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Experimental Investigation of Effect of Tool Length on Surface Roughness during Turning Operation and its Optimization

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Abstract: *In the turning operation, vibration is a frequent problem, which affects the result of the machining and in particular the surface finish. Tool life is also influenced by vibrations. Severe acoustic noise in the working environment frequently results as a dynamic motion between the cutting tool and the work piece. In all cutting operations like turning, boring and milling vibrations are induced due to deformation of the work piece. In the turning process, the importance of machining parameter choice is increased, as it controls the surface quality required. Tool overhang is a cutting tool parameter that has not been investigated in as much detail as some of the better known ones. It is appropriate to keep the tool overhang as short as possible; however, a longer tool overhang may be required depending on the geometry of the work piece and when using the hole-turning process in particular. In this study, we investigate the effects of changes in the tool overhang in the external turning process on both the surface quality of the work piece and tool wear. For this purpose, we used work pieces of AISI 1050 material with diameters of 20, 30, and 40 mm; and the surface roughness of the work piece were determined through experiments using constant cutting speed and feed rates with different depth of cuts (DOCs) and tool overhangs. We observed that the effect of the DOC on the surface roughness is negligible, but tool overhang is more important. The deflection of the cutting tool increases with tool overhang. Two different analytical methods were compared to determine the dependence of tool deflection on the tool overhang. Also, the real tool deflection values were determined using a comparator. We observed that the tool deflection values were quite compatible with the tool deflection results obtained using the second analytical method.*

Keywords: *Over hang Tool length, Surface Roughness, Optimization Turning operation, and Minitab,*

I. Introduction

Machining processes are manufacturing methods for ensuring processing quality, usually within relatively short periods and at low cost. Several machining parameters, such as cutting speed, feed rate, work piece material, and cutting tool geometry have significant effects on the process quality. Many researchers have studied the impact of these factors. The cutting tool overhang affects the surface quality, especially during the turning process, but this has not been reviewed much. Based on applications and theoretical approaches, it is known that cutting tools need to be clamped as short as possible to achieve the desired surface quality of the work piece. For the internal turning method in particular, the cutting tool should be attached with the proper length, not with the shortest distance. This situation may also be the case for external turning processes, depending on the work piece geometry. In this study, we investigate the effects of cutting tool overhang on both the surface quality in external turning processes. Because the tool holder is subject to bending and buckling depend on effect point of the cutting force (tangential force), cutting tool displaced. This situation has negative effects on the surface e quality as shown in Fig.1.

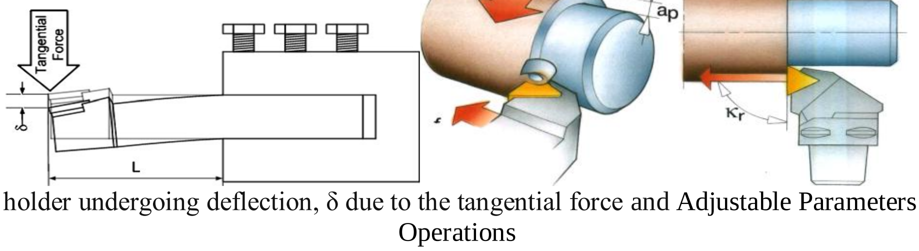


Fig 1: Tool holder undergoing deflection, δ due to the tangential force and Adjustable Parameters in Turning Operations

