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Enhancement of Turning Parameters and Tool Wear On AISI 1045 Using Standard Element Analysis

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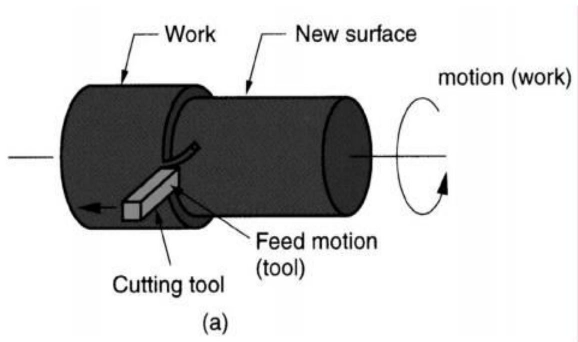
Abstract — Quality and productivity play significant role in today's manufacturing market. From customers' viewpoint quality is very important because the extent of quality of the procured item (or product) influences the degree of satisfaction of the consumers during usage of the procured goods. Therefore, every manufacturing or production unit should concern about the quality of the product. Apart from quality, there exists another criterion, called productivity which is directly related to the profit level and also goodwill of the organization. Every manufacturing industry aims at producing a large number of products within relatively lesser time. But it is felt that reduction in manufacturing time may cause severe quality loss. , The study aimed at evaluating the best process environment which could simultaneously satisfy requirements of both quality and as well as productivity with special emphasis on reduction of cutting tool flank wear. Because reduction in flank wear ensures increase in tool life. The predicted optimal setting ensured minimization of surface roughness, height of flank wear of the cutting tool and maximization of MRR (Material Removal Rate). In view of the fact, that traditional Taguchi method cannot solve a multi-objective optimization problem; to overcome this limitation grey relational theory has been coupled with Taguchi method. Furthermore to follow the basic assumption of Taguchi method i.e. quality attributes should be uncorrelated or independent. But is practical case it may not be so. To overcome this shortcoming the study applied Principal Component analysis (PCA) to eliminate response correlation that exists between the responses and to evaluate independent or uncorrelated quality indices called Principal Components. Finally the study combined PCA, grey analysis, utility concept and Taguchi method for predicting the optimal setting. Optimal result was verified through confirmatory test. This indicates application feasibility of the aforesaid techniques for correlated multi-response optimization and off-line quality control in turning operation.

Keywords— quality, productivity, straight turning, surface roughness, MRR (Material Removal Rate), flank wear, grey-Taguchi method, Principal Component analysis (PCA)



1.INTRODUCTION

Turning is the removal of metal from the outer diameter of a rotating cylindrical work piece. Turning is used to reduce the diameter of the work piece, usually to a specified dimension, and to produce a smooth finish on the metal. Often the work piece will be turned so that adjacent sections have different diameters.

Turning is the machining operation that produces cylindrical parts. In its basic form, it can be defined as the machining of an external surface:

- With the work piece rotating.
- With a single-point cutting tool, and
- With the cutting tool feeding parallel to the axis of the work piece and at a distance that will remove the outer surface of the work.

Taper turning is practically the same, except that the cutter path is at an angle to the work axis. Similarly, in contour turning, the distance of the cutter from the work axis is varied to produce the desired shape. Even though a single-point tool is specified, this does not exclude multiple-tool setups, which are often employed in turning. In such setups, each tool operates independently as a single-point cutter

Fig. 1: Adjustable parameters in turning operation

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II. ADJUSTABLE CUTTING FACTORS IN TURNING

The three primary factors in any basic turning operation are speed, feed, and depth of cut. Other factors such as kind of material and type of tool have a large influence, of course, but these three are the ones the operator can change by adjusting the controls, right at the machine.

Speed:

Speed always refers to the spindle and the work piece. When it is stated in revolutions per minute (rpm) it tells their rotating speed. But the important feature for a particular turning operation is the surface speed, or the speed at which the work piece material is moving past the cutting tool. It is simply the product of the rotating speed times the circumference of the work piece before the cut is started. It is expressed in meter per minute (m/min), and it refers only to the work piece. Every different diameter on a work piece will have a different cutting speed, even though the rotating speed remains the same

$$V = \pi DN / 1000 \text{ m min-1}$$

Here, v is the cutting speed in turning, Dis the initial diameter of the work piece in mm, and N is the spindle speed in RPM.

