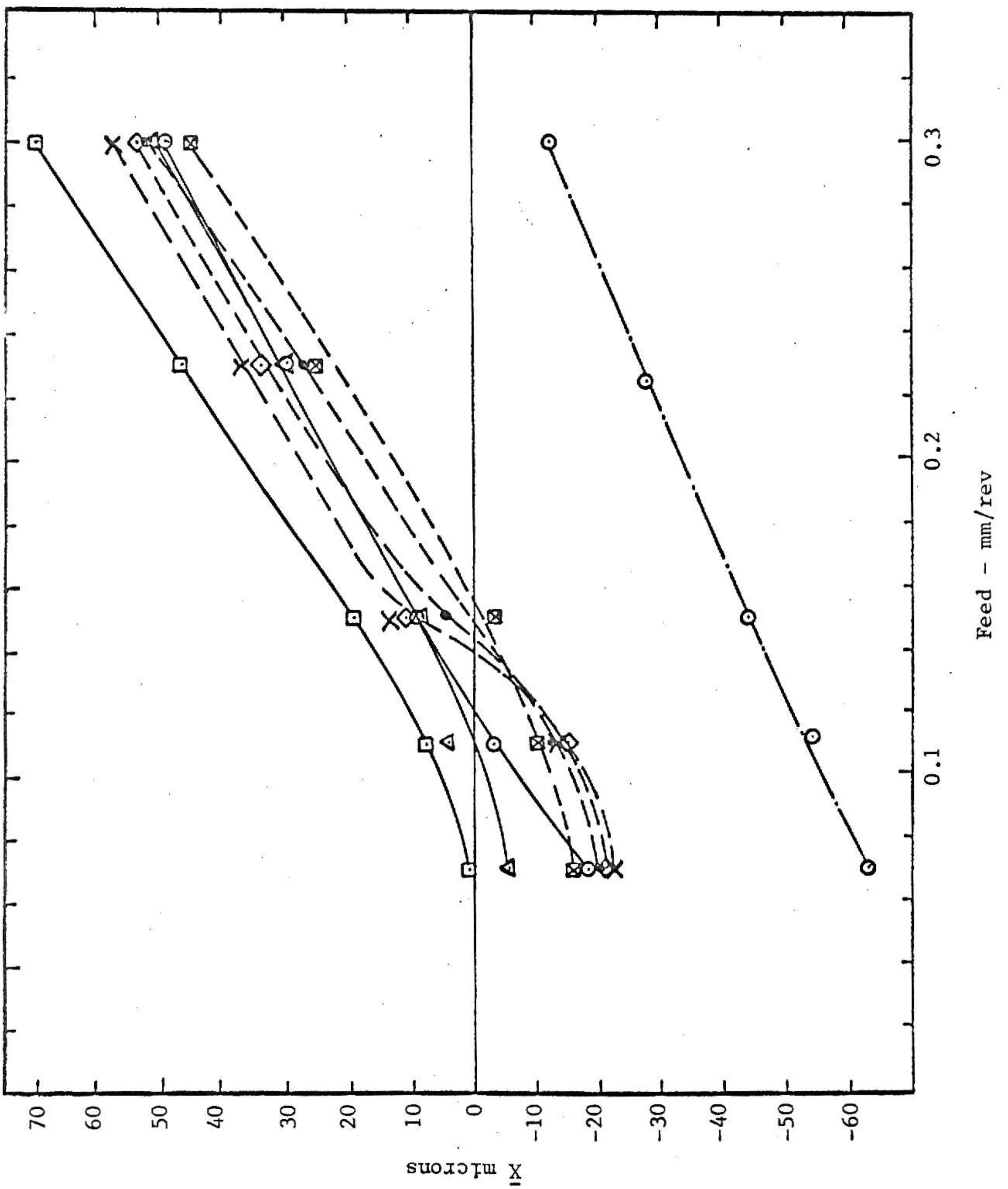
vel. = 125 m/min

St. SAE 1035

vel. = 65 m/min

Depth of cut = 0.5 mm

Plate II



0.1
0.2
0.3
Feed - mm/rev
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
X̄ microns

