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# Optimization of Turning Process Parameters Using Multivariate Statistical Method-PCA Coupled with Taguchi Method

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## Abstract:

Optimization of machining process parameters to achieve a set of quality attributes is important in bridging up the quality and productivity requirements especially in a turning operation. The quality attributes considered are surface finish, material removal rate and tool flank wear. The Present work applies to optimize the process parameter for turning medium carbon steel bar using HSS tool bit via conventional machining. Optimizing one quality attribute may lead to loss of other quality attribute. Hence in order to simultaneously satisfy all the three quality requirements a multi objective optimization is required. To achieve this exploration of grey relational theory, utility concepts are attempted. To meet the basic assumption of taguchi method that quality attributes should be uncorrelated the study applies PCA based multivariate statistical method and eliminates correlation that exists in between the responses. Experiments have been conducted based on taguchi's L9 Orthogonal array design with different combinations of process control parameters: (Cutting speed, Feed, Depth of cut). Surface roughness, Material removal rate, Tool Flank wear are the response parameters that will be optimized. The obtained result will be verified through confirmatory test. This work highlights the effectiveness of proposed method for solving multi objective optimization of turning process. The above said methodology has been found fruitful in the cases where simultaneous optimization of huge responses is required.

**Keywords:** Turning Process, Surface roughness, Material removal rate, Tool Flank wear, Taguchi method, Multi variate statistical method.

## 1.PRIOR STATE OF ART

Literature depicts [4] that a considerable amount of work has been carried out by previous investigators for parametric optimization of surface properties of the product in turning operation. Most of the authors solved the single objective optimization few works are carried out in the area of multi objective problems. Hence multi response optimization has become an increasingly important issue in a modern manufacturing practice where more than one correlated responses must be assessed simultaneously for avoid quality loss to other quality attributes [1].The above said reasons are lead to the optimization of multi objective problem. Multi-objective optimization problems have also been solved using Grey Relational [2] & Utility concept based [3] taguchi method. How ever these approaches are based on the assumption responses are uncorrelated. So this procedure does not necessarily lead to the global optimum because the possible correlation among the responses may still not be considered. And it contradicts with the basic assumptions of taguchi optimization.To Over come the above said difficulties Present work implement a Multivariate Statistical method Based on Principal component Analysis to convert correlated responses into uncorrelated response index called principal components [1].Finally Grey relational & Utility concept based Taguchi method has been applied to solve this optimization problem through overall multi response index. Correlated multiple surface roughness characteristics, material removal rate, tool flank wear of a turned product will be optimized and the result will be verified through confirmatory test.

## 2.MATERIALS AND METHOD

**Machine:** The experiment was carried out on the Kirolskar Turn master 35 lathe with Variable speed and feed which is

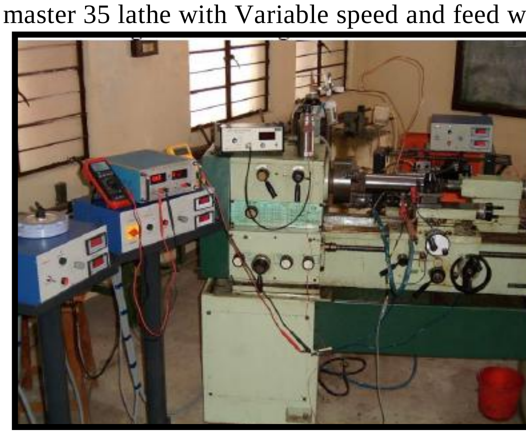

**Fig:2.1 Kirloskar Turn Master**

available at CRDM LAB (Centre for Research in Design and Manufacturing) Karunya university, Coimbatore and it's mentioned in fig 2.1.Various speeds and feed can be achieved through varying the input voltage and current to the base motor. Technical specifications are: Centre height:175 mm,

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Distance between centers (max): 800 mm. Main motor power: 2HP /2.2KW.