Feed:

Feed always refers to the cutting tool, and it is the rate at which the tool advances along its cutting path. On most power-fed lathes, the feed rate is directly related to the spindle speed and is expressed in mm (of tool advance) per revolution (of the spindle), or mm/rev.

$$Fm = f * N \; mm.\,min{-1}$$

Here, Fm is the feed in mm per minute, f is the feed in mm/rev and N is the spindle speed in r.p.m.

Depth of Cut:

Depth of cut is practically self explanatory. It is the thickness of the layer being removed (in a single pass) from the work piece or the distance from the uncut surface of the work to the cut surface, expressed in mm. It is important to note, though, that the diameter of the work piece is reduced by two times the depth of cut because this layer is being removed from both sides of the work.

III. CUTTING TOOLS FOR LATHES: TOOL GEOMETRY

Tool Geometry:

For cutting tools, geometry depends mainly on the properties of the tool material and the work material. The standard terminology is shown in the following figure. For single point tools, the most important angles are the rake angles and the end and side relief angles.

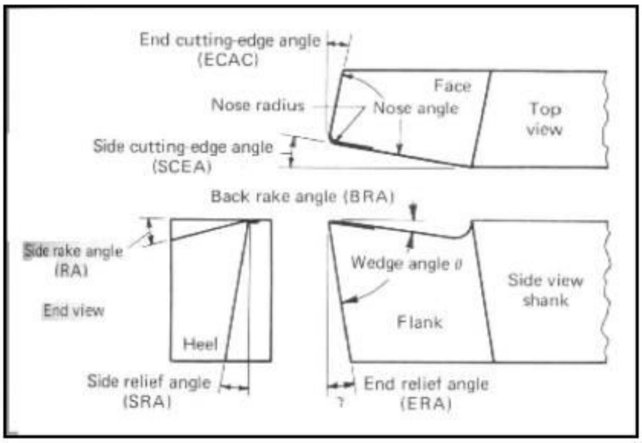

Fig. 2: Geometry of a single point turning tool

Flank:

A flat surface of a single-point tool that is adjacent to the face of the tool. During turning, the side flank faces the direction that the tool is fed into the work piece, and the end flank passes over the newly machined surface.

Face: The flat surface of a single point tool through which, the work piece rotates during turning operation. On a typical turning setup, the face of the tool is positioned upwards.

Back rake angle:

If viewed from the side facing the end of the work piece, it is the angle formed by the face of the tool and a line parallel to the floor. A positive back rake angle tilts the tool face back, and a negative angle tilts it forward and up.

Side rake angle:

If viewed behind the tool down the length of the tool holder, it is the angle formed by the face of the tool and the centerline of the work piece. A positive side rake angle tilts the tool face down toward the floor, and a negative angle tilts the face up and toward the work piece.

Side cutting edge angle:

If viewed from above looking down on the cutting tool, it is the angle formed by the side flank of the tool and a line perpendicular to the work piece centerline. A positive side cutting edge angle moves the side flank into the cut, and a negative angle moves the side flank out of the cut.

End cutting edge angle:

If viewed from above looking down on the cutting tool, it is the angle formed by the end flank of the tool and a line parallel to the work piece centerline. Increasing the end cutting edge angle tilts the far end of the cutting edge away from the work piece.

Side relief angle:

If viewed behind the tool down the length of the tool holder, it is the angle formed by the side flank of the tool and a vertical line down to the floor. Increasing the side relief angle tilts the side flank away from the work piece.

End relief angle:

If viewed from the side facing the end of the work piece, it is the angle formed by the end flank of the tool and a vertical line down to the floor. Increasing the end relief angle tilts the end flank away from the work piece.

Nose radius:

It is the rounded tip on the cutting edge of a single point tool. A zero degree nose radius creates a sharp point of the cutting tool.

IV. TOOL WEAR

Tool wear in machining is defined as the amount of volume loss of tool material on the contact surface due to the interactions between the tool and work piece. Specifically, tool wear is described by wear rate (volume loss per unit area per unit time) and is strongly determined by temperature, stresses, and relative sliding velocity generated at the contact interface.

Metal cutting tools are subjected to extremely arduous conditions, high surface loads, and high surface temperatures arise because the chip slides at high speed along the tool rake face while exerting very high normal pressures (and friction force) on this face. The forces may be fluctuating due to the presence of hard particles in the component microstructure, or more extremely, when interrupted cutting is being carried out. Hence cutting tools need:

Strength at elevated temperatures High toughness— & High hardness High wear resistance.