The determination of optimal cutting condition for specified surface roughness and accuracy of product are the key factors in the selection of machining process. Turning operations are associated with serious vibration-related problems. To reduce the problem of vibration and ensure that the desired shape and tolerance are achieved, extra care must be taken with production planning and in the preparations for the machining of a work-piece. A thorough investigation of the vibrations involved is therefore an important step toward solving the problem. In turning operation, the performances of cutting tools are depending on a few cutting conditions and parameters. The proper selection of feed rate has direct effect to the product surface roughness. Turning process by maximizing cutting speed and depth of cut will optimize the cutting process and minimize the production cost. The tool life, machined surface integrity and cutting forces are directly dependent on cutting parameters and will determine the cutting tool performances. The study of surface roughness form will resolve the characteristic and phenomena happening during the machining process. The questions to be answered at the end of the study are how the tool overhangs length and diameter influences the surface roughness during turning operation. The study was carried out to investigate the effects of cutting tool overhang on both the surface quality and cutting tool wear in external turning processes. Because the tool holder is subject to bending and buckling depend on effect point of the cutting force (tangential force), cutting tool displaced.(1) To evaluate the effects of different process parameter on turning operation.(2) To develop a mathematical model for predicting surface roughness for turning operation by using design of experiment approach.(3) Study the microstructure of the work piece turning operation. Machining operations tend to leave characteristic evidence on the machined surface. They usually leave finely spaced micro-irregularities that form a pattern known as surface finish or surface roughness. The quality of the finished product, on the other hand, relies on the process parameters; surface roughness is, therefore, a critical quality measure in many mechanical products. In the turning operation, chatter or vibration is a frequent problem affecting the result of the machining, and, in particular, the surface finish. Tool life is also influenced by vibration. Severe acoustic noise in the working environment frequently occurs as a result of dynamic motion between the cutting tool and the work piece. In order to achieve sufficient process stability, the metal removal rate is often reduced or the cutting tool changed. But as productivity is normally a priority in manufacturing, this is the wrong route to go. Instead the means of eliminating vibration and being able to machine at high rates should be examined. For these reason there have been research development with the objective of optimizing cutting condition to obtain a surface finish with making the process more stable. To study the optimum tool length and diameter bar used during cutting process will reduce the machining cost by reducing of changing the cutting tool and to increase the metal removal rate. The study has been conducted on the following scopes:(I) Turning machine (lathe) will be employed.(ii) Aluminum solid bar will be used as work piece materials.(iii) The different diameter of bar size 40 mm with HSS cutting tool will be used at various tool lengths.(iv) Cutting speed, feed and depth of cut are the other process factors investigated.(v) Performance will be primarily in terms of surface roughness (Ra Values); micro structure of the machined part will be briefly discussed.(vi) Design of Experiment technique will be used