Explanation of Plate III

Effect of Speed on Accuracy of Dimensions

St. 70

d.o.c. = 0.10 mm

d.o.c. = 0.25 mm

d.o.c. = 0.50 mm

d.o.c. = 0.78 mm

d.o.c. = 1.20 mm

St. 40

d.o.c. = 0.10 mm

d.o.c. = 0.25 mm

d.o.c. = 0.50 mm

d.o.c. = 1.20 mm

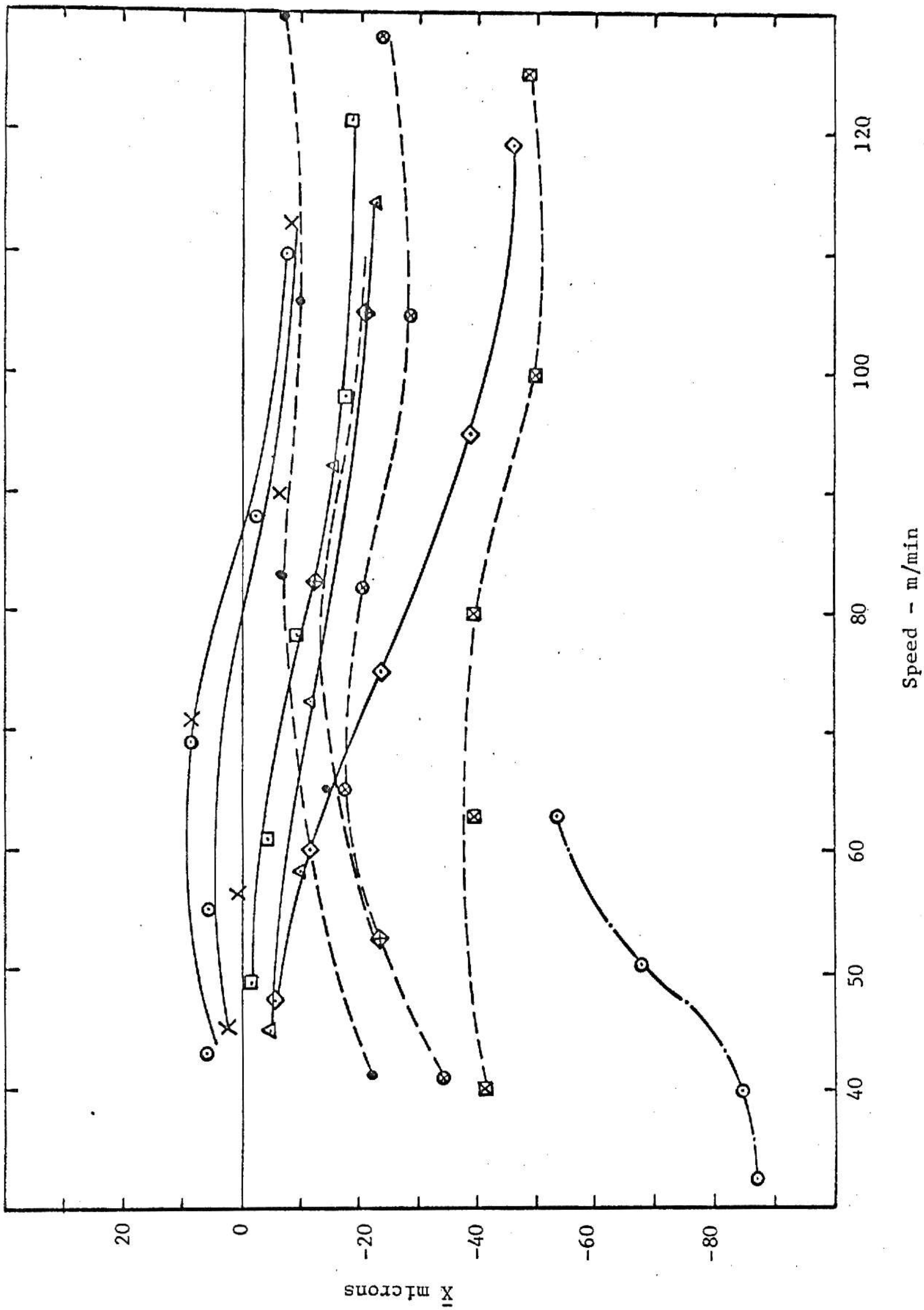
Feed = 0.11 mm/rev

St. SAE 1035

d.o.c. = 0.50 mm

Feed = 0.11 mm/rev

Plate III



Explanation of Plate IV

Effect of Depth of Cut on Accuracy of Dimensions

St. 70

Feed = 0.07 mm/rev

Feed = 0.11 mm/rev

Feed = 0.15 mm/rev

Feed = 0.23 mm/rev

Velocity = 75 to 80 m/min

St. 40

Feed = 0.07 mm/rev

Feed = 0.11 mm/rev

Feed = 0.15 mm/rev

Feed = 0.23 mm/rev

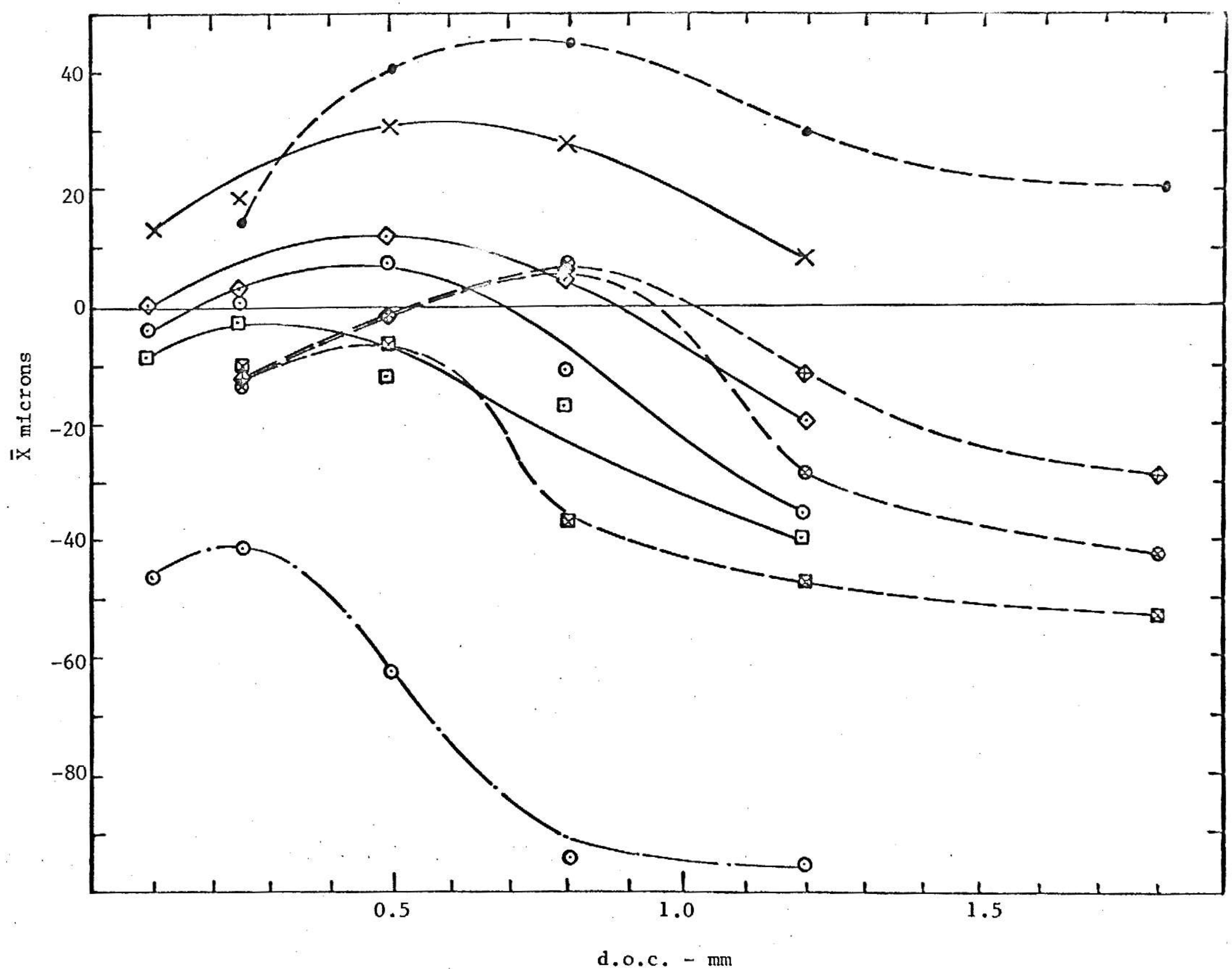
Velocity = 80 to 85 m/min

