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Optimization of Process Parameter using Theory of Constraints

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Abstract: *The aim of the paper is to apply five steps of theory of constraints (TOC) helps to optimize turning parameters. TOC identifies the machining constraints; exploit the constraints and elevate the constraints using experimental design and multi-criteria decision making (MCDM) tools. Thereafter, experimental design (DOE) and a comparison outcome of both the MCDM tools i.e. multi-objective optimization on the basis of ratio analysis (MOORA) and multi-objective optimization of simple ratio analysis (MOOSRA); that satisfies the subordination process and optimizes the process parameters. The numerical result shows that the optimized process parameter minimizes and enhances the process throughput i.e. quality. Therefore; the enhanced process parameter improves the product throughput of the Organization. In this work, cause and effect diagram of TOC identifies the process constraints and suggests measures to improve the system. The research is applicable to any production house in which product quality reduces the throughput of the organization.*

Keywords: *Hard turning; Taguchi method; MOORA; MOOSRA and TOC.*

1. INTRODUCTION

Hard turning operations, work pieces hardness varies in between 50 and 70 HRC are machined by using single point cutting tools have high hardness and wear resistance. The application of hard turning can be improved by utilizing effective optimization algorithms, which helps producer to make sure of effective decision in the presence of multiple objectives. Significant advantages have been seen in cutting tools and machine tools in few decades. Cutting parameters might be specified according to hardness of material and roughness of the surface of work piece. This paper explores an alternative approach of TOC and described as the application of scientific method to the challenges of managing complex organizations (Dettmer 1998). Theory of constraints was initially applied to production scheduling and later to various areas such as operations, finance and measures. Quality improvement (QI) is a key principle of modern quality management approaches. Many QI approaches such as failure mode and effects analysis and statistical process control do not directly consider the impact of QI decisions on the profitability of the company. These attitudes and approaches can be held partially responsible for QIs that fail in achieving satisfactory quality. A variety of modern management philosophies and techniques has been applied in the last decade to manufacturing organizations, the main purpose of improving the performance in an increasingly competitive environment. The TOC philosophy can be used effectively to assist the machining parameter to improve their performance and most effective solutions that emphasizes the importance of defining and understanding the global goal of the organization as a condition for success. In order to strengthen the chain, one must strengthen the weakest link. If a link other than the weakest is strengthened, the strength of the whole chain is not increased. The concept of chain can be used to represent processes in any organization. In this paper, the cutting parameter on surface roughness is one of the important factors and solved by theory of constraints philosophy to enhance the throughput.

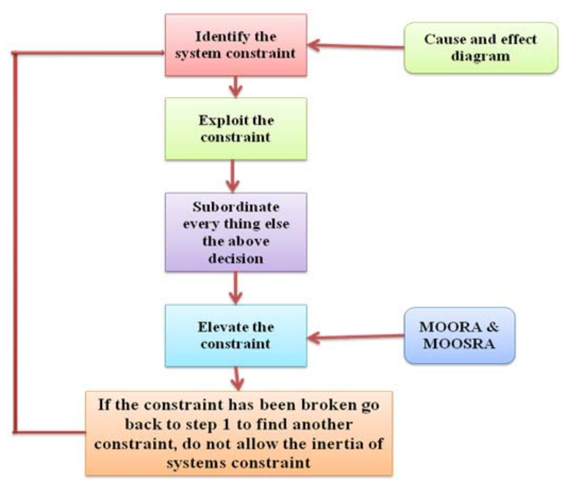

Fig. 1: block diagram of TOC

2. LITERATURE SURVEY

This section presents a brief review of cutting parameters on surface roughness. *Ucun et al* [3] describe the effects of the cutting parameters on surface roughness in hard turning. *Bhattacharya et al.* [4] Investigated the effects of cutting parameters on finish and power consumption by employing Taguchi techniques. Their results show a significant effect of cutting speed on the surface roughness, while the other parameters did not considerably affect the responses. Therefore, optimal cutting parameters were obtained. *Thamizhmanii et al*. [5] detected that the causes of poor surface finish were machine tool vibrations and chattering whose effects were ignored for analysis. Although the researcher has applied various Multi- Criteria Decision Matrix (MCDM) methods to obtain the various cutting parameters on surface roughness. This paper shows the application of MOORA as well as MOOSRA methodology for ranking the cutting parameters more preciously. The objective of this study is to obtain optimal turning parameters for minimum surface roughness to maximize throughput in terms of quality.