II. Literature Review

Metal cutting is one of the most significant manufacturing processes (Chen & Smith, 1997) in the area of material removal. Black (1979) defines metal cutting as the removal of metal from a work piece in the form of chips in order to obtain a finished product with desired attributes of size, shape, and surface roughness. Drilling, sawing, turning, and milling are some of the processes used to remove material to produce specific products of high quality. The theory of metal cutting is very well established. However, some aspects have gone through revision when the experimental results showed the new parameters involved in metal cutting. Many new alloys have also been developed to react to today applications. As a result, there will be always a need for continuous research and improvement to tool materials, cutting conditions and parameters to optimize the output. Finnie (1956) first reported that the earliest documented works in metal cutting was done by Cocquilhat in 1851. Taylor in 1906 was investigated the effect of tool material during cutting. He was formulated the famous Taylors tool life equation ($VT_n = C$) and the equation is still valid until now and was used by researchers as a basis to show the performance of a given tool. The mechanics of metal cutting are very complex. Turning is used to produce rotational, typically axis symmetric, parts that have many features, such as holes, grooves, threads, tapers, various diameter steps, and even contoured surfaces. Parts that are fabricated completely through turning often include components that are used in limited quantities, perhaps for prototypes, such as custom designed shafts and fasteners. Turning is also commonly used as a secondary process to add or refine features on parts that were manufactured using a different process. Due to the high tolerances and surface finishes that turning can offer, it is ideal for adding precision rotational features to a part whose basic shape has already been formed. The work piece rotates in the lathe, with a certain spindle speed (n), at a certain number of revolutions per minute. In relation to the diameter of the work piece, at the point it is being machined, this will give rise to a cutting speed, or surface speed (Vc) in m/min that shown in Figure 2.5. This is the speed at which the cutting edge machines the surface of the work piece and it is the speed at which the periphery of the cut diameter passes the cutting edge. The cutting speed is only constant for as long as the spindle speed and/or part diameter remains the same. In a facing operation, where the tool is fed in towards the centre, the cutting speed will change progressively if the work piece rotates at a fixed spindle speed. On most modern CNC-lathes, the spindle speed is increased as the tool moves in towards the centre. For some of the cut, this makes up for the decreasing diameter but for very small diameters, and very close to the centre, this compensation will be impractical as the speed range on machines is limited. Also if a work piece, as is often the case, has different diameters or is tapered or curved, the cutting speed should be taken into account along the variations. The feed (f_n) in mm/rev is the movement of the tool in relation to the revolving work piece. This is a key value in determining the quality of the surface being machined and for ensuring that the chip formation is within the scope of the tool geometry. This value influences, not only how thick the chip is, but also how the chip forms against the insert geometry. The entering angle can be selected for accessibility and to enable the tool to machine in several feed directions, giving versatility and reducing the number of tools needed. Alternatively it can be made to provide the cutting edge with a larger corner and can add cutting edge strength by distributing machining pressure along a greater length of the cutting edge. It can also give strength to the tool at entry and exit of cut and it can direct forces to provide stability during the cut. The cutting depth (ap) in mm is the difference between un-cut and cut surface. It is half of the difference between the uncut and cut diameter of the work piece. The cutting depth is always measured at right angles to the feed direction of the tool. The entering angle can be selected for accessibility and to enable the tool to machine in several feed directions, giving versatility and reducing the number of tools needed. Alternatively it can be made to provide the cutting edge with a larger corner and can add cutting edge strength by distributing machining pressure along a greater length of the cutting edge. It can also give strength to the tool at entry and exit of cut and it can direct forces to provide stability during the cut. The cutting edge approach to the work-piece is expressed through the entering angle (kr). This is the angle between the cutting edge and the direction of feed and is an important angle in the basic selection of a turning tool for an operation. The necessary chip formation force required to overcome the developed stresses during chip formation process can be divided into three components: cutting force (*Fs*), feed force (*Fv*) and radial force (*Fp*). Cutting forces developed during turning are depicted in Fig. 2.4. Cutting force (*Fs*) acts against the work piece turning motion and forces the cutting tool downwards perpendicular to the work piece axis. Feed force (*Fv*) acts parallel to the work piece turning axis and is in the reverse direction of the feed. Radial force (F_p) acts perpendicularly to the machined surface and forces the cutting tool backwards. If a cutting tool fixed on the tool post is considered a cantilever beam as shown in Fig. 3, the deflection of the tool due to *Fs* force should be ideally zero during cutting.

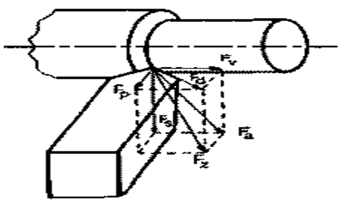


Fig 2: Cutting forces acting on the cutting tool during turning.

2.1Turning Material

In turning, the raw form of the material is a piece of stock from which the work pieces are cut. This stock is available in a variety of shapes such as solid cylindrical bars and hollow tubes. Custom extrusions or existing parts such as castings or forgings are also sometimes used. Turning can be performed on a variety of materials, including most metals and plastics. Fig 2 shows the shape of turning material. Common materials that are used in turning include aluminum, brass, magnesium, nickel, steel, thermoplastics, titanium and zinc. When selecting a material, several factors must be considered, including the cost, strength, resistance 9 to wear, and machine ability. The mach inability of a material is difficult to quantify, but can be said to posses the following characteristics.