During the past 100 years there has been extensive research and development which has provided continuous improvement in the capability of cutting tool. A key factor in the wear rate of virtually all tool materials is the temperature reached during operation; unfortunately it is difficult to establish the values of the parameters needed for such calculations. However, experimental measurements have provided the basis for empirical approaches. It is common to assume that all the energy used in cutting is converted to heat (a reasonable assumption) and that 80% of this is carried away in the chip (this will vary and depend upon several factors - particularly the cutting speed). This leaves about 20% of the heat generated going into the cutting tool. Even when cutting mild steel tool temperatures can exceed 550oC, the maximum temperature high speed steel (HSS) can withstand without losing some hardness. Cutting hard steels with cubic boron nitride tools will result in tool and chip temperatures in excess of 1000oC. During operation, one or more of the following wear modes may occur:

(a) Flank
(b) Notch
(c) Crater
(d) Edge rounding Edge chipping
(e) Edge cracking
(f) Catastrophic failure

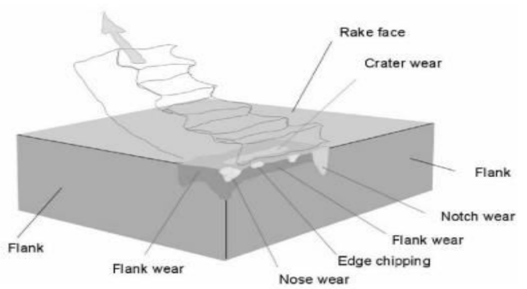

Fig. 3: Different modes of wear

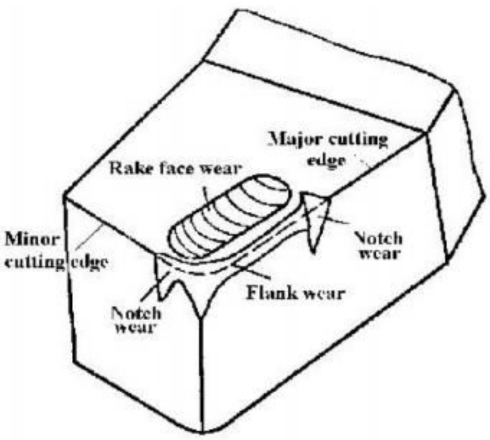

Fig. 4: Tool wear phenomena

Cutting tools are subjected to an extremely severe rubbing process. They are in metalto-metal contact between the chip and work piece, under conditions of very high stress at high temperature. The situation is further aggravated (worsened) due to the existence of extreme stress and temperature gradients near the surface of the tool. During machining, cutting tools remove material from the component to achieve the required shape, dimension and surface roughness (finish). However, wear occurs during the cutting action, and it will ultimately result in the failure of the cutting tool. When the tool wear reaches a certain extent, the tool or active edge has to be replaced to guarantee the desired cutting action.

Rake face wear:

Crater wears:

The chip flows across the rake face, resulting in severe friction between the chip and rake face, and leaves a scar on the rake face which usually parallels to the major cutting edge. The crater wear can increase the working rake angle and reduce the cutting force, but it will also weaken the strength of the cutting edge. The parameters used to measure the crater wear can be seen in the diagram. The crater depth KT is the most commonly used parameter in evaluating the rake face wear.

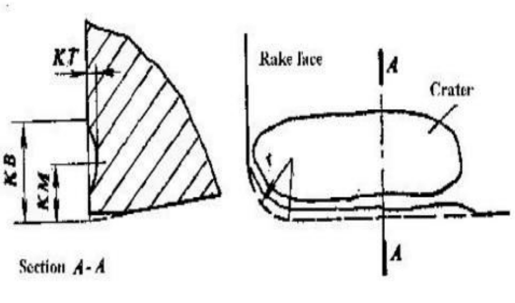

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Fig. 5: Crater wear

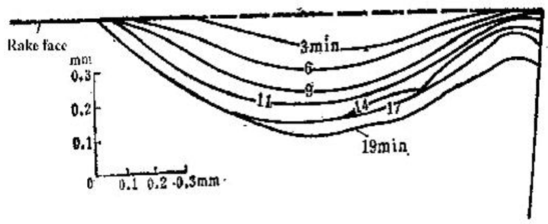

Fig. 6:Crater wear and wear depth KT and width KB with cutting time

Flank wear (Clearance surface): Wear on the flank (relief) face is called Flank wear and results in the formation of a wear land. Wear land formation is not always uniform along the major and minor cutting edges of the tool. Flank wear most commonly results from abrasive wear of the cutting edge against the machined surface. Flank wear can be monitored in production by examining the tool or by Fig. 4: Tool wear phenomena

Flank wear can be measured by using the average and maximum wear land size VB and VBmax.

