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Theoretical and Experimental Investigation of Tool Inclination Angle in Turning Operation

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Abstract

This paper introduces a mathematical model to calculate the amount of tool inclination angle in turning operation depending on controlling the chip flow along the cutting edge, and to simplify the setting of this angle and the direct relation with nose setting distance, a model is achieved to calculate the setting nose distance instead of changing the inclination angle. Results conducted on a series of experiments by changing tool nose setting distance where most of the cutting conditions kept constant, except tool nose setting below and above the workpiece centre, and its effect of obtained surface roughness was measured at each step.

Theoretical results for finishing turning operation, for depth of cut less than 1 mm, show that setting tool nose below the workpiece centre will be similar to that of setting positive angle of inclination.

The main function of the derived model of the inclination angle is to make equal chip flow along the cutting edge and the chip will be cured far enough from the machined surface and therefore eliminate the chip and hence improve the workpiece surface roughness.

The proposed theoretical model proved that in external turning with finishing operation the suggested inclination angle (λ) must have positive values, and the setting distance has a negative value. While in the experimental work, the workpiece surface finish has been improved when setting distance has negative value below the workpiece centre.

Keywords: Turning Process, Tool Geometry, Tool Setting, Inclination Angle

دراسة نظرية وتجريبية لزاوية ميل الحد القاطع في عملية الخراطة

الخلاصة

يقدم هذا البحث نموذج رياضي لحساب قيمة زاوية ميل الحد القاطع في عملية الخراطة إعتماداً على السيطرة على جريان النحاتة على طول الحد القاطع للعدة، ولتبسيط ضبط الزاوية وعلاقتها المباشرة مع مسافة الضبط، تم أنجاز موديل لحساب مسافة ضبط مقدمة الأداة عوضاً عن تغيير زاوية ميل الحد القاطع. إعتمدت النتائج على مجموعة من التجارب العملية بتغيير مسافة ضبط مقدمة الأداة مع تثبيت معظم ظروف القطع ماعدا مسافة ضبط مقدمة الأداة أسفل وأعلى محور المشغولة وتم قياس تأثيرها على الخشونة السطحية لكل مرحلة.

النتائج النظرية لعملية الخراطة الناعمة، لعمق قطع أقل من 1 ملم، بينت بأن مسافة ضبط مقدمة الأداة أسفل محور الأداة يشابه ضبط أستخدام زاوية ميل حد قاطع موجبة.

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الوظيفة الرئيسية للموديل المشتق لحساب زاوية الحد القاطع هو بجعل سرعة جريان النحاته متساوية على طول الحد القاطع وعليه سوف تقوس النحاتة بعيداً بشكل كافي عن السطح المشغل وبالتالي يتم ابعاد النحاته وعليه تحسين الخشونة السطحية للمشغولة.

ان الموديل الرياضي المقترح للخراطة الخارجية الناعمة أثبت وجوب أن تكون قيم زاوية ميل الحد القاطع المقترحة (λ) موجبة، وقيمة مسافة الضبط سالبة. بينما في الجانب التجريبي، تم تحسين الخشونة السطحية للمشغولة عند قيم ضبط سالبة أسفل محور المشغولة.

Nomenclature:

λ is the tool inclination angle (deg.)
φ is the suggested setting angle (deg.)
h_A and h_B are the setting distance for point A and B respectively (mm)
h_{old} and h_{new} are the old and new tool nose setting distance (mm)
L_1 and L_2 are the length of arc_1 and arc_2 respectively (mm)
OO` is the cutting edge
V_1 is the workpiece periphery speed (mm/sec.)
V_2 is the machined surface speed (mm/sec.)

Introduction

The general process of shaping, sizing or finishing any workpiece to given size or dimension is known as metal cutting process. Metal cutting represents a machining process by which finished surface of desired shape and dimension is obtained by separating a layer from the parent workpiece by pressing a wedge-shaped device called cutting tool to the workpiece [1].

In order to produce any machine part at a certain quality by any metal removal technique, cutting parameters should be arranged properly. Dependent upon workpiece material and geometry to be desired, cutting forces have important influence on determining of machining cost related to cutting speed, feed rate, undeformed chip thickness, cutting tool material and geometry [2].

In metal removal operations, many researches were carried out in the past and many are continuing for the purpose of decreasing production cost and manufacturing parameters without reducing product quality.