**The Tool:** HSS tool with the alloying elements: chromium, tungsten, cobalt etc. has comparatively better resistance to heat and wear. In this experiment HSS TOOL BITS with 10% Cobalt (SAE T42) is used. Material specifications and chemical composition are mentioned in table 2.1. This quality of tool bits retains its hardness even at very high temperatures and is recommended where the generation of heat is very high and the tool should not get blunt at high temperatures.

**Table 2.1 Chemical composition cutting tool material**

| Chemicals | As per T-42 in % |
|---|---|
| C | 1.40 |
| Cr | 4.2 |
| Mo | 3.6 |
| W | 10 |
| Co | 10 |
| V | 3.5 |

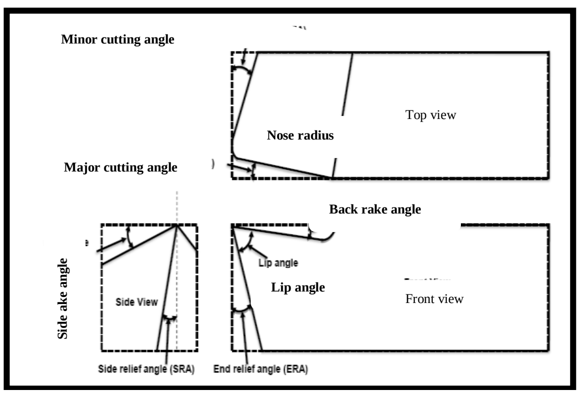


**Fig:2.2 Tool geometry**

**Table 2.2 Tool specification**

| Nomenclature | Angles in deg |
|---|---|
| Back rack angle | 10° |
| Side rack angle | 12° |
| Side relief angle | 07° |
| End relief angle | 07° |
| Major cutting edge | 15° |
| Minor cutting edge | 15° |
| Nose radius | 0.8 mm |
| Size of square tool bit | 12 *12 $mm^2$ |
| Length of tool bit | 100 mm |

Grade: 3X 10%CO:AISI T-42 HRC 65-67, Brand: Rohit. The single point HSS tool geometrical specifications are as follows in fig 2.2 and table 2.2. and it confirmed to Indian manufacturing standard IS: 11143.

**Work piece:** Work piece of standard dimensions was used for machining. Diameter of work piece: 38 mm, length of work piece: 100 mm. length of turning: 40 mm. AISI: 1040(ISO 683-1:C40) medium carbon steel is selected for work piece material because it is used wide variety of general purpose engineering. Chemical composition of work piece material is mentioned in table 2.3. These steels are of particular importance because of unique combination of strength.and toughness after heat treat treatment. Medium Carbon Steels are similar to low carbon steel except that the carbon ranges from 0.30 to 0.60 & the manganese from 0.50 to 0.90%.

**Table no:2.3 Chemical composition of work piece material**

| Chemicals | specification |
|---|---|
| Carbon | 0.35-0.45 |
| Manganese | 0.60-0.90 |
| Phosphorous | 0.05 max |
| Sulphur | 0.05 max |
| Silicon | 0.10-0.35 |
| Iron | remaining |

**Surface roughness measurement:** The instrument used to measure surface roughness was "Time surface roughness tester TR 100". Surface roughness readings were recorded at three locations on the work piece and the average value was used for analysis mentioned in fig 2.3. Specifications of Instrument used: Tracing length 6 mm, tracing speed 1 mm/sec, cutoff lengths 0.25 mm/0.8 mm/ 2.5 mm.Measuring range Ra:0.05-10µm, Rz:0.1-50µm.

**Fig 2.3 TIME TR100 Surface roughness tester**

**Tool makers microscope:** Metzer tool makers microscope is used to measure the cutting tool flank wear.

Specification of Tool Makers Microscope:

* 150mm X 150mm square X-Y Measuring stage 25mm travel expendable to 50mm with slip gauges.
* Gonimeter eyepieces 10X with scale.
* Base illumination 12V/20W incident illumination 12V/20W
* Magnification 30X with field of view 12mm and working

distance 80 mm.

**Cutting Conditions and Experimental Procedures:** Before implementing the optimization procedure selection of control factors and its levels, responses are important to design the experiment as mentioned in the table 2.4.