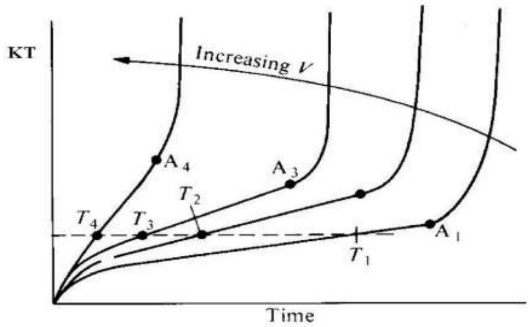

Fig.7: Effects of cutting speed V and cutting time T on crater wear depth KT

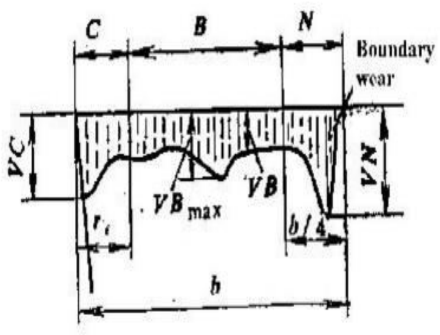

Fig.8: Flank wear

V. RELATED WORKS

M.S.Chua, M.Rahman,(1993). Developed a process planning or NC part programming, optimal cutting conditions are to be determined using reliable mathematical models representing the machining conditions of a particular work tool combinations. In this the mathematical models for Tin-coated carbide tools and Rochling T4 medium carbon steel were developed then used in the formulation of objective and constraint function for the optimization of a multipass turning operation.

Youssef.A(1994), Investigated on comparison of three different experimental designs aimed at studying the effects of cutting parameters variation on surface finish. The results revealed that the effect obtained by analyzing both the factorial (16trails) and taguchi (16 trails) design were comparable to those obtained by the full factorial design (288 trails) only the most important effects on surface roughness, feed rate(f) and tool nose radius (r) were reveled using these screening designs

Marc Thomas, Yves Beauchamp(1996), Investigated on cutting parameter effects of surface roughness in a lathe dry boring operation the results revealed that using short tool length always provide good surface roughness and that only slight improvement on surface roughness can achieved by properly controlling the cutting parameters and for the type of boring bar used the results also revealed that using a long tool length may set excessive vibrations that could be effectively controlled by the use of a damped boring bar.

.Dimla Sr, P.M.Lister(2000) examined on tool wear depend upon the vibration and cutting tool forces acting on a tool experimental setup was proposed to find dynamic and static forces by implementing experimental and analytical method for one such techniques involving the use of three mutually perpendicular components of the cutting forces and vibration signature mesurments.

L.J.Xie, J.Schmidt(2005) Developed a new program for predict tool wear in turning operation by the integrating ABAQUS/explicit and ABAQUS/standard with python user program to perform the 2D tool wear estimation in orthogonal cutting of turning operation.

Ahmed (2006) developed the methodology required for obtaining optimal process parameters for prediction of surface roughness in Al turning. For development of empirical model nonlinear regression analysis with logarithmic data transformation was applied. The developed model showed small errors and satisfactory results. The study concluded that low feed rate was good to produce reduced surface roughness and also the high speed could produce high surface quality within the experimental domain.

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Kassab and Khoshnaw (2007) examined the correlation between surface roughness and cutting tool vibration for turning operation. The process parameters were cutting speed, depth of cut, feed rate and tool overhanging. The experiments were carried out on lathe using dry turning (no cutting fluid) operation of medium carbon steel with different level of aforesaid process parameters. Dry turning was helpful for good correlation between surface roughness and cutting tool vibration because of clean environment. The authors developed good correlation between the cutting tool vibration and surface roughness for controlling the surface finish of the work pieces during mass production. The study concluded that the surface roughness of work piece was observed to be affected more by cutting tool acceleration; acceleration increased with overhang of cutting tool. Surface roughness was found to be increased with increase in feed rate.