Cutting tools are insistently subject to pressure and opposing stresses during cutting even though their cutting edges are sufficiently sharp while machining metallic and nonmetallic materials. Many researchers spent efforts to determine optimum tool cross-sections and their ideal angles to withstand cutting forces.

Some Related Works

The paper of S. G. Ahmed [3] presents a methodology for selecting optimal machining process parameters to obtain the required surface roughness. Nonlinear regression analysis, with logarithmic data transformation was applied in developing the empirical model. Metal cutting experiments and statistical tests have demonstrated that the model developed in this research produces smaller errors and have satisfactory results.

The work of B. Sidda Reddy, et al [4], deals with the development of surface roughness prediction model for machining of aluminum alloys, using adaptive neuro-fuzzy inference system (ANFIS). The experimentation has been carried out on CNC turning machine with carbide cutting tool for machining aluminum alloys covering a wide range of machining conditions. The ANFIS model has been developed in terms of machining parameters for the prediction of surface roughness using train data. The Experimental validation runs were conducted for validating the model. To judge the accuracy and ability of the model percentage deviation and average percentage deviation has been used. The Response Surface Methodology (RSM) is also applied to model the same data. The ANFIS results are compared with the RSM results. Comparison results showed that the ANFIS results are superior to the RSM results.

The study of S. Y. Kassab [5] is to find a correlation between surface roughness and cutting tool vibration in turning. The ranges of process cutting parameters in the present study are limited: cutting speed (34, 70, 130 m/min), depth of cut (0.1, 0.2mm), feed rate (0.07, 0.13, 0.17mm/rev) and tool overhanging (25, 30, 35, 40mm). The data are generated by lathe dry turning of medium carbon steel samples at different levels of the mentioned above parameters. Dry cutting tests (without using cutting fluid) are conducted to simulate a good turning, the dry turning provided a clean environment to obtain undisturbed clear cutting vibration, which results in more accurate and clear correlation between cutting vibrations and roughness. The analysis of variance reveal in this study is that the best surface roughness condition is achieved at a low (feed rate less and equal 0.13mm/rev), and with smaller tool overhang less and equal 30mm). The results also show that the cutting speed has small effect on surface roughness than feed rate and tool overhang. The depth of cut has not a significant effect on surface roughness in this study.

Above results can be obtained when there is no built up edge and no damage of the tool tip. Finally experimental results have shown good correlation between cutting tool vibration and surface roughness which can be used to control the finish surface of the workpieces during the mass production.

Hasan Gökkaya and Muammer Nalbant [6] investigate the effects of different insert radii of cutting tools, different depths of cut, and different feed rates on the surface quality of the workpieces depending on various processing parameters. Properly, the AISI 1030 steel is processed at a digitally controlled computerized numerical control (CNC) turning lathe without using cooling water with three different insert radii (0.4, 0.8, and 1.2 mm) of cemented carbide cutting tools. The effects of five different depths of cut (0.5, 1, 1.5, 2, 2.5 mm) and five different feed rates/advancing steps (0.15, 0.2, 0.25, 0.30, 0.35 mm/rev) on the surface roughness values have been investigated by a turning process while from the cutting parameters the cutting speed is kept constant at (300 m/min). The surface roughness has been improved by 293% when the insert radius (0.4 mm) was increased by 200% (1.2 mm). When the feed rate (0.35 mm/rev) was reduced by 133% (0.15 mm/rev), the surface roughness have been improved by 313%, and by reducing the depth of cut (0.5 mm) by 400% (0.25 mm), an amelioration of 23% has been obtained on the surface roughness.

Dilbag Singh and P. Venkateswara Rao [7] conducted experiments to determine the effects of cutting conditions and tool geometry on the surface roughness in finish hard turning of the bearing steel (AISI 52100) using mixed ceramic inserts made up of aluminum oxide and titanium carbide with different nose radius and different effective rake angles as cutting tools. They found that the feed is the most dominant factor determining the surface finish followed by nose radius and cutting velocity.

A study by Mustafa Günaya, et al [8], presents the influence of tool rake angle on the main cutting force for machining rotational parts by sharp cutting tools. A special dynamometer was designed and produced to measure the forces for this purpose. Two strain gages were placed in the proper position onto machine tool and cutting tool. Replacements of the tool caused by cutting forces were sensed by these proper placements. The well-known material, AISI 1040, was used in the experiments. Main cutting force (F_c) was measured for eight different rake angles ranging from negative to positive and five cutting speeds while depth of cut and feed rate remaining constant. As a result of experimental evaluation, cutting force decreasing trend was observed due to rake angle increasing in positive.