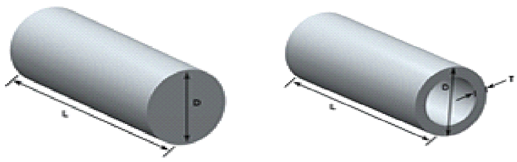


Fig 3: Types of material being machined

Aluminum is a soft, lightweight, malleable metal with appearance ranging from silvery to dull gray, depending on the surface roughness. The yield strength of pure aluminum is 7–11 MPa, while aluminum alloys have yield strengths ranging from 200 MPa to 600 MPa. Aluminum has about one-third the density and stiffness of steel. It is ductile, and easily machined, cast, and extruded. Aluminum is one of the few metals that retain full silvery reflectance in finely powdered form, making it an important component of silver paints. Aluminum is a good thermal and electrical conductor, by weight better than copper. Aluminum is capable of being a superconductor, with a superconducting critical temperature of 1.2 Kelvin and a critical magnetic field of about 100 gauss. In turning, the speed and motion of the cutting tool is specified through several parameters. These parameters are selected for each operation based upon the work piece material, tool material, tool size, and more. Turning parameter that can affect the process is: Cutting speed -The speed of the work piece surface relative to the edge of the cutting tool during a cut, measured in surface feet per minute (SFM).Spindle speed - The rotational speed of the spindle and the work piece in Revolutions per minute (RPM), the spindle speed is equal to the cutting speed divided by the circumference of the work piece where the cut is being made. In order to maintain a constant cutting speed, the spindle speed must vary based on the diameter of the cut. If the spindle speed is held constant, then the cutting speed will vary. Feed rate - The speed of the cutting tool's movement relative to the work piece as the tool makes a cut. The feed rate is measured in millimeter per revolution (RPM) Axial depth of cut - The depth of the tool along the axis of the work piece as it makes a cut, as in a facing operation. Radial depth of cut - The depth of the tool along the radius of the work piece as it makes a cut, as in a turning or boring operation. A large radial depth of cut will require a low feed rate, or else it will result in a high load on the tool and reduce the tool life.This study was fundamentally based on an axiom which states that if tool over hang is increased while machining a work piece the surface roughness of the work piece increases i.e. surface quality decreases. The whole idea behind this experimentation is to determine as what material is affected by how much when undergone such changes in the tool over hang.

III. Experimental Setup

In this study, we selected the work piece diameter, DOCs and tool overhang as variable experimental parameters and measured the surface roughness of the work piece and cutting. Our experimental studies were carried using a conventional lathe. As the cutting tool, we used P10 grade-coated sintered carbide and HSS inserts (the standard DNMG150608 and PDJNR2525 type tool holders) in dynamometer. The work pieces used in the experiments were 40 mm in diameter. The literature survey provided information about selection of the work piece diameter, and these values lay in the range 23–100 mm. In the present study, we selected work pieces of materials and diameters that are widely used in industrial applications. We used a tailstock to prevent deflection of slender work pieces during machining operations, and the work piece length was kept short to establish a more rigid setup. As the work piece material, we selected the quite commonly preferred steel in the manufacturing industry, AISI 1050. This material contains 0.48–0.55% C, 0.17% Mn, and 0.69% Si, and has a hardness value of between 175 and 207 HV, depending on the applied heat treatment. The tool overhang lengths were 23, 28 and 33 mm. The DOCs we selected were 0.25, 0.5 and 1.0 mm. The cutting speed and feed rate were selected as 315, 500 and 775 rpm and 0.045 mm/rev (at constant values), respectively. The external turning processes were carried out using the anticipated parameters. The processes can be seen Fig 4.

Fig 4: Turning process, testing under way and Lathe Tool Dynamometer

A Mitutoyo Surf test SJ-400 Portable Surface Roughness Tester measuring instrument show in Figure 3.4 was used to process the measured profile data. The SJ-400 is capable of evaluating surface textures including waviness with the variety of parameters according to various digitally/graphically on the touch panel and output to built-in printer. The stylus of the SJ-400 detector unit traces the minute irregularities of the work piece surface. Surface roughness is determined from the vertical stylus displacement produced during the detector traversing over the surface irregularities and the measuring setup shows in Fig 4. The Lathe Tool Dynamometer has been designed so that it can be directly fixed on to the tool post using the hole provided on the dynamometer. The dynamometer can measure 3 forces in mutually perpendicular directions, i.e. horizontal, vertical and thrust, and is provided with 3 connector sockets. Instrument comprises of three independent digital display calibrated to display force directly using three component tool dynamometer. This instrument comprises independent DC excitation supply for feeding strain gauge bridges, signal processing system to process and compute respective force value for direct independent display in kgf units. Instrument operates on 230v, 50 c/s

AC mains. Size – 150x475x270 mm nominal. Cutting condition need to setup in this experiment, to make sure all the experiment run follow according the data given. A fractional factorial is selected so that all intersection between the independent variables could be investigated. The dependent variable is the resulting first 58 cut surface roughness. The level was selected to cover the normal cutting operation.