Mahmoud and Abdelkarim (2006) studied on turning operation using High-Speed Steel (HSS) cutting tool with 450 approach angle. This tool showed that it could perform cutting operation at higher speed and longer tool life than traditional tool with 900 approach angle. The study finally determined optimal cutting speed for high production rate and minimum cost, tool like, production time and operation costs

Natarajan et al. (2007) presented the on-line tool wear monitoring technique in turning operation. Spindle speed, feed, depth of cut, cutting force, spindle-motor power and temperature were selected as the input parameters for the monitoring technique. For finding out the extent of tool wear; two methods of Hidden Markov Model (HMM) such as the Bar-graph Method and the Multiple Modeling Methods were used. A decision fusion centre algorithm (DFCA) was used for increasing the reliability of this output which combined the outputs of the individual methods to make a global decision about the wear status of the tool. Finally, all the proposed methods were combined in a DFCA to determine the wear status of the tool during the turning operations.

Ozel et al. (2007) carried out finish turning of AISI D2 steels (60 HRC) using ceramic wiper (multi-radii) design inserts for surface finish and tool flank wear investigation. For prediction of surface roughness and tool flank wear multiple linear regression models and neural network models were developed. Neural network based predictions of surface roughness and tool flank wear were carried out, compared with a non-training experimental data and the results thereof showed that the proposed neural network models were efficient to predict tool wear and surface roughness patterns for a range of cutting conditions. The study concluded that best tool life was obtained in lowest feed rate and lowest cutting speed combination.

Wang and Lan (2008) used Orthogonal Array of Taguchi method coupled with grey relational analysis considering four parameters viz. speed, cutting depth, feed rate, tool nose run off etc. for optimizing three responses: surface roughness, tool wear and material removal rate in precision turning on an ECOCA-3807 CNC Lathe. The MINITAB software was explored to analyze the mean effect of Signal-to-Noise (S/N) ratio to achieve the multi-objective features. This study not only proposed an optimization approaches using Orthogonal Array and grey relational analysis but also contributed a satisfactory technique for improving the multiple machining performances in precision CNC turning with profound insight

Shetty et al. (2008) discussed the use of Taguchi and response surface methodologies for minimizing the surface roughness in turning of discontinuously reinforced aluminum composites (DRACs) having aluminum alloy 6061 as the matrix and containing 15 vol. % of silicon carbide particles of mean diameter 25µm under pressured steam jet approach. The measured results were then collected and analyzed with the help of the commercial software package MINITAB15. The experiments were conducted using Taguchi's experimental design technique. The matrix of test conditions included cutting speeds of 45, 73 and 101 m/min, feed rates of 0.11, 0.18 and 0.25 mm/rev and steam pressure 4, 7, 10 bar while the depth of cut was kept constant at 0.5 mm. The effect of cutting parameters on surface roughness was evaluated and the optimum cutting condition for minimizing the surface roughness was also determined finally. A second order model was established between the cutting parameters and surface roughness using response surface methodology. The experimental results revealed that the most significant machining parameter for surface roughness was steam pressure followed by feed. The predicted values and measured values were fairly close, which indicated that the developed model could be effectively used to predict the surface roughness in the machining of DRACs

K.V.Santhakumari, Dipak rajan(2010), were studied about accuracy of component is one of the most critical considerations for any manufacturer. Hence we can conclude that for what weight, deviation of tool when set, then what change in angle of tool should be set to get the correct result, where adverse effect on tool and work-piece will not occur. Thus we can get greater accuracy of job/work in turning operation.

VI PROPOSED SYSTEM

Literature depicts that a considerable amount of work has been carried out by previous investigators for modeling, simulation and parametric optimization of surface properties of the product in turning operation. Issues related to tool life, tool wear, cutting forces have been addressed to. Apart from optimizing a single response (process output), multi objective optimization problems have also been solved using Taguchi method followed by Utility theory. However, this approach is based on the assumption that quality indices being uncorrelated or independent [Datta et al. (2009)]. But it is felt that, in practice, there may be some correlation among various quality indices (responses) under consideration. To overcome this limitation of grey based Taguchi approach, the present study proposes application of Principal Component Analysis (PCA) to convert correlated responses into uncorrelated quality indices called principal components. Finally based on utility concept, Taguchi method has been applied to solve this optimization problem. The study demonstrates detailed methodology of the proposed optimization technique which integrates PCA, grey relational analysis and utility based extended Taguchi method; and validates its effectiveness through case studies in which correlated multiple surface roughness characteristics, MRR of a turned product along with depth of flank wear of the cutting tool have been optimized