Turning Operation

The cylindrical workpiece is produced by revolving the workpiece and moving the cutting tool parallel to the axis of revolution in a feeding motion.

The difference in the speed of chip flow along the tool cutting edge during the cutting will effect on the chip flow direction and thus causes accumulation and jamming the chip on the regions which have less speed.

In the boring process, the accumulation of the chip will be on the back of the edge direction which has less speed and this is the cause of random force distribution along the cutting edge [9].

In the turning process the chip will accumulate at the front of the cutting edge, which will lead the chip to press on a small spot at the front of the tool and this will cause additional and high resistance and unevenness in the thickness of the chip layer and finally will cause worming of the tip of the tool and roughness of the cutting surface [9].

The inclination angle of the main cutting edge (λ), as shown in fig. (1), could be defined as the angle formed between the cutting edge and the line going through the tool nose which is parallel to the basic plane, and this angle is measured in the plane which passes through the main cutting edge which is perpendicular on the basic plane. The sign of the inclination angle defines the chip-flow direction, as shown in fig. (2). When (λ) is positive, the chip flows to the right and when (λ) is negative, the chip flows to the left [10].

Theoretical Computations Used

The following theoretical procedure has been recommended to calculate the inclination angle value that makes the chips velocity the same along the cutting edge.

According to the model shown in the fig. (3), the normal line (OO`) represents the shear plane that passes through the cutting edge. As a result of different speeds at which the chip is cut at the periphery of the workpiece (V_1) and at the machined surface (V_2) to compensate the speed difference the tool inclination angle (λ) suggested to be positive angle ($+\lambda$) inclined with respect to cutting edge along the line (AB) that makes ($V_1 = V_2$) along the cutting edge.

Length of arc$_1$ (at the periphery of the workpiece) $= L_1 = r_1 \times \theta$

Length of arc$_2$ (at the machined surface) $= L_2 = r_2 \times \theta$

$$\Delta L = L_2 - L_1 = (r_2 - r_1) \times \theta$$

$$\varphi = \frac{\Delta L}{r_2} = \frac{r_2 - r_1}{r_2} \times \theta$$

$$\varphi = \left(1 - \frac{r1}{r2}\right) \times \theta \qquad \ldots\ldots\ldots (1)$$

Where φ represents the suggested setting angle that makes the velocities of points A and B same.

Since $\lambda + \beta = \pi$

And by using Sine law

$$\frac{\sin \varphi}{AB} = \frac{\sin \beta}{r_1}$$

And by Cosine law

$$AB = \sqrt{r_1^2 + r_2^2 - 2\, r_1\, r_2 \cos(\varphi)}$$

$$\sin \beta = \sin(\pi - \lambda) = \text{Sin } \lambda$$

$$\sin \lambda = \frac{r_1 \sin \varphi}{AB}$$

$$\lambda = \sin^{-1}\left(\frac{r_1 \sin \varphi}{AB}\right)$$

for $-\frac{\pi}{2} \leq \lambda \leq \frac{\pi}{2}$ ……… (2)

The relation between setting distance of the tool nose (h) and the tool inclination angle can be derived through the following equations, assuming ($\lambda=0$) it was seen that the height of the tool nose setting distance (h_{old}) along the cutting edge is:

$$h_{old} = h_A - h_B$$

Where, the setting distance for point (A) is; $h_A = r_1 \times \sin \theta$ and the setting distance for point (B) is; $h_B = r_2 \times \sin \theta$ $h_{old} = (r_1 - r_2) \times \sin \theta$ (represent the old setting)

Hence, at the same manner the new setting distance (h_{new}) of the suggested inclination angle that makes equal linear velocity at the periphery of the workpiece and the machined surface is;

$h_{A`} = r_1 \times \sin(\theta - \varphi)$

$h_{B`} = r_2 \times \sin(\theta - \varphi)$

$h_{new} = h_{A`} - h_{B`}$

$h_{new} = (r_1 - r_2) \times \sin(\theta - \varphi)$ (represent the new setting)

To calculate the setting distance (h_{new}) in terms of tool inclination angle (λ), and from equation (1):

$$\theta = \frac{1}{1 - \frac{r_1}{r_2}} \times \varphi = \frac{r_2}{r_2 - r_1} \times \varphi$$