IV. Experimental Results

The study was undertaken to investigate the effect of process parameters on surface roughness, tool wear and chip formation produced by turning operation when turning solid material Aluminum, Brass and mild steel. Machining data of surface roughness, tool wears and chip formation were tabulated accordingly. A Portable Surface Roughness Tester measuring instrument was used to process the measured profile data. Surface roughness is determined from the vertical stylus displacement produced during the detector traversing over the surface irregularities. The chips were collected from time to time for further investigation. For surface roughness analysis, the result from the performance of the turning operating produced as per experimental plan is also shown in Table 1. The average value of surface roughness (Ra) result was plotted on a graph to acquire a better understanding of the results.

Table 1 for Aluminum machined by HSS for tool overhang 23mm

S.NO	Bar Diameter	Cutting Speed	Feed Rate	Depth Of Cut	Tool Overhang	Fx	Fy	Fz
	(mm)	(rpm)	(mm/rev)	(mm)	(mm)	(N)	(N)	(N)
1	40	315	0.045	1	23	20	80	10
2	40	315	0.045	0.5	23	20	10	10
3	40	315	0.045	0.25	23	20	20	0
4	40	500	0.045	1	23	30	10	90
5	40	500	0.045	0.5	23	10	40	10
6	40	500	0.045	0.25	23	10	20	10
7	40	775	0.045	1	23	20	40	10
8	40	775	0.045	0.5	23	20	20	10
9	40	775	0.045	0.25	23	10	10	40

Table 2 for Aluminum machined by HSS for tool overhang 28mm

SNO	Bar Diameter	Cutting Speed	Feed Rate	Depth Of Cut	Tool Overhang	Fx	Fy	Fz
	(mm)	(rpm)	(mm/rev)	(mm)	(mm)	(N)	(N)	(N)
1	40	315	0.045	1	28	10	10	10
2	40	315	0.045	0.5	28	20	10	10
3	40	315	0.045	0.25	28	10	30	0
4	40	500	0.045	1	28	10	10	20
5	40	500	0.045	0.5	28	10	20	10
6	40	500	0.045	0.25	28	10	20	0
7	40	775	0.045	1	28	20	20	20
8	40	775	0.045	0.5	28	20	20	10
9	40	775	0.045	0.25	28	10	0	10

V. Experimental Results For Surface Roughness (Ra) Values Determined

The average values of surface roughness (Ra) result determine the surface roughness achieved when tool over hang is varied for different materials. Without performing any transformation on the responses, the revealed design status was evaluated. Following are the experimental results of surface roughness (Ra) values for aluminum rods of different diameters.

Table 3: Surface roughness (Ra) values for Aluminum 30mm rod

S.NO	Depth Of Cut	Speed	Tool Overhang	Surface Roughness	Deflection	MRR	Tool life
	(mm)	(rpm)	(mm)	**(µm)**	(mm)	(mm^3/min)	mins
1	1	315	28	1.5	$6.353*10^{-3}$	3.12	1780.38
2	0.5	315	28	0.9	$1.270*10^{-2}$	4.16	890.19
3	0.25	315	28	0.6	$1.906*10^{-2}$	4.16	445.09
4	1	500	28	1.4	$1.270*10^{-2}$	3.12	2826
5	0.5	500	28	0.5	$1.270*10^{-2}$	2.08	1413
6	0.25	500	28	0.4	$1.270*10^{-2}$	2.08	706.5
7	1	775	28	1.2	$1.270*10^{-2}$	2.08	4380.3
8	0.5	775	28	0.5	$1.270*10^{-2}$	3.12	2190.15
9	0.25	775	28	0.2	$6.350*10^{-3}$	1.04	1095.07