3. MATERIAL AND METHOD

In this paper, a work piece made of AISI 4140 grade steel was used. Its sizes were 110 × 600 mm. As thermal treatment, the steel was tempered at higher temperature for an hour and quenched at lower temperature for two hour to eliminate stresses and to reduce hardness. The experiment was conducted under dry cutting conditions. The surface roughness was measured by portable device within the sampling length of 2.5 cm. Theory of constraints describes that if any organizations, industry, firm has at least one constraint that would resist the throughput of the organization in terms of quality. Management team implemented various performance enhancement projects based on several opportunities finding out by the team. The strategic level people reviewed that an improvement opportunity has to bring in terms of quality from the system aspects which focus on global improvement. After organizing brainstorming sessions between the top level people, middle level people and bottom level people comes to a conclusion that in among the three cutting parameters feed rate is more effective for the surface roughness. After fixing that the feed rate is drastically hampering the surface roughness the governing bodies decided to exploit the constraint using the existing technique to a certain extent of new capital investment recommended by TOC principle.

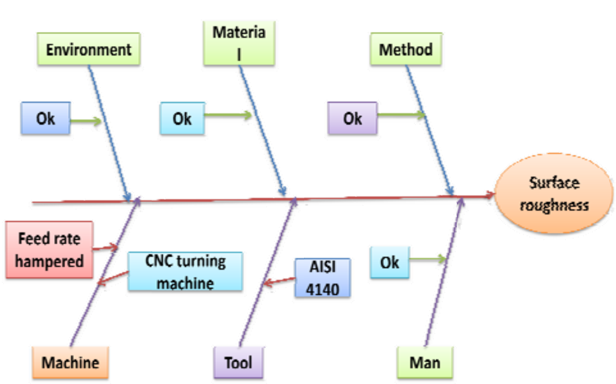

Fig. 2 cause and effect diagram

At this phase, the management team decided to exploit the constraint relative to what the system is trying to achieve. For the purpose of process parameter evaluation, some values of feed rate, cutting speed, depth of cut and surface roughness have been taken as consideration. The traditional optimization methods are too complicated and very difficult to use in manufacturing organizations while a large number of experiment has to be carried out when the number of manufacturing parameters increases. From the principle of TOC this paper suggest that the process parameters are not optimized to enhance the throughput in terms of quality. Now the management team decided to exploit the constraint using experimental design using Taguchi method. The Taguchi method is an experimental design technique, which is useful to reduce the experiments drastically by using the orthogonal arrays and also minimizes the effects of factors. The basic principle of Taguchi method is to ensure equality in design phases and also decrease the experimental time, to reduce the cost and found out the most beneficial factors in lesser time. The overall aim of the quality engineers is to make products that are most robust with respect to all factors. The most important stage of DOE lies in the selection of factors. Taguchi used the signal-to-noise (S/N) ratio as the quality characteristic of choice. S/N ratio is used as a measurable standard deviation (SD) because as the mean decrease, the SD also decreases and vice versa. In real life practice the mean target value may changes during process development. The concepts of S/N ratio are useful to determine the improvement of quality through inconsistency diminution and the enhancement of measurement. To influential the optimum cutting conditions according to S/N ratio, while the relations between the cutting parameters was established with the help of variance analysis.