St. SAE 1035

Feed = 0.106 mm/rev

Velocity = 70 to 75 m/min

Plate IV



Explanation of Plate V

Effect of Feed on Relative Precision Index

St. 70

Vel. = 58 m/min

Vel. = 83 m/min

Vel. = 106 m/min

St. 40

Vel. = 60 m/min

Vel. = 80 m/min

Vel. = 100 m/min

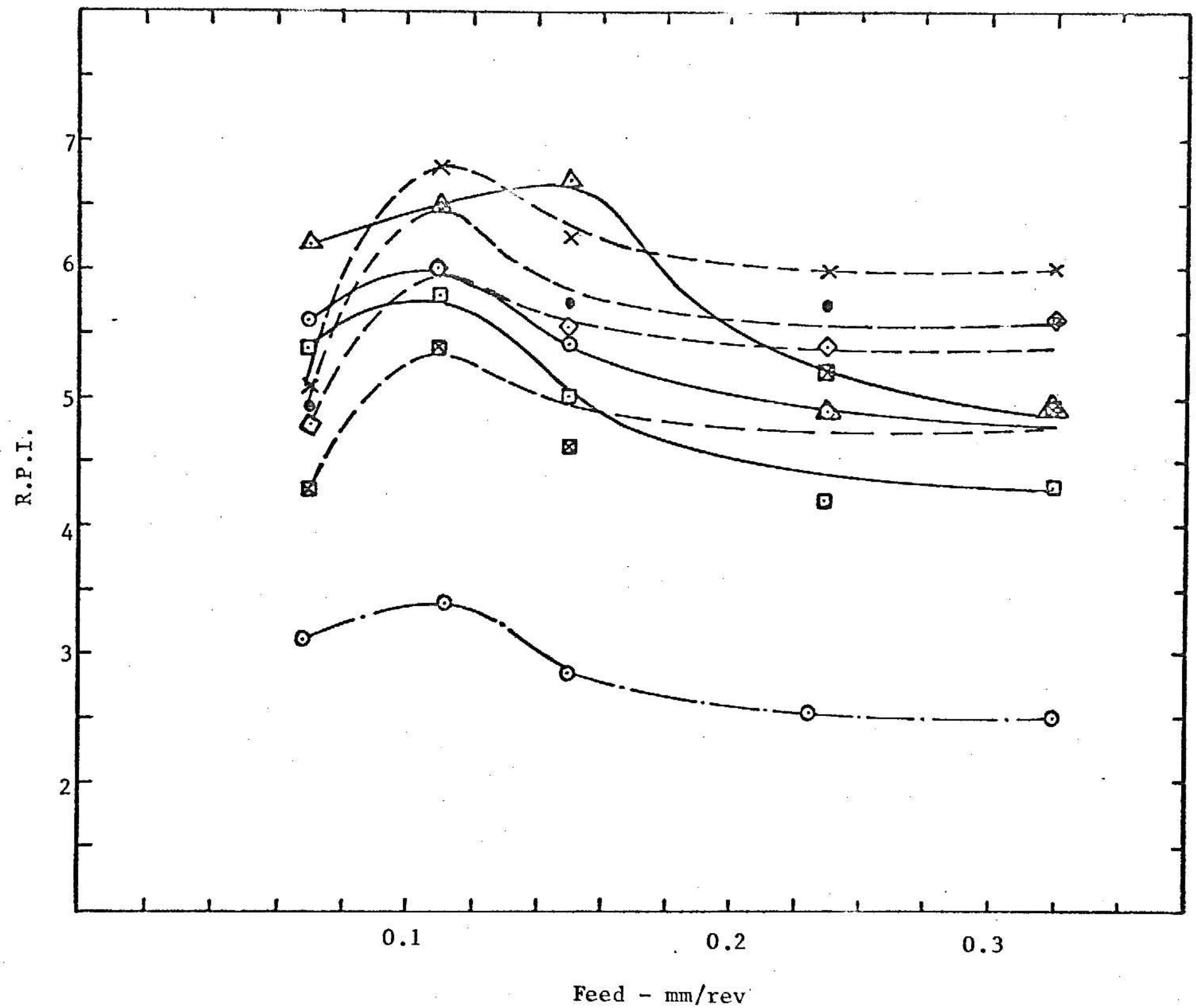
Vel. = 125 m/min

St. SAE 1035

Vel. = 65 m/min

Depth of cut = 0.5 mm

Plate V



Explanation of Plate VI

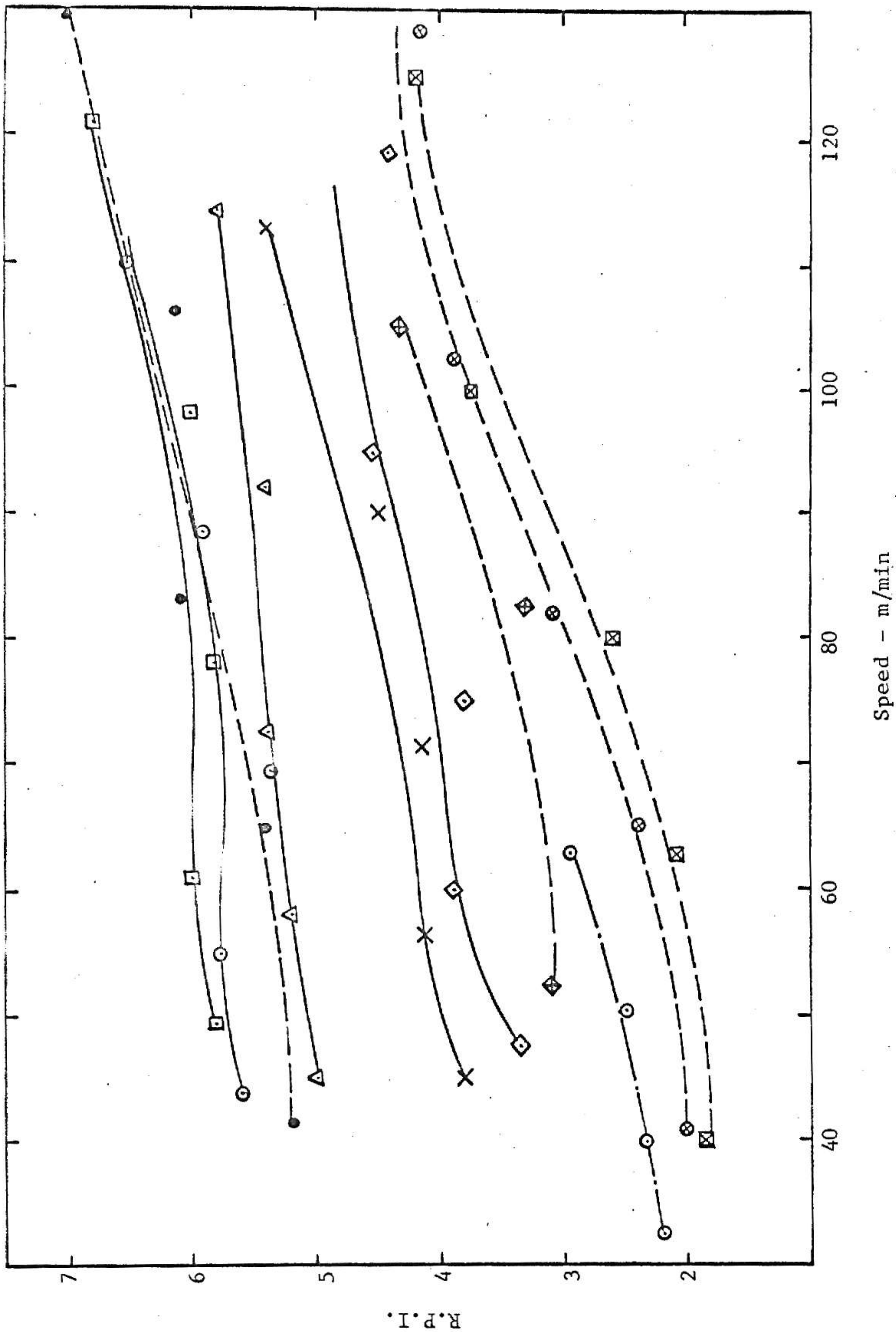
Effect of Speed on Relative Precision Index

St. 70		St. 40	
—△—	d.o.c. = 0.10 mm	– –⊠– –	d.o.c. = 0.10 mm
—⊡—	d.o.c. = 0.25 mm	– –⊗– –	d.o.c. = 0.25 mm
—⊙—	d.o.c. = 0.50 mm	– –•– –	d.o.c. = 0.50 mm
—×—	d.o.c. = 0.78 mm	– –⊕– –	d.o.c. = 1.20 mm
◈	d.o.c. = 1.20 mm		