$= R \times \varphi$

$h_{new} = (r_1 - r_2) \times \sin(R \times \varphi - \varphi)$

$= (r_1 - r_2) \times \sin\left[(R - 1) \times \varphi\right]$

And from equation (2):

$$\varphi = \sin^{-1}\left[\frac{AB \times \sin \lambda}{r_1}\right]$$

$$h_{new} = (r_1 - r_2) \times \sin \left[(R - 1) \times \sin^{-1}\left(\frac{AB \times \sin \lambda}{r_1} \right) \right]$$

Experimental Investigation

1- Experimental Setup

The work material used for the present investigation is aluminum alloy 6082 cylindrical workpieces with 30 mm in diameter. The chemical composition of the material used in this work is given in Table (1). While the machining equipment used in this study is all commonly available, which include Celtec Germany traditional turning machine with a tool of commercial available tungsten based cemented carbide inserts, and the tool geometry used in the experiments is presented in Table (2). A surface roughness tester model TR200 , as shown in fig. (4), was used to measure surface roughness, with 0.8mm cutoff length, and gauge length equal 20mm. This surface roughness measuring device is the most widely used instrument in industry and research laboratories, because it is computerized, fast, consistent, easy to use, and relatively inexpensive.

2-Experimental Procedure

The certain relation between tool inclination angle and tool nose setting distance (h) and the difficulties to the operator to achieve the variation of these parameters, therefore; for simpilisity to deal with setting distance, this study done by a set of eleven experiments with different setting distance above and below the workpiece centre 2.5, 2.0, 1.5,1.0, 0.5, 0.0, -0.5, -1.0, -1.5, -2.0, and -2.5 mm and all cutting conditions remains constant; feed rate = 0.01 mm/rev, speed = 1200 rpm, depth of cut = 1 mm. The surface roughness of each section is measured with a surface measuring instrument and the results plotted against the setting distance

Results and Discussion

In this study, a theoretical model has been produced to calculate inclination angle depending upon the uneven chip flow speed along the tool cutting edge. Unfortunately there is no theoretical model to represent the inclination angle and its effect whereas all researches represent the magnitude of this angle from experimental results depending upon the direction of chip flow. As practically recommended from most researches in this field to apply a negative value of inclination angle for finishing and a positive value of inclination angle are more expedient.

Equation (2) represents the calculation of suggested inclination angle that’s makes uniform chip flow along the cutting edge and the chip far enough from the machined surface and indirectly keeping the effect of cured chip to mar the machined surface. It’s observed that the main factor affecting the calculated inclination angle is the diameter of periphery and machined diameters which are depend upon change of depth of cut, the cutting condition that the operator can control during the turning process, which mean the ability of the operator to change the process from roughing and finishing operations. It is known that the depth of cut has little effect upon the natural surface roughness, but it seems from the fig. (5), which is based on applying equation (2), that the calculated inclination angle with different values of depth of cut that cover the finishing and roughing operations. All extracted suggested angles depends upon making the chip flow along the cutting edge is equal, in another mean, far enough from the machined surface whatever was the amplitude of depth of cut. To achieve this suggested inclination angle it must be precisely controlled during finishing and roughing turning operation. Positive value of suggested (λ) till depth of cut reaches 2.1 mm then more than this value it exchange to a negative angle. For finishing operation usually depth of cut 1 mm or less referred to the final cutting pass, the suggested inclination angle has a positive value.

Angle (λ) has an effect on the direction of chip flow; it influence the size of the tool point and determine the point of the initial contact of the cutting edge with the layer been cut off. As a result of different speed at which the chip is cut at the periphery of the work and at the machined surface, this certainly concern with external turning.

In external turning operation with (λ =0) and with the tool nose set at the workpiece centre, whatever was the velocity and the value of the uncut chip thickness, the chip is deflected toward the machined surface and will flow in the direction opposite to the feed, and it can be wind up on the workpiece and mar machined surface, hindering the operator. The derived inclination angle gives more accurate results from that inclination angle where its observed from the calculation of the (λ) model that it get positive values whatever was the difference between the rotation of the linear speed of periphery diameter and machined diameter and this will prevent the chip to deflect toward the machined surface however it deflect far enough. In external turning with finishing operation the suggested (λ) must have positive values.