Subordinate the above discussion once the new parameters are in place the goal shifts to supporting the change and monitoring the parameters to make sure the improvement are sustained. The phase is designed to document and monitor the new parameter conditions which will be enhanced by this methodology. In this paper, multi-objective optimization on the basis of ratio analysis (MOORA) method as well as multi-objective optimization on the simple ratio analysis (MOOSRA) method is used to elevate the constraint. In a decision making problem, the purpose must be measurable with respect to their outcomes and measure for every available alternatives. The MOORA method and MOOSRA method considers both the non-beneficial criterions for this problem ranking the alternatives from the set of available options. The first step in MOORA method is to make a decision matrix exhibiting the performance of different alternatives with respect to various criterions;

$$M = \begin{pmatrix} M_{11} & M_{12}..... & M_{1n} \\ M_{21} & M_{22}..... & M_{2n} \\ M_{m1} & M_{m2}..... & M_{mn} \end{pmatrix} \quad (1)$$

Then the decision matrix is normalized so that it becomes dimensionless and all the elements of that matrix are comparable.

$$M_{ij}^{*} = \frac{M_{ij}}{\sum_{i=1}^{a} M_{ij}} \quad (2)$$

From normalized matrix we have to decide the non-beneficial criterion which conflict the process and find out the assessment value (Z_i) using the given expression;

$$Z_i = \sum_{j=1}^{g} M_{ij}^{*} - \sum_{j=g+1}^{n} M_{ij}^{*} \quad (3)$$

Where g is the number of criteria to be maximized, (n-g) is the number of criteria to be minimized and Z_i is the assessment value of i^{th} alternative with respect to the entire criterion. Then the decision matrix is normalized by using equation (2) so that it becomes dimensionless and all the elements of that matrix are comparable. From the normalized matrix find out the assessment value (Z_i) using equation (3) has been shown in Table 1 and Table 2 respectively.

Table 1: Normalized Decision Matrix by MOORA

Sl No	Ra	Rz	Ra for S/N ratio	Rz for S/N ratio
1	0.076336	0.080501877	0.07147685	0.09840919
2	0.085401	0.130231706	0.056944914	0.120186394
3	0.201336	0.181976371	0.210882055	0.135333486
4	0.057729	0.078944958	0.039202433	0.097731585
5	0.117844	0.107335837	0.132984116	0.111528678
6	0.180344	0.145984064	0.18232511	0.125357046
7	0.055821	0.079311292	0.056944914	0.097783708
8	0.105439	0.084714717	0.118114228	0.100718262
9	0.119752	0.110999176	0.13112538	0.11295165

Table 2 assessment value and ranking

Zi	**0.326723796**	**0.392764**	**0.7292779**	**0.273607984**	**0.469692143**	**0.634009732**	**0.289860525**	**0.408986139**	**0.474828115**
Rank	7	6	1	9	4	2	8	5	3

The MOOSRA methodology starts with the definition of decision matrix which has in general four components respectively alternatives, Criteria or attributes, Subjective weights or significance coefficients of each criterion, measure of performance of alternatives with respect to the criteria. Where P_i represents the alternatives, i = 1, 2,…,m; C_j represents *j*th criterion or attribute, j = 1, 2,…,*n*, related to i^{th} alternative. The criteria or attributes are classified as either beneficial criteria or non-beneficial criteria. The subjective weight of the *j*th attribute is denoted by W_j; and K_{ij} indicates the performance of each alternative *Ai* with respect to each criterion C_j.

$$K_{ij} = \begin{array}{c} \\ P_1 \\ P_2 \\ \cdots \\ \cdots \\ P_i \\ \cdots \\ \cdots \\ P_m \end{array} \begin{array}{c} \begin{array}{cccccccc} S_1 & S_2 & \cdots & \cdots & S_j & \cdots & \cdots & S_n \end{array} \\ \begin{bmatrix} K_{11} & K_{12} & \cdots & \cdots & K_{1j} & \cdots & \cdots & K_{1n} \\ K_{21} & K_{22} & \cdots & \cdots & K_{2j} & \cdots & \cdots & K_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ K_{i1} & K_{i2} & \cdots & \cdots & K_{ij} & \cdots & \cdots & K_{in} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ K_{m1} & K_{m2} & \cdots & \cdots & K_{mj} & \cdots & \cdots & K_{mn} \end{bmatrix} \end{array} \quad (4)$$