St. SAE 1035	
—·—⊙—·—	d.o.c. = 0.50 mm

Feed = 0.11 mm/rev

Plate VI



Explanation of Plate VII

Effect of Depth of Cut on Relative Precision Index

St. 70

Feed = 0.07 mm/rev

Feed = 0.11 mm/rev

Feed = 0.15 mm/rev

Feed = 0.23 mm/rev

Velocity = 75 to 80 m/min

St. SAE 1035

Feed = 0.106 mm/rev

Velocity = 70 to 75 m/min

St. 40

Feed = 0.07 mm/rev

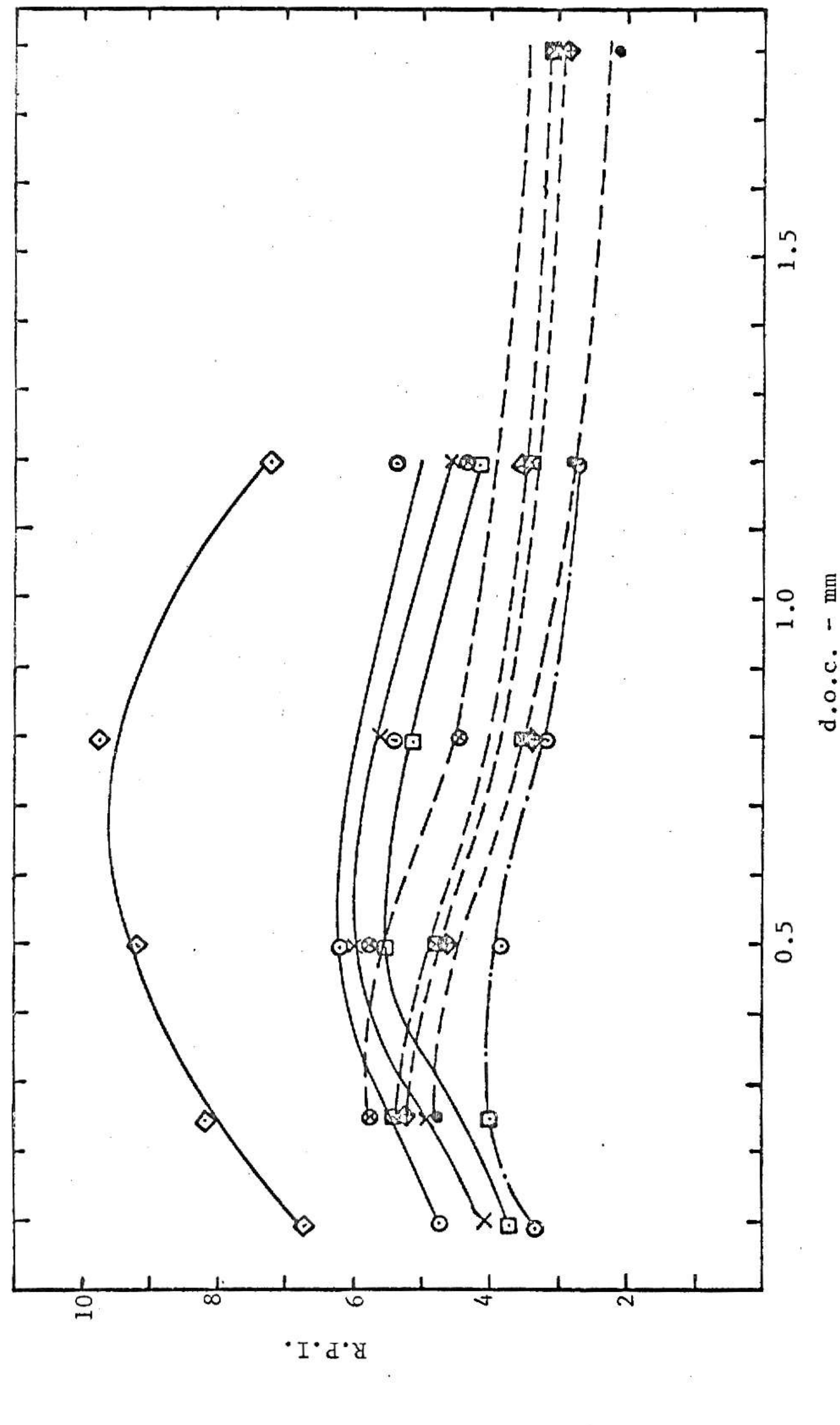
Feed = 0.11 mm/rev

Feed = 0.15 mm/rev

Feed = 0.23 mm/rev

Velocity = 80 to 85 m/min

Plate VII



CONCLUSIONS

The effects of feed, speed, and d.o.c. on the dimensional accuracy for turned pieces on a lathe were collected respectively for each steel.

The feed has a significant effect on the obtained dimensions. The diameter increases with the increase of feed. This increase is due mainly to the geometrical effects. The precision of operations increases with the feed until a feed of 0.11 mm/rev. [0.0045 in/rev] is reached and decreases with further increase of feed. These trends are valid for all steels.

The effect of speed on the obtained diameters is not as strong, but it has the trend of increasing the dimensions up to the optimum velocity for each steel, then decreasing and approaching a limit after about 110 m/min. The precision of operations increases gradually with increased speed, and also tends to approach a limit at about 110 m/min.

The increase of d.o.c. has the effect of increasing the diameter to a maximum value, then the diameter decreases with further increase in d.o.c. The minimum diameter obtained for each experiment depends on kind of material, feed, and speed as well as the d.o.c. The precision of operations increases by increasing d.o.c. to a certain value, and then decreases. But the maximum values are about the same for the same material. The rates of decrease are very low at larger depths of cut and approach a limit after about 0.5 mm d.o.c.

Both dimensions and accuracy increase as the hardness of material increases for the same conditions, except in effect of d.o.c. on $\bar{x}$; this is valid to 0.5 mm d.o.c. only.

Steel SAE 1035 gave the same trends, but the values of $\bar{x}$ and R.P.I. are much less than those of steel 40 and steel 70. These trends were due to the change of material properties, machine, tool, and fixation of tool and workpiece.

The optimum values obtained for $\bar{x} \simeq 0$ and maximum R.P.I. for different parameters are in Table 2.

Table 2

Material	Dimensional accuracy	Feed mm/rev	Speed m/min	d.o.c. mm
St. 40	$\bar{x}$	0.13-0.16	75-80	0.5
	R.P.I.	0.11	increases with speed	0.25
St. SAE 1035	$\bar{x}$	-	over 65	0.25
	R.P.I.	0.11	increases with speed	0.25-0.35
St. 70	$\bar{x}$	0.1-0.14	55-65	0.1 -0.3
	R.P.I.	0.11	increases with speed	0.5 -0.7

The table indicates that there are certain ranges for feed, speed, and depth of cut which give the best values for the dimensional accuracy of turning steels on a lathe. By increasing the hardness of steels, the values increase from the lower up to the upper values of the following optimum ranges:

Feed = 0.1 - 0.14 mm/rev [0.004 - 0.0055 in/rev]

Speed = optimum for each steel when turned by carbide tool

d.o.c. = 0.25 - 0.6 mm [0.01 - 0.024 in]

DISCUSSION

The machining operation is a complex problem. Many factors affect the machining quality due to their effect on the mechanics and physics of the cutting operation. The separation and study of the effect of one particular item from the others is very difficult. Only special results for certain conditions were obtained. No general rules were deduced for a particular item, or definite relation for any experiment; but a range in which the conditions are valid was established. The change of one condition affects the machining operation in many aspects, some considerably.

Most of these different factors and their effects were mentioned in the Introduction and Review of Literature. The combination of all factors causes the stability or unstability of the cutting operation, according to quality and magnitude. The stability of the cutting operation is in direct relation to chatter and vibrations induced during machining. The result will affect the shape, dimensions, and surface finish.

By comparing the obtained results with those in the Review of Literature, the following analysis can be considered. The changes due to feed are due mainly to the geometry of cutting. The dimensions increase with the increase of feed. But, at low feeds, forced vibrations exist and the amplitude of vibration increases due to decrease in feed, causing the decrease of dimensions. At the same time, the b.u.e. increases with the increase of feed, causing a reverse effect. The accumulation of these effects results in the best surface finish at moderate feeds. The deterioration of surface finish at low feeds is due to vibration effects, while that at large feeds is due to tool geometry and b.u.e. formation.

At low cutting speeds, the b.u.e. plays a significant part in decreasing both dimensions and accuracy. The b.u.e. effect decreases with speed increase up to the optimum speed of the material. With further increases in speed, the effects of vibration appear. An increase of speed increases the amplitude of vibration until a limit where it reaches a stable amplitude or decreases slightly, while the tool frequency increases continuously; these cause a good surface finish. The combination of these effects causes an increase of dimensions with speed increased to the recommended speed for each material. Then dimensions decrease slightly, then seem to increase again or remain stable for a wide range. The accuracy improves gradually with speed increases, then approaches a limit.

The effects of depth of cut are greatly influenced by the chip formation and the cutting forces. For large depth of cuts, large forces increase the deflection of the tool. And an increase of depth of cut will introduce a gap between the tool tip and the surface of the workpiece, then the depth of the material in the workpiece increases. Also, the increase in chip thickness will form cracks which deteriorate the surface finish, (16), (17).

For small depth of cut, the force deforms the workpiece surface. The surface was strain hardened from the previous operation, and a discontinuous chip formation like a powder is produced, which tends to decrease the dimensions slightly and deteriorates the surface finish.

As the hardness of the material decreases, the formation of b.u.e. increases and also its size. Thus, the decrease in material hardness results in a decrease in dimensions and deterioration in surface finish. This is also the case when increasing the ductility of the material. Cold-working improved machinability particularly in lower carbon grades, and the yield strength is increased proportionally greater than the increase in tensile strength. The high yield strength ratio resulting minimizes the plastic flow of metal during machining, permitting much of the tool energy to be utilized in shearing the chip. Increase in sulfur content is beneficial to machinability.