It is difficult to control and set the inclination angle values during external turning, that may be effect the another tool angles (rake angle and side relive angle) and to simplify the process for the operator, especially when working with numerical controlled machines (CNC) it is easier to change the setting distance and instead of changing the inclination angle, and to do so, in this study it has been derived an equation to calculate the setting distance built upon the values of inclination angle as presented in equation (3) has been suggest a model to achieve the relation between inclination angle and setting distance

Fig. (6) illustrate the calculated relation between inclination angle and setting distance, its observed for setting distance equal zero the suggested inclination angle is zero too, but setting distance have opposite sign with different inclination angle. the calculated setting distance for different depth of cut (for each pass) are shown in fig. (7), its observed that for finishing operation, less than 1 mm depth of cut, the setting distance always has negative value

From the above results in external turning operation when (λ =0) the chip cured toward the machined surface while, the suggested (λ) must be positive that makes the suggested model more understandable for chip flow direction along the cutting edge in any turning process (external, internal, facing …etc.) for roughing and finishing operation.

In experimental work, different setting distance values have been taking above and below the workpiece centre and for each step the surface roughness measured for eleven samples with 1 mm depth of cut with fixed cutting conditions 1200 rpm as listed in Table (3) and shown in fig. (8), from this figure it is observed that the best surface finish values can be seen at setting distance equal to 0.5 mm below the workpiece centre in external turning.

Conclusions

From the present work, the main conclusions can be summarized as:

1- A theoretical model has been achieved to calculate inclination angle that makes equal chip flow along the cutting edge of periphery and machined surface as derived in equation (2).

2- The derived inclination angle gives more accurate results from that inclination angle.

3- In external turning with finishing operation the suggested (λ) must have positive values.

4- The setting distance must be negative during the finishing operation in external turning and the best value can be calculated from equation (3).

5- The main factor that improves the surface roughness is by changing the setting distance, at the same manner the inclination angle, by eliminating the chip curl far enough from the machined surface.

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Table (1) Chemical composition of Aluminum alloy 6082

Composition	Cu	Mg	Si	Fe	Mn	Cr	Others	Al
Weight %	0.1	1.0	0.9	0.6	0.8	0.35	0.3	Balance

Table (2) Tool geometry used in the experiments

Tool rake angle	- 5 ^{o}
Tool clearance angle	+ 5 ^{o}
Nose radius	0.8 mm

Table (3) The surface roughness obtained from different setting distance

Experiment	1	2	3	4	5	6	7	8	9	10	11
Setting Distance h (mm)	-2.5	-2	-1.5	-1	-0.5	0	0.5	1	1.5	2	2.5
Surface Roughness Ra (µm)	3.702	3.661	3.526	3.372	3.461	3.111	2.568	3.037	3.112	3.451	3.511

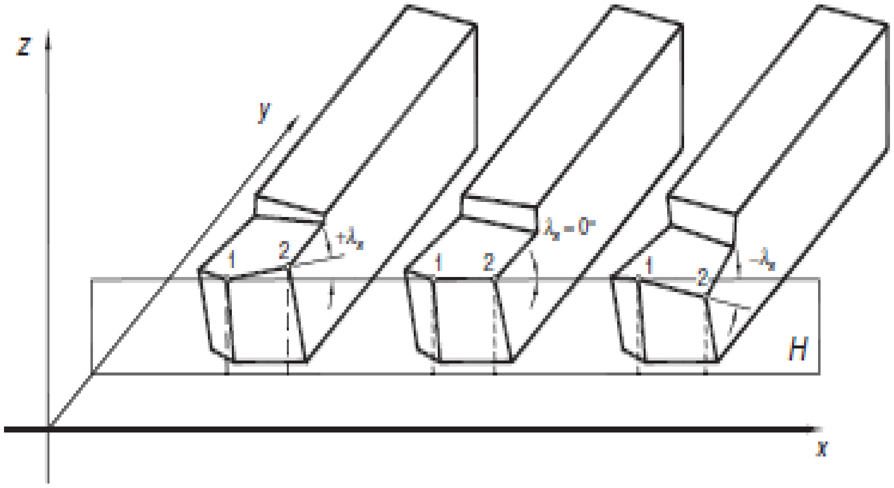

Figure (1) [10] Sense of the sign of the inclination angle (λ)