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METHODOLOGY FLOW CHART

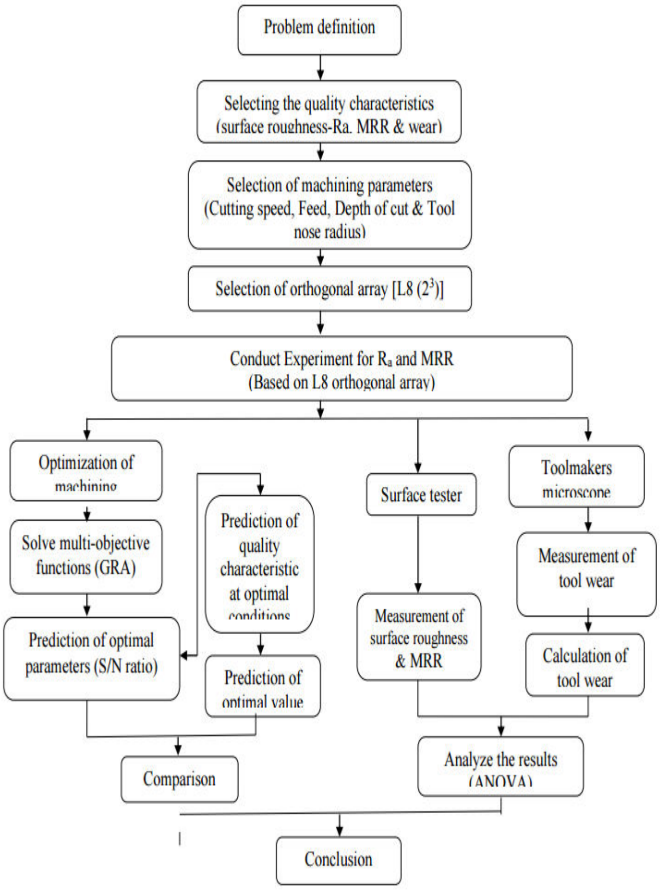

Fig.9: optimization of machining parameters for gun metal in end milling process

VII. EXPERIMENTAL RESULTS

The scope and objectives of the present work have already been mentioned in the forgoing chapter. Accordingly the present study has been done through the following plan of experiment

a) Checking and preparing the Centre Lathe (GEDEE WELILER LZ350) ready for performing the machining operation.

b) Cutting AISI1040 bars by power saw and performing initial turning operation in Lathe to get desired dimension of the work pieces.

c) Calculating weight of each specimen by the high precision digital balance meter before machining.

d) Performing straight turning operation on specimens in various cutting environments involving various combinations of process control parameters like: spindle speed, feed and depth of cut.

e) Calculating weight of each machined plate again by the digital balance meter.

f) Time for each cut were measured by digital stop watch.

g) Measuring surface roughness and surface profile with the help of a portable stylus-type profilometer, Talysurf (Taylor Hobson, Surtronic 3+, UK

h) Measuring cutting tool flank wear in tool makers microscope.

DESIGN OF EXPERIMENT

Experiments have been carried out using Taguchi's L8 Orthogonal Array (OA) experimental design which consists of 8 combinations of spindle speed, longitudinal feed rate and depth of cut. According to the design catalogue [Peace, G., S., (1993)] prepared by Taguchi, L8 Orthogonal Array design of experiment has been found suitable in the present work. It considers three process parameters (without interaction) to be varied in three discrete levels. The experimental design has been shown in Table 2.2 (all factors are in coded form). The coded number for variables used in Table 2.1 and 2.2 are obtained from the following transformation equations:

$$Spindle\ Speed: A = \frac{N - N_o}{\Delta N} \quad (1)$$

$$Feed\ Rate: B = \frac{f - f_0}{\Delta f} \quad (2)$$

$$Depth\ of\ cut: C = \frac{d - d_0}{\Delta d} \quad (3)$$

PARAMETERS Y USING L8 ORTHOGONAL ARRY

S.NO	SPEED	FEED	DEAPTH OF CUT	A	B	C
1	400	0.041	0.5	1	1	1
2	400	0.041	1	1	1	2
3	400	0.103	0.5	1	2	1
4	400	0.103	1	1	2	2
5	800	0.041	0.5	2	1	1
6	800	0.041	1	2	1	2
7	800	0.103	0.5	2	2	1
8	800	0.103	1	2	2	2