The effects of feed, speed, and depth of cut on the total dimensional variation of the diameter was determined. The total variation is that due to the deflection of the system, Y_{system}, the geometry of cut, vibration, and built-up edge. As the feed increases, the total reduction in diameter increases, and then remains constant after 0.23 mm/rev. As the speed increases, the total reduction in diameter decreases until the optimum speed then increases; however, the changes were small. The total reduction in diameter decreases with increasing d.o.c. up to 0.8 mm, then it increases at a faster rate. [See Appendix IV.]

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APPENDICES

APPENDIX I

GEOMETRY OF THE CUT

The geometry of cut depends mainly on the shape of tool and the amount of feed, (5), (6).

For sharp corner tool, Fig. 11, a.

D = depth of cut

f = feed per revolution

h = depth of the unremoved ridge

θ = cutting plane angle of tool

ϕ = trailing plane angle of tool

$$f = h(\cot\phi + \cot\theta)$$

$$= h\left(\frac{\cos\phi}{\sin\phi} + \frac{\cos\theta}{\sin\theta}\right)$$

$$= h\left(\frac{\sin\theta\ \cos\phi + \cos\theta\ \sin\phi}{\sin\phi\ \sin\theta}\right)$$

$$= h\left(\frac{\sin(\theta+\phi)}{\sin\ \theta\sin\phi}\right)$$

$$h = f\left(\frac{\sin\theta\ \sin\phi}{\sin\ (\theta+\phi)}\right)$$

h is the peak to valley roughness

$\theta = 68°$

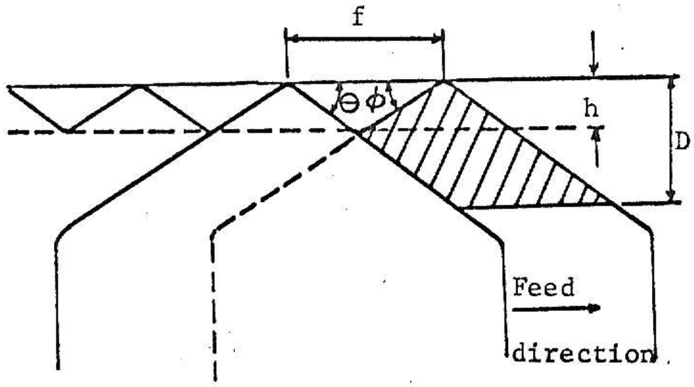
$\phi = 22°$

For a rounded tool, the peak to valley roughness was shown to be

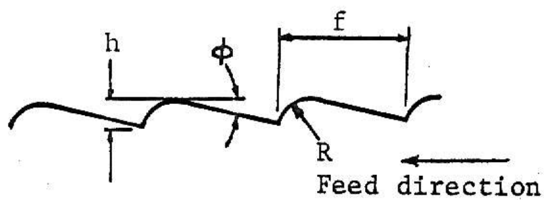
$$h = (1-\cos\phi)R + f\sin\phi\ \cos\phi - \sqrt{2fR\ \sin^3\phi - f^2\sin^4\phi}$$

where

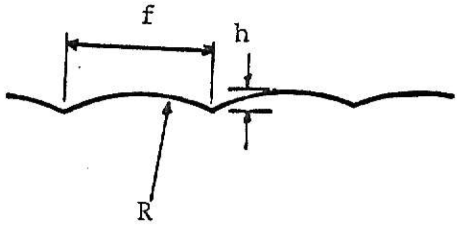
R = nose radius of tool



(a). Sharp edge tool



(b). Round edge tool



(c). Round edge tool with R >> f

Fig. 11. Geometry of Cut.

For small feeds, where the tool is cutting entirely on its nose radius,

$f \leq 2R \sin \phi$

$h = R - \frac{1}{2}\sqrt{4R - f}$

by expanding in a binomial series, h, can be approximated to:

$$h = \frac{f}{8R}$$

for R = 1 mm

Table 3
Roughness due to sharp corner tool

f mm/rev	h mm	f mm/rev	h mm
0.07	0.0243	0.23	0.0798
0.11	0.0382	0.30	0.104
0.15	0.052		

APPENDIX II

EQUIPMENT USED

Specifications of First Machine

High Speed Tool Room Lathe Model IK62

Distance between centers	1400 mm
Height of centers	215 mm
Bar capacity	36 mm
Swing over bed	400 mm
Swing over cross slide	220 mm
Thread cutting range:	
Metric, pitch in mm	1-192 mm
English thread per inch	24-2
Speeds and feeds:	
No. of spindle speeds	23
Range of spindle speeds	12.5-2000 r.p.m.
No. of feeds	28
Range of feeds	0.07-1 mm/rev.
Main drive:	
Three phase electric motor	
Power	10 KW
Speed	1500 r.p.m.

Specifications of Second Machine

Reed-Prentice (Kordenbrock Machining Company)

Distance between centers	750 mm [30"]
Bar capacity	41 mm [1 5/8"]
Swing over bed	200 mm [8"]

Swing over cross slide	126 mm [5"]
Thread cutting range	1½-96 thread/in
No. of spindle speeds	16
Range of spindle speeds	18-536 r.p.m.
No. of feeds	54
Range of feeds	0.0625-4.0 mm/rev [0.0025-0.16 in/rev]

Specifications of measuring machine used for the last 3 experiments

Doall Comparator Gage

It is an electrical comparator which has two scales, one of a sensitivity of 0.025 mm [0.001 in], and the other of a sensitivity of 0.0025 mm [0.0001 in]. It has a round tipped anvil, and rectangular fixed table 38 x 125 mm [1.5 x 5 in]

The maximum measuring range 100 mm [4 in]

Specifications of Measuring Machine Used

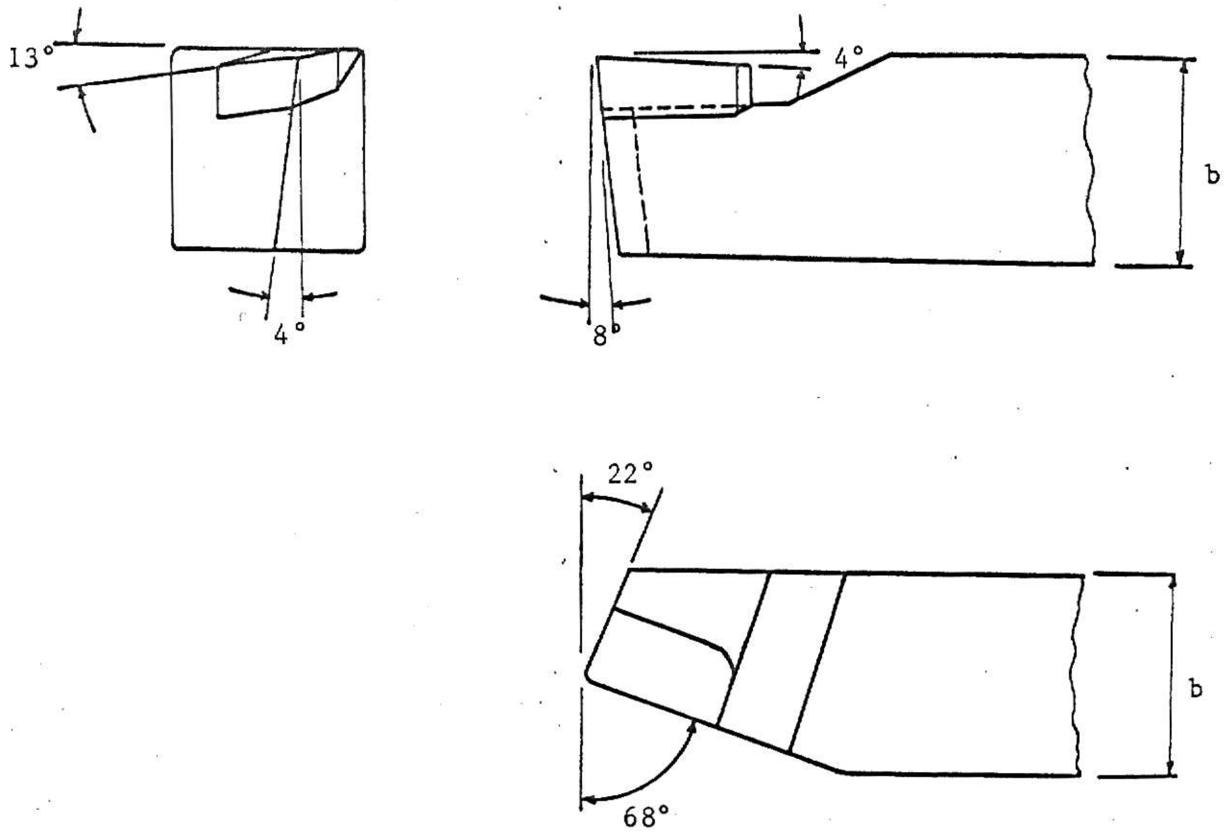
It is a universal horizontal metroscope, which reads to a sensitivity of one micron [= 0.001 mm]. It is used for direct measuring of outside and inside diameters, slabs, and threads. It has two anvils, one moveable carrying a scale, and one fixed anvil, a floating table and arms for internal measurements. Various shapes for anvil tips, and a complete set of rods and wires for thread measurements are available. It has two centers equipped for holding cylindrical work, and other clamping devices to meet the other measuring purposes. It has a differential measuring attachment, which reads with respect to the scale attached to the moveable anvil. The table has cross and vertical movements adjusted by two micrometers. The anvils adjust the longitudinal movement. A magic eye is used for internal measurements.