**Table no:2.4 Process parameter and it's levels**

| Factor | Level -1 | Level 0 | Level 1 |
|---|---|---|---|
| (A) Speed rpm | 210 | 530 | 850 |
| (B) Feed mm/rev | 0.045 | 0.090 | 0.135 |
| (C) Depth of Cut- mm | 0.5 | 1.0 | 1. 5 |

The minimum number of experimental trails required in orthogonal array is given by $N_{min}$= (L-1) F + 1; Where F= no. of factors= 3, L= no. of levels=3, $N_{min}$= 7; So that instead of conducting full factorial taguchi L9 Orthogonal array is used to conduct the experiment and the response parameters surface roughness Ra, Rz in µm, Tool flank wear(VB) in mm, Material removal rate in $mm^3$/min are measured. The present study has been done through the following plan of experiment.

1.Checking and preparing the Centre Lathe ready for performing the machining operation.

2.Cutting steel bars by power saw and performing initial turning operation in Lathe to get desired dimension (diameter of 38mm and length 100mm) of the work pieces.

3.Performing straight turning operation on specimens as per taguchi L9 orthogonal array mentioned in table 2.5 involving combinations of process control parameters like: spindle speed, feed and depth of cut.

4.Surface roughness, Tool flank wear, Material removal rate are measured through surface roughness tester, tool makers microscope, Digital weighing machine economy (R) series respectively.

**Table no:2.5 Taguchi orthogonal Array combination**

| Exp. No | Factorial combination | | |
|---|---|---|---|
| | A | B | C |
| **1** | -1 | -1 | -1 |
| **2** | -1 | 0 | 0 |
| **3** | -1 | 1 | 1 |
| **4** | 0 | -1 | 0 |
| **5** | 0 | 0 | 1 |
| **6** | 0 | 1 | -1 |
| **7** | 1 | -1 | 1 |
| **8** | 1 | 0 | -1 |
| **9** | 1 | 1 | 0 |