The normalized elements of the decision matrix in MOOSRA method are computed using the equation (2). In this method, each performance of an alternative on an objective is compared to a denominator which is a representative for all the alternatives concerning that objective. Out of different types of ratio system, Brauers et al. concluded that for this denominator, the best choice is the square root of the sum of squares of each alternative per objective the ratio is expressed bellow and shown in table 3.

$$K_{ij}^{*} = \frac{K_{ij}}{\sqrt{\sum_{i=1}^{m} K_{ij}^{2}}} \quad (5)$$

The value K_{ij}^{*} represents the normalized performance of *i*th alternative on *j*th objective. This value belongs to the interval of [0, 1] and it is a dimensionless number. The performance score (Y_i) of alternative is computed as the simple ratio of weighted sum of beneficial criteria to the weighted sum of non-beneficial criteria expressed bellow and shown in Table 4.

$$Y_i = \frac{\sum_{j=1}^{g} W_j K_{ij}^{*}}{\sum_{j=g+1}^{n} W_j K_{ij}^{*}} \quad (6)$$

With j = 1, 2,…,g indicate the beneficial criteria, and j = g + 1, g + 2,…,n indicate the non-beneficial criteria. W_j = associated weight of the j^{th} attribute. If we consider that the attributes are equally important then the optimization formula becomes:

$$Y_i = \frac{\sum_{j=1}^{g} K_{ij}^{*}}{\sum_{j=g+1}^{n} K_{ij}^{*}} \quad (7)$$

Table 3: Normalized Decision Matrix by MOOSRA

Ra	Rz	Ra for S/N ratio	Rz for S/N ratio
0.336205338	2.030814329	0.808997515	5.536610748
0.420795127	5.314857952	0.513483218	8.258159777
2.338780917	10.37739154	7.041993557	10.47088072
0.192280561	1.953021394	0.243356204	5.460627548
0.80123248	3.610336586	2.80037323	7.111247349
1.876498577	6.678348881	5.263920748	8.984008889
0.179777925	1.971188937	0.513483218	5.46645377
0.64142988	2.248929983	2.209127613	5.799480858
0.827393458	3.860981393	2.722637959	7.293866904

Table 6: Performance Score and Rank

Yi	0.340143 3	0.477844 6	1.568164 8	0.260632 4	0.675420 4	1.213098 2	0.280432 2	0.529070 8	0.684806 2
Rank	7	6	1	9	4	2	8	5	3

Now, by comparing the co-efficient of variance obtained by using equation number (8); the two MCDM methods i.e. 34.64% by MOORA method and 66.47% by MOOSRA method, it can be concluded that MOOSRA method is a better method than MOORA method to elevate the constraint.

$$CV = \frac{\sigma}{\bar{X}} \times 100\% \qquad (8)$$

The improvement project was initiated once the operation was improved and became efficient it would no longer be the bottleneck of the system. The team continued to analyze the manufacturing performance to detect potential new constraints, which would be a target of new improvement project in terms of quality.

4. DISCUSSION AND CONCLUSION

This paper started by describing the fundamentals of hard turning, Taguchi method, MOORA, MOOSRA and the theory of constraint(s) philosophy was used for obtaining the optimum parameters. Optimization procedures based on the above approaches have been developed and successfully implemented. Significant improvement is obtained with the above techniques when compared by coefficient of variance for two MCDM techniques. Results obtained in this work are intended for the use of numerically control machines. According to TOC management philosophy, the feed rate has an effect on surface roughness. Thus theory of constraint(s) philosophy has been introduced to minimize the surface roughness and increases the throughput in terms of quality. Experimental results were analyzed using MCDM techniques to find out the advancement of the process. The numbers of experiments were reduced by using Taguchi experimental design to enhance the optimum cutting conditions by using theory of constraints philosophy. Satisfactory results were obtained and might be used in future academic research. It has been seen that MOOSRA methodology gives better result for the cutting parameters with the help of TOC philosophy and graphs in MOORA and MOOSRA shows the alternatives and criterions for the best research.

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