EQUIPMENTS USE

CENTRE LATHE

Model: GEDEE WELILER LZ350

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Fig10. Experimental setup

Make	GEDDE WEILER
Model	LZ350
Cutting speed rang	25-2500 rpm
Height of the center	190mm
Distance bet. center	1250mm
Swing over bed	300mm
Main motor power	7.5 H.P
Type of check	Four jaw check

ANOVA ANALYSIS

The ANOVA analysis was carried at 95% confidence level. The analysis of variance was carried out for determining the influence of process parameters on the response variables

ANOVA Table for surface roughness Ra

source	DOF	Seq SS	Adj MS	F-test	P-Value	% of contribution
s	1	2.5736	1.6276	15.9	0.318	26.77124
f	1	5.4921	3.4824	24.89	0.126	57.13023
d	1	1.1518	1.1518	59.1	0.082	11.98132
s*f	1	0.2206	0.3507	2.83	0.235	2.294737
s*d	1	0.0193	1.0193	0.25	0.668	0.200764
Error	2	0.1559	0.078			1.621712
Total	7	9.6133				100

From the above table 9.1 factors s (Cutting Speed), f (Feed rate) and d (Depth of cut), iterations s*f and s*d has significant effect on the output parameters. The feed rate has high influence (57.13%) on surface roughness Ra and speed has (26.77%) of influence on surface quality character Ra.

ANOVA Table for surface roughness Rq

Source	DOF	Seq SS	Adj MS	F-test	P-Value	% of contribution
s	1	4.7401	4.7401	16.61	0.323	31.76734
f	1	7.7185	7.7185	19.75	0.141	51.72807
d	1	1.7131	1.7131	34.75	0.107	11.4809
s*f	1	0.3907	0.3907	2.53	0.253	2.618405
s*d	1	0.0493	0.0493	0.32	0.629	0.3304
Error	2	0.3094	0.1547			2.073546
Total	7	14.9212				100%

From the above table 9.2 factors s (Cutting Speed), f (Feed rate) and d (Depth of cut), iterations s*f and s*d has significant effect on the output parameters. The feed rate has high influence (51.72%) on surface roughness Rq and speed has (31.76%) of influence on surface quality character Rq. T

ANOVA table for Tool wear

source	DOF	Seq SS	Adj MS	F-test	P-Value	% of contribution
s	1	0.0013	0.0016	3.22	0.945	4.296100463
f	1	0.0052	0.0062	2.01	0.391	17.19101124
d	1	0.0198	0.0098	76.56	0.076	65.43291474
s*f	1	0.00259	0.00376	1.12	0.401	8.565763384
s*d	1	0.00013	0.00178	0.06	0.836	0.423000661
Error	2	0.00124	0.00232			4.097818903
Total	7	0.03026				100

From the above table 9.2 factors s (Cutting Speed), f (Feed rate) and d (Depth of cut), iterations s*f and s*d has significant effect on the output parameters. The depth of cut has greater influence (65.4329) on tool wear and feed has (17.19) of influence on tool wear.

VIII CONCLUSION

The foregoing study deals with optimization of multiple surface roughness parameters along with material removal rate (MRR) in search of an optimal parametric combination (favorable process environment) capable of producing desired surface quality of the turned product in a relatively lesser time (enhancement in productivity). The study proposes an integrated optimization approach using Principal Component Analysis (PCA), utility concept in combination with Taguchi's robust design of optimization methodology. The following conclusions may be drawn from the results of the experiments and analysis of the experimental data in connection with correlated multi-response optimization in turning.

1. Application of PCA has been recommended to eliminate response correlation by converting correlated responses into uncorrelated quality indices called principal components which have been as treated as response variables for optimization
2. Based on accountability proportion (AP) and cumulative accountability proportion (CAP), PCA analysis can reduce the number of response variables to be taken under consideration for optimization. This is really helpful in situations were large number of responses have to be optimized simultaneously.

3. Utility based Taguchi method has been found fruitful for evaluating the optimum parameter setting and solving such a multi-objective optimization problem.

4. The said approach can be recommended for continuous quality improvement and offline quality control of a process/product.

By doing Analysis of variance test the following results were obtained.

1. The factor feed rate (f) has greater influence(51.728 & 57.130) on the surface roughness values Ra & Rq respectively.

2. The factor depth of cut has greater influence (65.432) on the tool wear of machining operation.

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