Scale reads to	1 micron [0.00004 in]
Apparent width of scale division	6 mm
Measuring range	0-100 microns

Using differential measuring attachment.

Ranges:

Outside measurements	0-450 mm
Inside measurements	
with photoelectric contact indicator	1-50 mm
with small contact arms	10-200 mm
with large contact arms	30-200 mm



Front Top Rake	4°	Side Top Rake	13°
Front Clearance	8°	Side Clearance	4°
Nose Radius	1 mm		

Shank Size = b x b = 25 x 25 mm (1 in. x 1 in.) for steels 40 to 70

= 15.6 x 15.6 mm (5/8 in. x 5/8 in.) for steel]035

Fig. 12. Tool Geometry.

APPENDIX III

STATISTICAL TREATMENT OF EXPERIMENTAL DATA

By statistical treatment we can condense the values of the experimental data, which always contain errors or deviations from the true value; into two values: One represents the value of the mean and the other is a measure for the expected variations of that value.

Statistical techniques can perform many useful functions, such as constructing the most representative line or curve through scattered data points, comparing two or more products or processes from overlapping test results and selecting the superior one, and generally supplying objective assistance in the engineer decision-making process.

There are three types of errors in experimental data.

Systematic errors cannot usually be detected by statistical analysis. Its effect can be minimized from outsets, i.e. from the selection of test specimens, the order of their preparation and testing, the selection of testing machines, instruments, and operators. This should all be done on a formally random basis. But the absolute value of all unknown systematic errors is assumed to be the same for all results and can be excluded. The experimental values have to be considered as sampling values, i.e. taken at random. All the experimental values are equivalent, i.e. all the measurable errors have been excluded.

Random errors, having an equal probability of being positive or negative, and small errors occur more frequently than large errors.

Mistakes are primarily operator errors due to carelessness in inattention. It can be minimized by training.

The characteristic values of a sampling distribution are:

$\bar{x}$ = arithmetic mean

$$= \frac{1}{n} \sum_{i=1}^{n} x_i$$

σ = standard deviation

$$= \sqrt{\frac{1}{n-1} \Sigma(x_i - \bar{x})^2}$$

An example for statistical treatment of the experiments is on the following pages, for the first point on the curves of effect of feed on $\bar{x}$ and σ, for steel SAE 1035, experiment No. 25. The conditions and measurements were taken in English system, and the data were converted to the Metric system, Plates VIII, IX.

PLATE VIII

Effect of Feed St. SAE 1035 Experiment No. 25

Vel.	= 65	m/min	212 f.p.m.
d.o.c.	= 0.5	mm	0.02 in
Feed	= 0.07	mm/rev	0.00275 in/rev
Final diameter	= 37.6	mm	1.505 in
Tool overhang	= 35	mm	1.4 in

Difference Between Obtained Diameter and Required Diameter

Point No. 1 (all measurements are negative) 0.0001 in

-26	26	24	23	27	24	28	24	26	27
25	26	22	23	27	25	28	24	26	28
25	25	22	24	28	26	28	25	27	28
28	27	22	27	28	25	28	23	27	28
27	26	24	28	29	27	29	27	28	29
26	26	25	22	27	24	25	23	27	27
26	25	25	22	27	24	25	24	27	27
25	25	26	23	28	25	24	24	28	28
25	26	28	25	28	26	24	25	28	29
26	24	27	24	25	24	24	26	28	30

28-24=4	28-22=6	29-24=5	29-23=6	30-26=4

$\bar{W} = \frac{25}{5}$

$= 0.5 \times 10^{-4}$ in [12.5 μ]

PLATE IX

Interval	μ	Frequency f	10	20	30
over -30	-29	1	x		
-29	-28	4	xxxx		
-28	-27	19	xxxxxxxxxx	xxxxxxxxx	
-27	-26	17	xxxxxxxxxx	xxxxxxx	
-26	-25	15	xxxxxxxxxx	xxxxx	
-25	-24	18	xxxxxxxxxx	xxxxxxxx	
-24	-23	16	xxxxxxxxxx	xxxxxx	
-23	-22	5	xxxxx		
-22	-21	5	xxxxx		

Effect of Feed St. SAE 1035 Point No. 1

Interval	μ	Frequency	y	f.y	y^2	$f.y^2$
over -30	-29	1	-4	-4	16	16
-29	-28	4	-3	-12	9	36
-28	-27	19	-2	-38	4	76
-27	-26	17	-1	-17	1	17
-26	-25	15	-	-	-	-
-25	-24	18	1	18	1	18
-24	-23	16	2	32	4	64
-23	-22	5	3	15	9	45
-22	-21	5	4	20	16	80
Total		100		14		352

$$\bar{X} = -25.5 + \frac{1 \times 14}{100}$$

$$= -25.36 \times 10^{-4}\text{in} \qquad [-63.2\ \mu]$$

$$\sigma = \sqrt{\frac{352}{100}}$$

$$= 1.88 \times 10^{-4} \qquad [4.7\ \mu]$$

APPENDIX IV

ANALYSIS OF DIMENSIONAL VARIATIONS

The deviations of the measured diameter from the required diameter are mainly due to the deflection of the system, the geometry of cut, vibrations, and the built-up edge. Approximate values for deflection of the system, Y_{system}, were obtained from the Review of Literature. The effect of geometry due to sharp corner tool was considered from Appendix I. The effect of vibrations were taken from (11). These three factors tend to increase the diameter. But the b.u.e. tends to decrease the diameter. The total decrease in dimensions obtained are mainly due to the b.u.e. formation. Three samples of the analysis are given in the following tables, for experiments 1, 7, and 10.