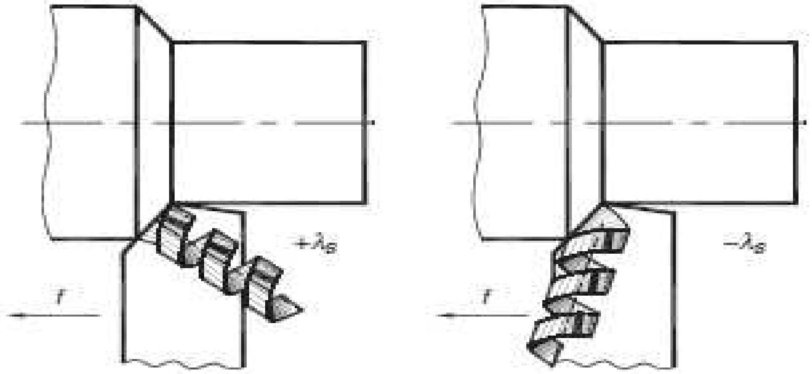

Figure (2) [10] Effect of the angle of inclination (λ) on the chip flow direction

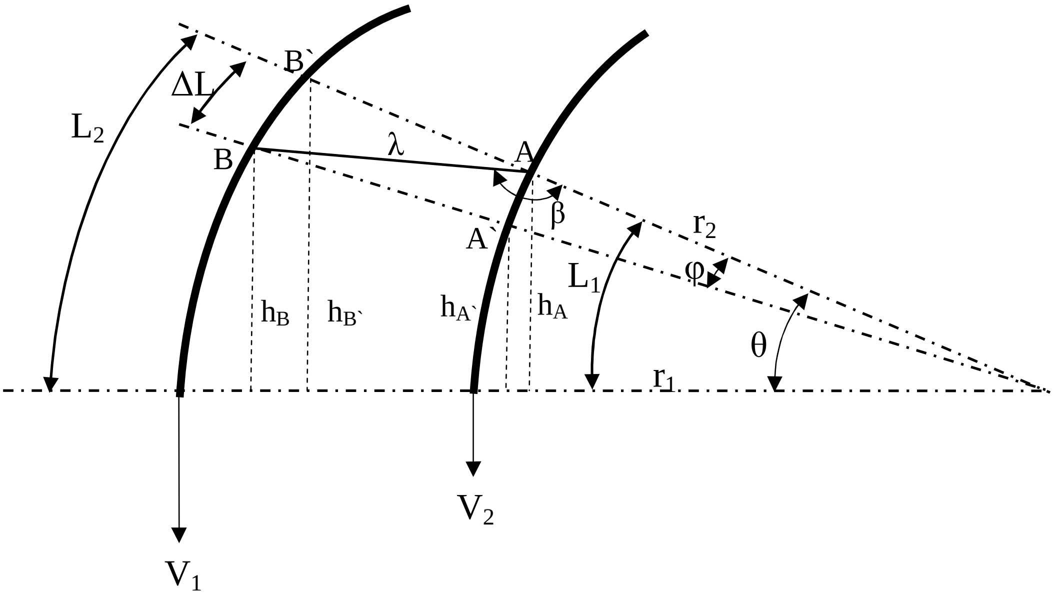

Figure (3) The proposed model to represent inclination angle and setting distance