Table 4 Surface roughness (Ra) values for Aluminum 33mm rod

S.NO	Depth Of Cut	Speed	Tool Overhang	Surface Roughness	Deflection	MRR	Tool life
	(mm)	(rpm)	(mm)	(µm)	(mm)	(mm^3/min)	mins
1	1	315	33	2.2	$3.120*10^{-2}$	3.12	1780.38
2	0.5	315	33	1.9	$4.160*10^{-2}$	4.16	890.19
3	0.25	315	33	1.5	$4.160*10^{-2}$	4.16	445.09
4	1	500	33	1.9	$3.120*10^{-2}$	3.12	2826
5	0.5	500	33	1.4	$2.080*10^{-2}$	2.08	1413
6	0.25	500	33	1.2	$2.080*10^{-2}$	2.08	706.5
7	1	775	33	1.8	$2.080*10^{-2}$	2.08	4380.3
8	0.5	775	33	1.3	$3.120*10^{-2}$	3.12	2190.15
9	0.25	775	33	1.1	$1.040*10^{-2}$	1.04	1095.07

VI. Minitab

In this work the general features of Minitab Version 13 statistical analysis software, as well as some specialized features for conducting statistical analysis is used. Statistical analysis computer applications have the advantage of being accurate, reliable, and generally faster than computing statistics and drawing graphs by hand. Minitab is relatively easy to use once you know a few fundamentals. The response function software package calculates the values of these coefficients and also to determine the significant direct and representing the output performance can be expressed as Y=f (V, F, A) Where Y = the response or yield, the values of the coefficients of the polynomial were calculated by regression method. The magnitude of the regression co-efficient is a good indication of the significance of the parameters. A statistical analysis interaction effects precisely. For the required response, all of the 9 observed values are given to the software as input. The significance of the coefficients was evaluated and insignificant coefficients are not included in the model. As per this technique, the calculated value of the F-ratio of the model developed does not exceed the standard tabulated value of F-Ratio for a desired level of confidence say 95 %.

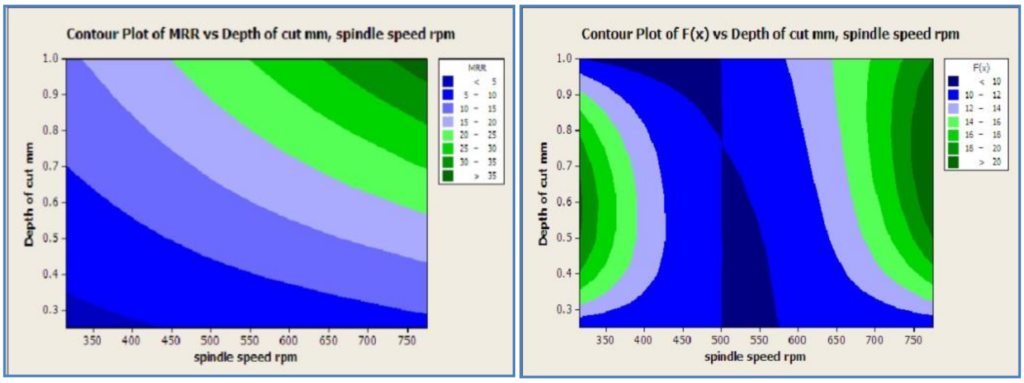


Fig 5: Contour plot of MRR vs spindle speed rpm, Depth of cut m

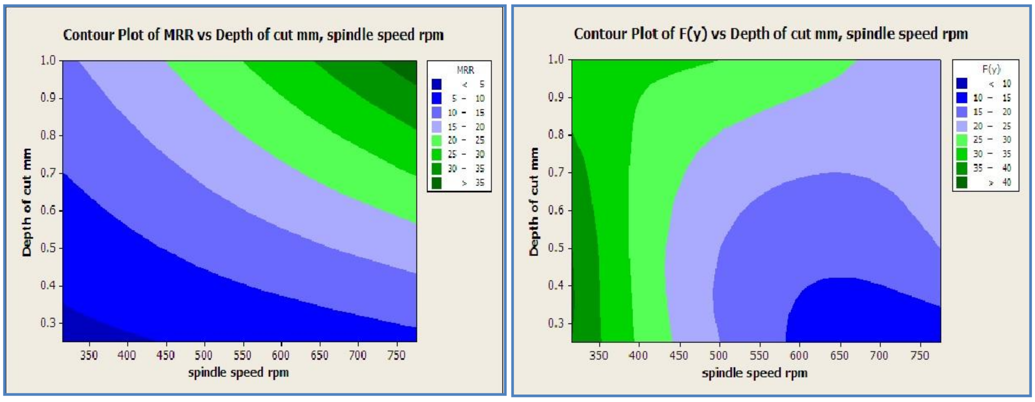


Fig 6: Contour plot of MRR vs spindle speed rpm and Contour plot of Fx vs. spindle speed rpm.