## 3. PROPOSED METHODOLOGY

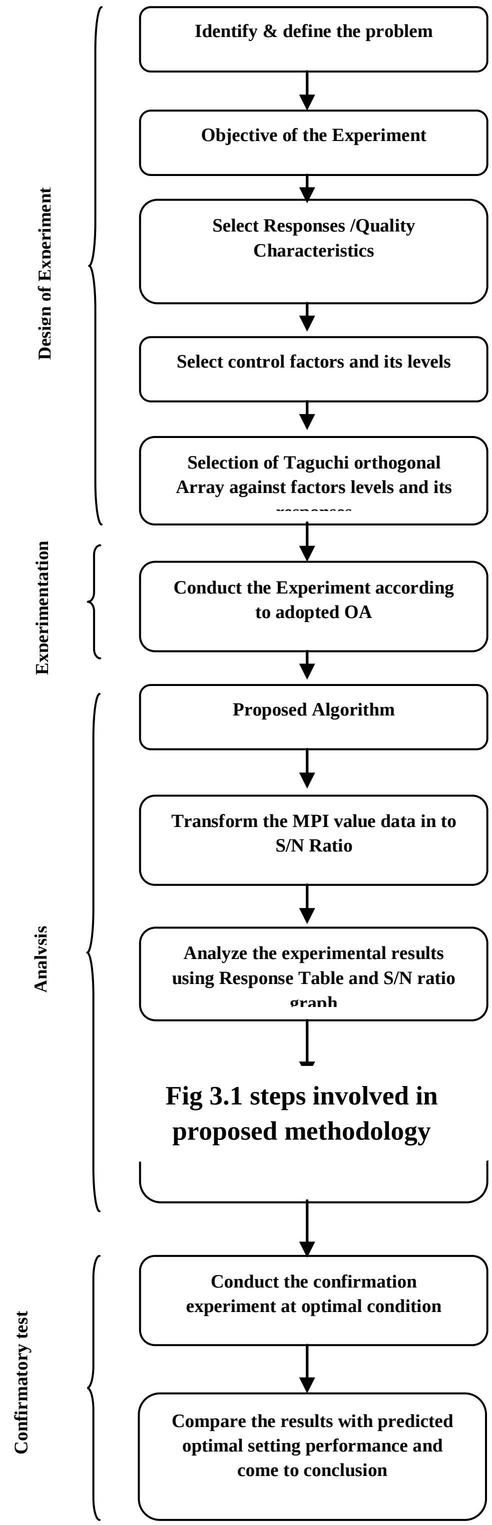


**Fig 3.1 steps involved in proposed methodology**

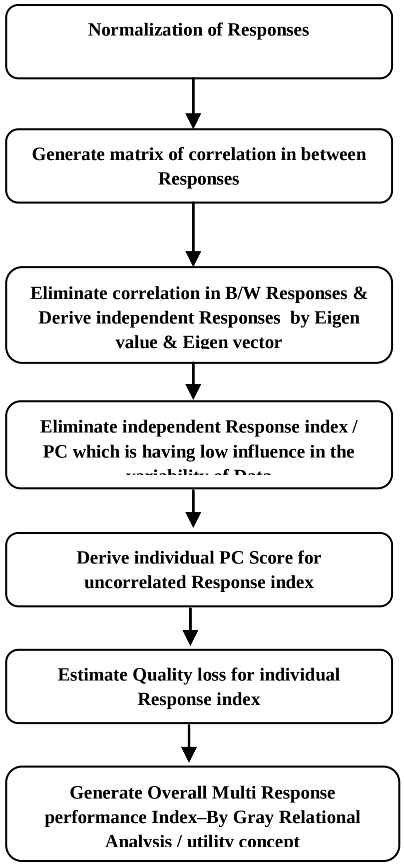


**Fig 3.2 steps involved in proposed algorithm**

In this experiment two surface roughness parameters and tool flank wear have to be minimized, material removal rate should be maximized and finally optimal combination of speed feed depth of cut are achieved. But these objective functions are correlated to each other. Therefore, Traditional Taguchi based optimization techniques with grey and utility concepts fails to meet this criteria. To overcome these, this paper introduces PCA based taguchi method[1] which is coupled with grey relational [2] and utility concepts[3]. The steps are as mentioned in fig 3.1 & 3.2.All statistical works and including principal component analysis with proposed algorithm are performed with the help of MINITAB R14 statistical software. At the end, results of proposed algorithm is compared with the results of confirmatory test and existing methods. Here larger the better criterion is used for optimizing the over all MPIndex.

## 4.ANALYSIS RESULTS AND DISCUSSION

Experimental results are shown in table no 4.1 Principal component of analysis are mentioned in the table no 4.2 . Evaluation of optimal settings in the form of signal to noise ratio graph are in the fig 4.1 & 4.2. Finally results of optimization at single stage and multistage are mentioned in the table no 4.3 to derive the conclusion for the above said proposed approach.

**Table no 4.1: Experimental Results**

| Exp no | Ra µm | Rz µm | VB mm | MRR $mm^3$/min |
|---|---|---|---|---|
| | avg | avg | | $mm^3$/min |
| 1 | 1.213 | 10.10 | 0.01 | 558.06 |
| 2 | 2.886 | 20.56 | 0.03 | 2136.75 |
| 3 | 3.750 | 16.00 | 0.04 | 4572.64 |
| 4 | 1.486 | 13.56 | 0.03 | 2780.35 |
| 5 | 3.653 | 5.26 | 0.06 | 8311.016 |
| 6 | 3.283 | 19.27 | 0.05 | 3645.64 |
| 7 | 2.023 | 8.46 | 0.06 | 5882.48 |
| 8 | 2.176 | 18.26 | 0.08 | 4615.38 |
| 9 | 2.646 | 20.56 | 0.09 | 11698.71 |