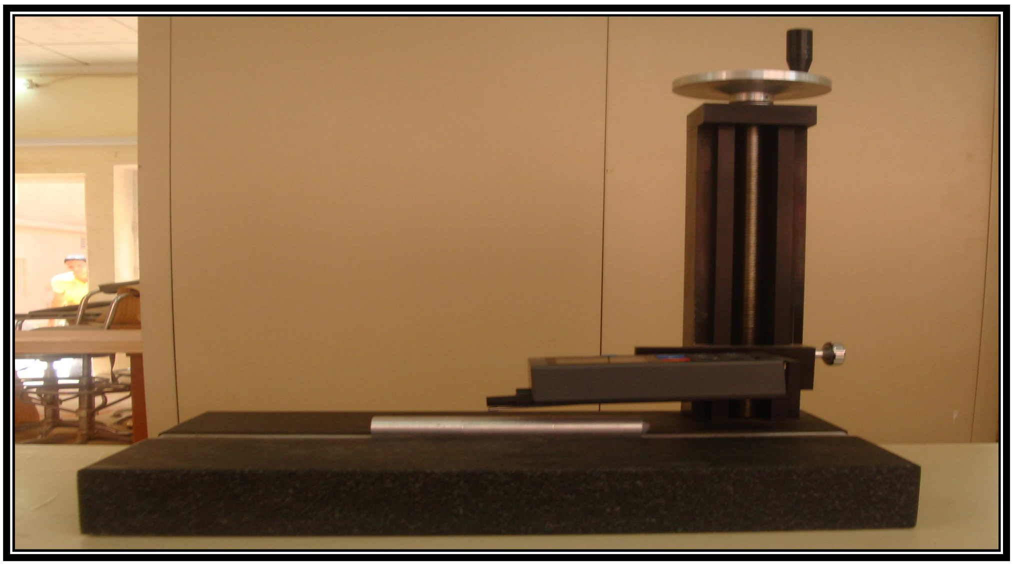

Figure (4) Instrument used for measuring surface roughness

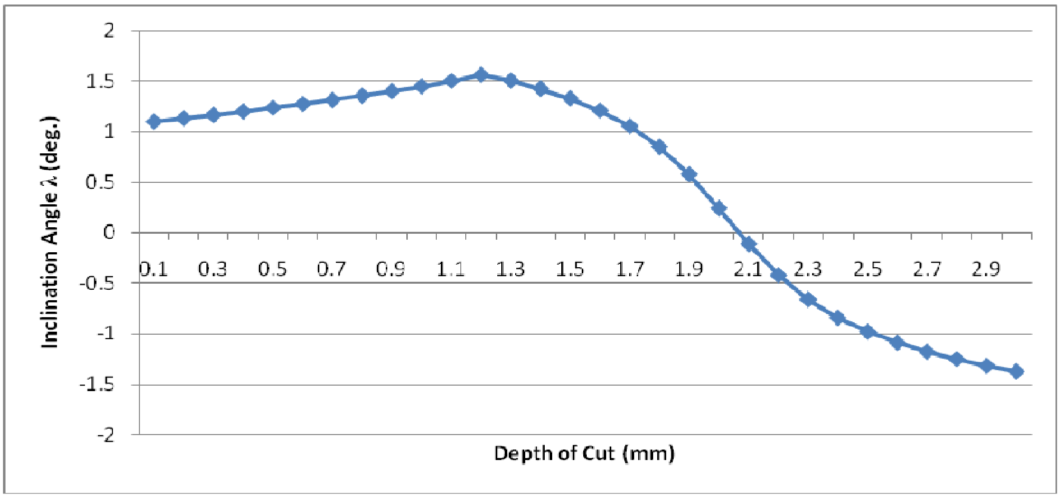

Figure (5) The suggested inclination angle with different depth of cut in finishing and roughing operations