The regression equation for F(x) = 25.8 - 0.0268 spindle speed rpm + 4.76 Depth of cut mm
The regression equation for F(y) = 45.6 - 0.0420 spindle speed rpm + 3.81 Depth of cut mm

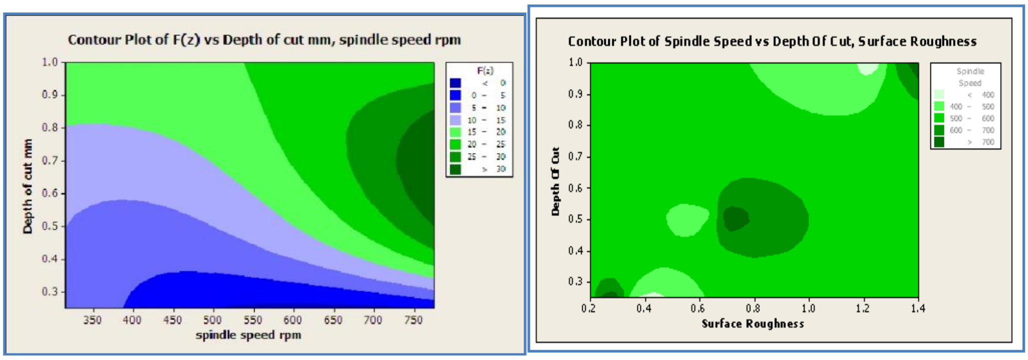


Fig 7: Contour plot for Fz vs. spindle speed rpm, Depth of cut mm

VII. Results And Discussions

Three major issue product surface integrity, tool performance. These will relate all research area in metal cutting. The influence of cutting condition will be discussed when evaluating the surface roughness. The results obtained from the experiments test using different cutting tool length parameter diameter when turning Aluminum showed that surface roughness were produced differently. Generally, when a short tool length is used, the surface roughness is always good, ranging from 0.75 to 3.41 µm. Within this range of surface roughness, the best result is obtained at a cutting speed (S) of 315 m/min at low feed rate 0.0415 mm/rev. From the result, it can be concluded that using a short tool length always provide good surface roughness in a turning boring operation, no matter what cutting parameter or type of boring bar used. In fact, only a slight improvement on surface roughness can be achieved when setting the cutting speed (S), feed rate (f) or depth of cut (doc) to the values specified above. At this point, it can be observed that turning operation using a long tool length may set excessive vibrations that decrease the surface quality.