**Table no 4.2: principal components**

| PCA | pc1 | pc2 | pc3 | pc4 |
|---|---|---|---|---|
| Eigen value | 2.285 | 1.066 | 0.452 | 0.196 |
| Eigen vector | -0.572 | -0.148 | 0.627 | 0.508 |
| | 0.054 | -0.944 | -0.290 | 0.145 |
| | -0.611 | -0.163 | 0.030 | -0.774 |
| | 0.544 | -0.244 | 0.722 | -0.350 |
| AP | 0.571 | 0.267 | 0.113 | 0.049 |
| CAP | 0.571 | 0.838 | 0.951 | 1.000 |

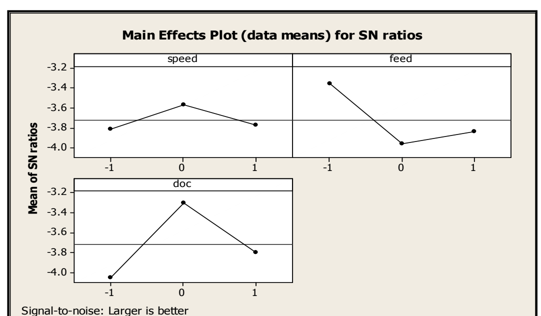


**Fig 4.1 Evaluation of optimal setting by grey rel**

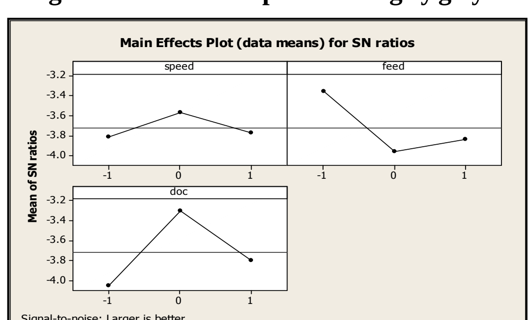


**Fig 4.2 Evaluation of optimal setting by utility**

**Table no 4.3: Comparison result**

| Simultaneous Optimization of multiple responses (Ra, Rz, VB, MRR) in turning process | | | | | | | | | Optimization of responses at single stage- by taguchi optimization | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Optimization technique for solving multiple responses based on quality concepts | | Predicted optimal setting | | | Predicted values | | Confirmatory test | | Responses | Predicted optimal setting | | |
| | | Speed (A) | Feed (B) | Depth of cut ( C) | S/N Ratio | Grey / utility. values | S/N Ratio | Grey / utility. values | | Speed | Feed | Depth of cut |
| Existing method | Grey relational-taguchi | -1 | -1 | -1 | - 5.4723 | 0.5626 | - 3.1903 | 0.6926 | Ra | 1 | -1 | -1 |
| | Utility taguchi | -1 | -1 | -1 | 18.292 | 7.2497 | 17.978 | 7.9232 | VB | -1 | -1 | -1 |
| Proposed method | Grey.rel taguchicouple with PCA | 0 | -1 | 0 | - 2.7954 | 0.7233 | - 2.957 | 0.711 | MRR | 1 | 1 | 1 |
| | Utilitytaguchi coupled with PCA | 0 | -1 | 0 | 11.7459 | 3.7654 | 10.455 | 3.332 | | | | |

Optimal combination of process parameter settings $A_0B_{-1}C_0$ is achieved through analysis.

## 5. CONCLUSION

From the analyses, the following conclusions can be drawn for the proposed approach

1. Here the application of PCA with grey or utility based taguchi method has been recommended for the optimization of manufacturing processes like turning processes which are having correlated multiple responses to find the optimum combination of process parameters with experimental objectives.

2. PCA has been utilized here to eliminate the correlation between the responses by converting correlated responses in to uncorrelated quality indices called principal components to meet the basic assumption of taguchi optimization.

3. By comparing the existing taguchi based multi response optimization method[2][3] the proposed approach meet the objectives of multiple responses simultaneously and produce best optimum combination of process parameter.

4. Over all multi response performance index based on PCA serves as a single response for solving multi response problem, really it will helpful where large number of responses to be optimized simultaneously.

5. From the experimentation and analysis depth of cut and feed showing greater influence than speed on surface roughness tool flank wear & material removal rate simultaneously.

6. The proposed approach can be recommended for off line quality control of process and product to improving the quality.

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