Table 4

Experiment 1. Effect of Feed on Dimensions

Ptgt Kg	Y_{system} μ	Geometry μ	Vibration amplitude μ	Total increase μ	$\bar{x}$ μ	Total decrease μ
12.6	1.2	24	3.5	28.7	-16.40	-45.10
16	1.6	38	3.5	48.1	-10.67	-58.77
20	2.0	52	3.5	57.5	- 3.75	-61.25
25	2.4	80	3.5	91.9	24.25	-66.65
28	2.7	104	3.5	110.2	44.18	-66.00

Table 5

Experiment 7. Effect of Speed on Dimensions

Ptgt Kg	Y_{system} μ	Geometry μ	Vibration aplitude μ	Total increase μ	$\bar{x}$ μ	Total decrease μ
16.2	1.6	38.2	2.2	42.0	-22.0	-64.0
16.2	1.6	38.2	4.0	43.8	-14.8	-58.6
16.2	1.6	38.2	5.0	44.8	- 6.7	-51.6
16.2	1.6	38.2	6.2	46.0	- 9.4	-55.4
16.2	1.6	38.2	7.4	49.2	- 7.7	-56.9

Table 6

Experiment 10. Effect of d.o.c. on Dimensions

Ptgt Kg	Y_{system} μ	Geometry μ	Vibration amplitude μ	Total increase μ	$\bar{x}$ μ	Total decrease μ
8.1	0.8	38.2	5.2	44.2	-13.6	-57.8
16.2	1.6	38.2	5.2	45.0	- 2.0	-47.0
26.0	2.6	38.2	5.2	46.0	7.2	-39.8
38.6	3.8	38.2	5.2	47.2	-28.0	-75.2
58.0	5.6	38.2	5.2	51.0	-42.9	-93.9

APPENDIX V

THE OBTAINED DATA

TABLES 7

Effect of Feed St 40

Experiment Number 1

Spec. No.	Feed mm/rev	Vel. m/min	d.o.c. mm	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	0.07	60	0.5	-16.40	3.35	9.00	4.30
2	0.11	60	0.5	-10.67	2.70	7.25	5.40
3	0.15	60	0.5	- 3.75	3.44	8.40	4.64
4	0.23	60	0.5	24.25	2.90	7.60	5.10
5	0.30	60	0.5	45.18	3.30	8.00	4.90

Experiment Number 2

Spec. No.	Feed mm/rev	Vel. m/min	d.o.c. mm	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	0.07	80	0.5	-19.35	4.25	8.00	4.90
2	0.11	80	0.5	-13.40	2.80	6.00	6.50
3	0.15	80	0.5	4.38	3.28	6.80	5.75
4	0.23	80	0.5	26.02	2.40	6.80	5.75
5	0.30	80	0.5	51.50	4.15	7.00	5.60

Effect of Feed St 40

Experiment Number 3							
Spec. No.	Feed mm/rev	Vel. m/min	d.o.c. mm	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	0.07	100	0.5	-20.90	3.7	8.25	4.8
2	0.11	100	0.5	-15.00	3.3	6.50	6.0
3	0.15	100	0.5	9.90	3.3	7.00	5.6
4	0.23	100	0.5	33.38	2.8	7.25	5.4
5.	0.30	100	0.5	52.45	3.0	7.00	5.6

Experiment Number 4							
Spec. No.	Feed mm/rev	Vel. m/min	d.o.c. mm	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	0.07	125	0.5	-22.40	2.50	7.60	5.1
2	0.11	125	0.5	-14.40	3.50	5.75	6.8
3	0.15	125	0.5	13.92	2.65	6.25	6.2
4	0.23	125	0.5	37.00	3.56	6.50	6.0
5	0.30	125	0.5	57.44	2.60	6.50	6.0

Effect of Speed St 40

Experiment Number 5							
Spec. No.	Vel. m/min	d.o.c. mm	Feed mm/rev	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	40	0.1	0.11	-41.80	8.80	21.30	1.83
2	63	0.1	0.11	-39.17	6.80	19.00	2.05
3	80	0.1	0.11	-39.63	5.15	15.00	2.60
4	100	0.1	0.11	-49.35	3.90	10.25	3.75
5	125	0.1	0.11	-48.95	4.70	9.25	4.20

Experiment Number 6							
Spec. No.	Vel. m/min	d.o.c. mm	Feed mm/rev	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	41	0.25	0.11	-34.28	5.10	19.2	2.04
2	65	0.25	0.11	-17.90	4.50	16.5	2.40
3	82	0.25	0.11	-20.50	4.00	12.6	3.10
4	105	0.25	0.11	-28.88	3.00	10.0	3.90
5	128	0.25	0.11	-23.11	3.25	9.4	4.15

Effect of Speed St 40

Experiment Number 7							
Spec. No.	Vel. m/min	d.o.c. mm	Feed mm/rev	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	41.5	0.5	0.11	-22.00	3.15	7.5	5.2
2	65.0	0.5	0.11	-14.76	3.20	7.2	5.4
3	83.0	0.5	0.11	- 6.76	3.05	6.4	6.1
4	106.0	0.5	0.11	- 9.38	3.70	6.4	6.1
5	130.0	0.5	0.11	- 7.72	3.20	5.6	7.0

Experiment Number 8							
Spec. No.	Vel. m.min	d.o.c. mm	Feed mm/rev	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	52.5	1.2	0.11	-23.40	3.9	12.60	3.1
2	83.0	1.2	0.11	-12.07	3.7	11.80	3.3
3	105.0	1.2	0.11	-20.94	3.6	8.75	4.45
4	-	-	-	-	-	-	-
5	-	-	-	-	-	-	-

Effect of D.O.C. St 40

Experiment Number 9							
Spec. No.	d.o.c. mm	Feed mm/rev	Vel. m/min	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	0.25	0.07	80-85	-10.37	2.60	7.25	5.40
2	0.50	0.07	80-85	- 6.60	3.37	8.20	4.75
3	0.80	0.07	80-85	-36.72	3.79	11.20	3.50
4	1.20	0.07	80-85	-47.60	3.76	11.40	3.40
5	1.80	0.07	80-85	-52.88	5.90	13.00	3.00

Experiment Number 10							
Spec. No.	d.o.c. mm	Feed mm/rev	Vel. m/min	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	0.25	0.11	80-85	-13.62	3.80	6.8	5.72
2	0.50	0.11	80-85	- 2.00	3.90	6.8	5.72
3	0.80	0.11	80-85	7.20	3.50	8.8	4.45
4	1.20	0.11	80-85	-28.06	3.68	9.0	4.34
5	1.80	0.11	80-85	-42.88	5.80	13.0	3.00

Effect of D.O.C. St 40

Experiment Number 11							
Spec. No.	d.o.c. mm	Feed mm/rev	Vel. m/min	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	0.25	0.15	80-85	-12.58	3.20	7.4	5.32
2	0.50	0.15	80-85	- 1.38	3.15	8.4	4.65
3	0.78	0.15	80-85	6.59	3.85	11.4	3.40
4	1.20	0.15	80-85	-11.62	3.65	11.0	3.50
5	1.80	0.15	80-85	-28.26	5.65	13.8	2.82

Experiment Number 12							
Spec. No.	d.o.c. mm	Feed mm/rev	Vel. m/min	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	0.25	0.23	80-85	14.35	3.40	8.2	4.75
2	0.50	0.23	80-85	40.70	3.65	8.4	4.65
3	0.78	0.23	80-85	45.50	3.40	11.2	3.50
4	1.20	0.23	80-85	29.05	5.00	14.4	2.70
5	1.80	0.23	80-85	20.20	6.20	19.4	2.03

Effect of Feed St 70

Experiment Number 13							
Spec. No.	Feed. mm/rev	Vel. m/min	d.o.c. mm	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	0.07	58	0.5	0.320	3.30	7.25	5.40
2	0.11	58	0.5	7.330	2.60	6.75	5.80
3	0.15	58	0.5	19.075	3.30	7.75	5.05
4	0.23	58	0.5	46.800	3.85	9.40	4.20
5	0.30	58	0.5	69.380	2.85	9.00	4.35

Experiment Number 14							
Spec. No.	Feed mm/rev	Vel. m/min	d.o.c. mm	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	0.07	83	0.5	-18.36	3.20	7.1	5.60
2	0.11	83	0.5	- 3.63	2.80	6.5	6.00
3	0.15	83	0.5	8.80	3.05	7.2	5.42
4	0.23	83	0.5	29.64	3.80	8.0	4.90
5	0.30	83	0.5	48.34	3.20	8.0	4.90