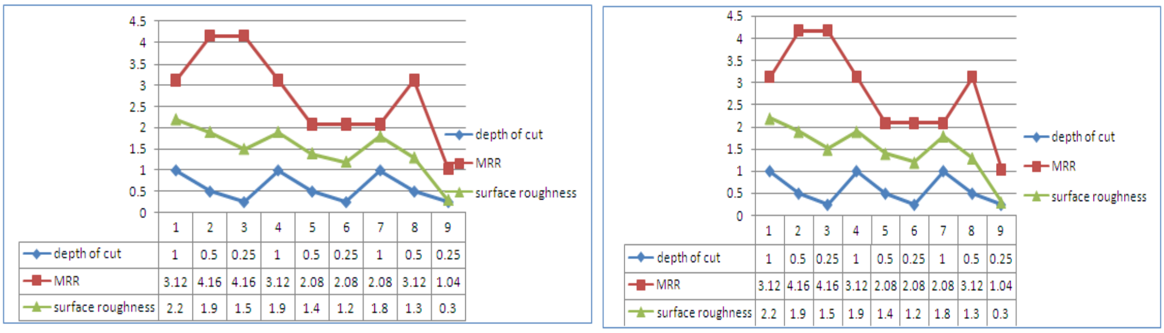


Fig 8: Aluminum 23 and 28 mm of surface roughness (Ra) Vs MRR Vs Depth of cut

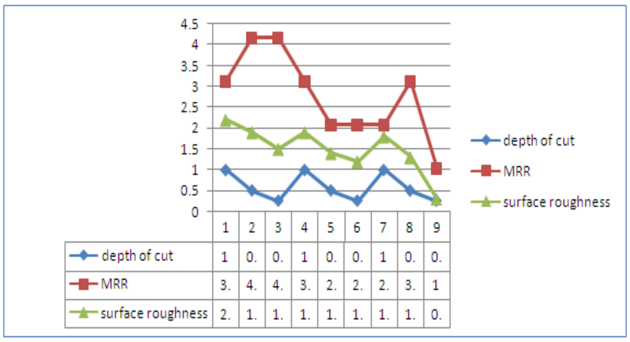
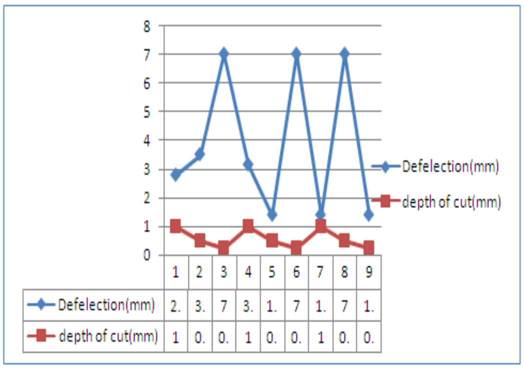


Fig 9: Aluminum 33mm of surface roughness (Ra) Vs MRR Vs Depth of cut



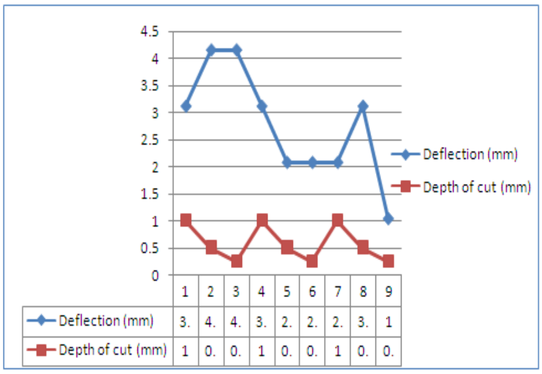


Fig 10: Variation of Deflection with respect to Depth of cut at tool overhangs 23 and 33 mm

VIII. Conclusion

In this study, we investigated the effects of the changes in tool overhang on the surface quality of the work piece, its microstructure and deflection of the tool experimentally.1. From the experiments performed on the machining parameters, we observed that the surface roughness of work piece increases as the tool overhang increases. 2. Using the same tool overhang, the surface roughness of the work piece increases as the DOC increases. These results are compatible with the literature. 3. In the measurements performed after the experiments were complete, we observed that the cutting tool deflection values increased as the tool overhang increased. 4. Depth of cut parameter adversely affects surface finish. 5. The maximum deviation observed and estimated by Minitab is very minimal and within the recommended regions of MRR in turning. 6. The predicted values of Minitab output can be further precisely predicted with the change of structure and the weights to the system by increasing the number of experiments. 7. The MRR equation shows that the depth of cut is the main factor affecting 8. The results also revealed that using a long tool length may set excessive vibrations that could be efficiently controlled by the use of short tool length. With a long tool length, the cutting variables become important factors to control in order to significantly improve surface roughness results no matter what type of bar is used. With the increasing competitiveness as observed in the recent times, manufacturing systems in the industry are being driven more and more aggressively. So there is always need for perpetual improvements. Thus for getting still more accurate results we can take into account few more parameters as given as (1) CNC machines can be used for experimentation to have the better control of the process variables and also parameters can be set to the desired accuracy.(2)The present work can be extended with different diameter of TURNING tools, process parameters, material thickness, other combinations of machine and type to test the ability of the expert systems in prediction of the output which the findings can be applied for indirect tool condition monitoring in unmanned manufacturing system.(3) The experiments can be conducted for constant time period instead of constant volume.(4) Further research can be extended on temperature measurements.(5) The force signals generated in the present work was collected by a dynamometer, which is relatively expensive and usually inconvenient for industrial applications.

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