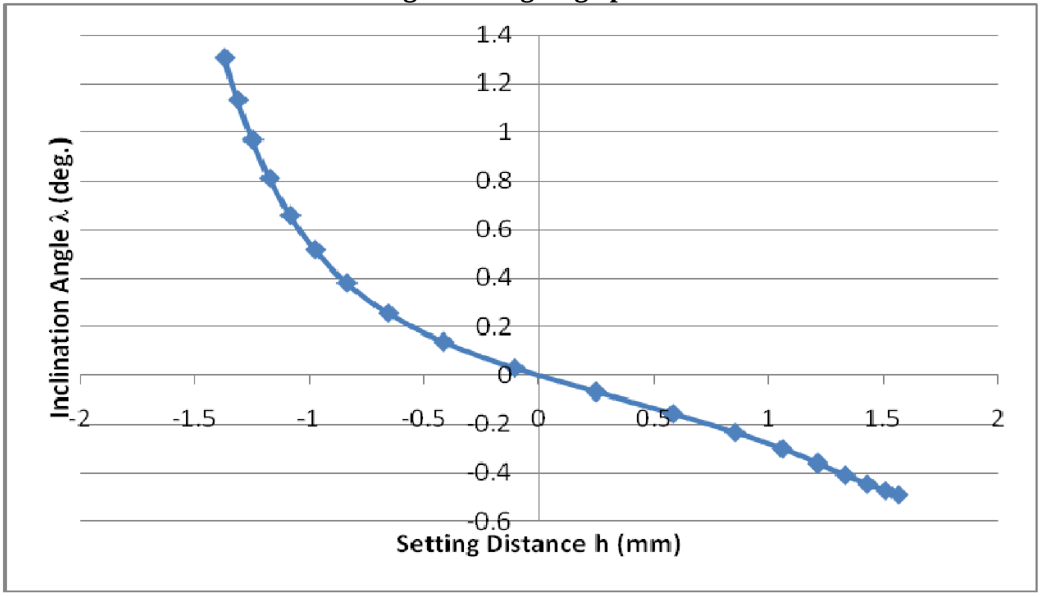

Figure (6) The relation between suggested inclination angle and setting distance

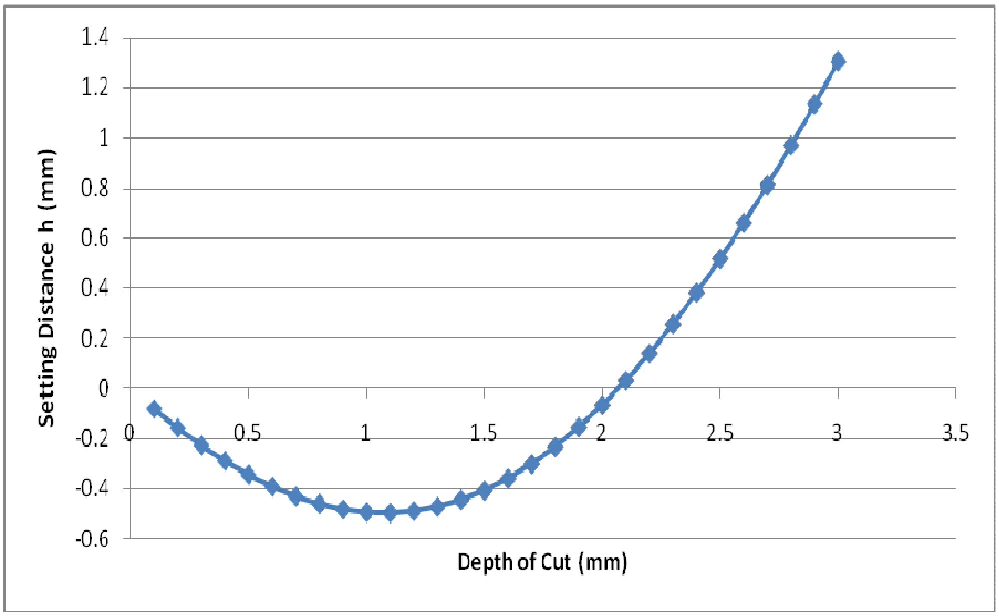

Figure (7) The calculated setting distance with different depth of cut

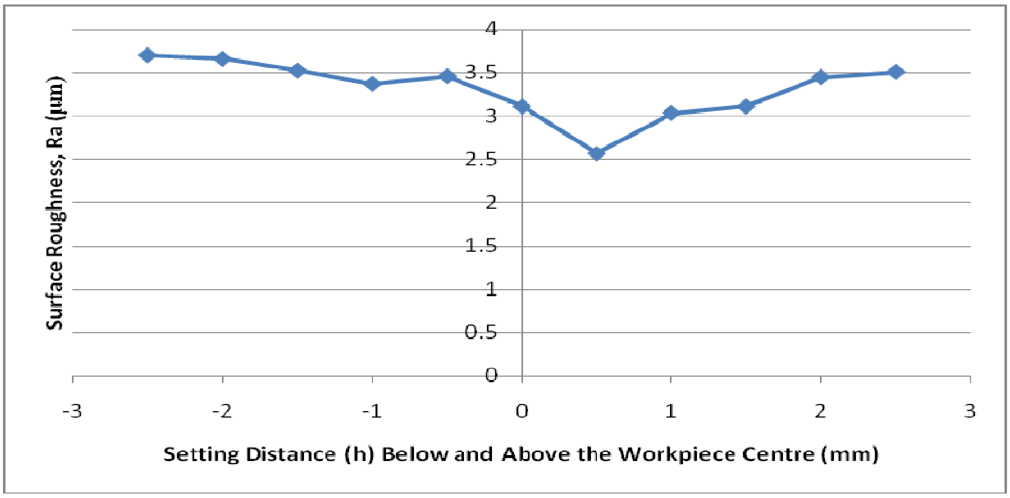

Figure (8) The surface roughness obtained from different setting distance, cutting speed 1200 rpm, feed rate 0.01 mm/rev, depth of cut 1 mm, and λ=0