Effect of Feed St 70

Experiment Number 15							
Spec. No.	Feed mm/rev	Vel. m/min	d.o.c. mm	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	0.07	106	0.5	- 5.550	4.10	6.25	6.25
2	0.11	106	0.5	4.075	3.10	6.00	6.50
3	0.15	106	0.5	8.080	2.80	5.00	6.70
4	0.23	106	0.5	29.400	2.70	8.00	4.90
5	0.30	106	0.5	51.580	3.65	8.00	4.90

Effect of Speed St 70

Experiment Number 16							
Spec. No.	Vel. m/min	d.o.c. mm	Feed mm/rev	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	45.0	0.10	0.11	- 4.72	3.00	7.75	5.00
2	58.0	0.10	0.11	- 9.65	3.00	7.50	5.20
3	72.5	0.10	0.11	-11.50	2.95	7.25	5.40
4	92.0	0.10	0.11	-15.25	3.15	7.25	5.40
5	114.0	0.10	0.11	-22.35	2.80	6.75	5.80

Experiment Number 17							
Spec. No.	Vel. m/min	d.o.c. mm	Feed mm/rev	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	49	0.25	0.11	- 1.66	3.8	6.75	5.8
2	61	0.25	0.11	- 4.27	3.8	6.50	6.0
3	78	0.25	0.11	- 9.60	4.0	6.75	5.8
4	98	0.25	0.11	-17.35	2.8	6.50	6.0
5	121	0.25	0.11	-18.10	2.1	5.66	6.8

Effect of Speed St 70

Experiment Number 18							
Spec. No.	Vel. m/min	d.o.c. mm	Feed mm/rev	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	44	0.5	0.11	5.34	2.60	7.00	5.60
2	55	0.5	0.11	5.77	3.55	6.75	5.75
3	69	0.5	0.11	8.48	3.53	7.50	5.30
4	88	0.5	0.11	-2.88	2.85	6.75	5.90
5	110	0.5	0.11	-7.40	2.80	6.00	6.50

Experiment Number 19							
Spec. No.	Vel. m/min	d.o.c. mm	Feed mm/rev	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	45.0	0.78	0.11	2.22	3.30	10.25	3.80
2	56.5	0.78	0.11	0.82	3.00	9.40	4.15
3	71.5	0.78	0.11	8.65	3.00	9.40	4.15
4	90.0	0.78	0.11	-6.55	3.20	8.75	4.50
5	113.0	0.78	0.11	-8.77	2.85	7.25	5.40

Effect of Speed St 70

Experiment Number 20							
Spec. No.	Vel. m/min	d.o.c. mm	Feed mm/rev	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	47.5	1.2	0.11	- 5.1	4.60	11.75	3.35
2	60.0	1.2	0.11	-11.46	4.50	10.00	3.90
3	75.0	1.2	0.11	-23.18	5.40	10.50	3.80
4	95.0	1.2	0.11	-38.66	3.95	8.50	4.60
5	119.0	1.2	0.11	-45.45	3.75	9.00	4.35

Effect of D.O.C. St 70

Experiment Number 21							
Spec. No.	d.o.c. mm	Feed mm/rev	Vel. m/min	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	0.10	0.07	75-80	- 8.375	4.35	10.5	3.71
2	0.25	0.07	75-80	- 2.330	3.88	9.6	4.05
3	0.50	0.07	75-80	-11.770	2.80	7.0	5.56
4	0.80	0.07	75-80	-16.350	2.50	7.5	5.20
5	1.20	0.07	75-80	-39.660	4.00	9.2	4.25

Experiment Number 22							
Spec. No.	d.o.c. mm	Feed mm/rev	Vel. m/min	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	0.10	0.11	75-80	- 3.80	4.8	8.25	4.75
2	0.25	0.11	75-80	0.50	3.4	7.75	5.40
3	0.50	0.11	75-80	7.07	2.4	6.25	6.25
4	0.80	0.11	75-80	-10.90	2.8	7.25	5.40
5	1.20	0.11	75-80	-35.50	3.6	7.25	5.40

Effect of D.O.C. St 70

Experiment Number 23							
Spec. No.	d.o.c. mm	Feed mm/rev	Vel. m/min	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	0.10	0.15	75-80	- 0.58	2.85	5.75	6.80
2	0.25	0.15	75-80	2.96	3.14	4.80	8.20
3	0.50	0.15	75-80	12.37	3.75	4.25	9.20
4	0.80	0.15	75-80	4.87	3.07	4.00	9.72
5	1.20	0.15	75-80	-19.38	3.65	5.40	7.25

Experiment Number 24							
Spec. No.	d.o.c. mm	Feed mm/rev	Vel. m/min	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	0.10	0.23	75-80	13.00	1.92	9.5	4.10
2	0.25	0.23	75-80	18.66	2.30	8.0	4.85
3	0.50	0.23	75-80	30.93	3.10	6.5	6.00
4	0.80	0.23	75-80	28.50	3.36	7.0	5.60
5	1.20	0.23	75-80	7.90	3.05	8.5	4.60

Effect of Feed St SAE 1035

Experiment Number 25							
Spec. No.	Feed mm/rev	Vel. m/min	d.o.c. mm	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	0.070	65	0.5	-63.2	4.70	12.5	3.10
2	0.110	65	0.5	-54.2	4.78	11.5	3.35
3	0.150	65	0.5	-44.5	5.90	13.5	2.85
4	0.225	65	0.5	-28.1	7.30	15.0	2.56
5	0.300	65	0.5	012.5	7.20	15.5	2.50

Effect of Speed St SAE 1035

Experiment Number 26							
Spec. No.	Vel. m/min	Feed mm/rev	d.o.c. mm	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	32.5	0.11	0.5	-87.0	5.20	17.7	2.20
2	40.0	0.11	0.5	-85.0	5.86	16.7	2.34
3	50.5	0.11	0.5	-67.5	7.75	15.7	2.50
4	63.0	0.11	0.5	-53.5	6.20	13.2	2.96

Effect of D.O.C. St SAE 1035

Experiment Number 27							
Spec. No.	d.o.c. mm	Feed mm/rev	Vel. m/min	$\bar{X}$ μ	σ μ	$\bar{w}$ μ	R.P.I.
1	0.10	0.108	70.75	-46.0	6.60	11.2	3.46
2	0.25	0.108	70.75	-41.0	7.20	9.5	4.10
3	0.50	0.108	70.75	-62.5	7.45	10.1	3.85
4	0.80	0.108	70.75	-94.0	5.40	12.0	3.25
5	1.20	0.108	70.75	-96.0	8.50	14.0	2.80

Note: Tables of experiment 25, 26, and 27 indicate data converted to the Metric system. Original data was obtained in the English system.

EFFECT OF FEED, SPEED, AND DEPTH OF CUT ON THE DIMENSIONAL ACCURACY OBTAINED FOR A WORKPIECE TURNED ON A LATHE

by

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ABSTRACT

The purpose of this study is to find the effect of feed, speed, and depth of cut on the dimensional accuracy obtained for a workpiece turned on a lathe, to obtain the optimum conditions for dimensional accuracy to save time in machining operations.

The experiments were done on three types of steel with different properties and carbon content, two standard carbon steels, cold drawn, steel 40 with 0.15% carbon, and steel 70 with 0.45% carbon. The third was steel SAE 1035 (corresponds to steel 60), basic open hearth and acid Bessemer carbon steel, hot rolled, with 0.35% carbon. It was used to verify the trend of the experiments obtained from steels 40 and 70. A set of curves were obtained showing the effect of feed, speed, and depth of cut, on the obtained difference in dimensions from the required diameter, $\bar{x}$, and also on the precision of the obtained dimensions, which is indicated by the relative precision index (R.P.I.). The results show the optimum regions for feed, speed, and depth of cut for the best requirements of both dimensions and accuracy of the machines workpiece. The trends of each set are almost the same, while the values may differ, and depend greatly on the changes of material properties, equipment, and methods of fixations. The equipment used, and the experimental technique and data were discussed in detail.