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METHODOLOGY AND STUDY OF OPTIMIZATION TECHNIQUE: TAGUCHI METHOD

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ABSTRACT

In manufacturing sector for efficient and quality of work, various optimization techniques are used in industries. Out of them, Taguchi method of optimization gives a new concept to a term "quality". The main advantage of Taguchi design of experiment is that it will give optimal solution in combination of input process parameters with less no of trials of experiments. In this research paper, the main focus is laid on the concept and methodology of Taguchi method in manufacturing field by optimising the input process parameters with the help of signal to noise (S/N) ratio. A brief introduction of ANOVA (Analysis of Variance) technique and L9 (OA) orthogonal array are also been studied by taking an example of friction-welding process. The input process parameters like profile of tool, welding speed and revolution of tool are studied by L_9 orthogonal array of Taguchi method, which will give optimal solution in-terms of combination of input process parameters.

Keywords: Taguchi, ANOVA, Design of experiments, L9 orthogonal array, S/N ratio

1. Introduction

Traditionally, optimal solution was obtained by performing number of experiments by trial and error method, which was a cumbersome as well as time consuming process. Hence Many scientists worked over the design of experiments (DOE), which would give optimal solution in minimum number of trials. Box and Meyer [1] studied a new technique to find variance of response and identified the process parameters which have small non-replicated design effects. Dr. CR Rao, an Indian statistician also gave a new concept to design of experiments. In 1980's Taguchi, a Japanese scientist developed a new approach of design of experiments to reduce the variation in quality. He introduced his ideas to US at AT&T. He gave a new concept to quality. The main aim of Taguchi method is to minimise the variation of process, while keeping target constant.

A. Concept of quality loss

Earlier, upper and lower limit defines the quality of product i.e. good or bad. If the product dimensions and specifications lie within the higher and lower limit, then there will be no loss in terms of quality. But according to Taguchi, when there is a deviation from the target value then there will be loss even if product is within the allowable limits. This gives a new concept to quality function. Figure 1 shows the traditional and Taguchi quality loss function concept.

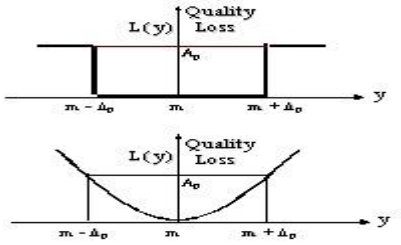

Figure 1. Traditional and Taguchi quality loss function

B. Objective of taguchi method

Taguchi method is used in manufacturing sector for improving the quality. It is generally applied at pre-manufacturing stage and hence one of the most efficient and cost saving approach. Figure 2 shows the division of Taguchi approach into three levels.

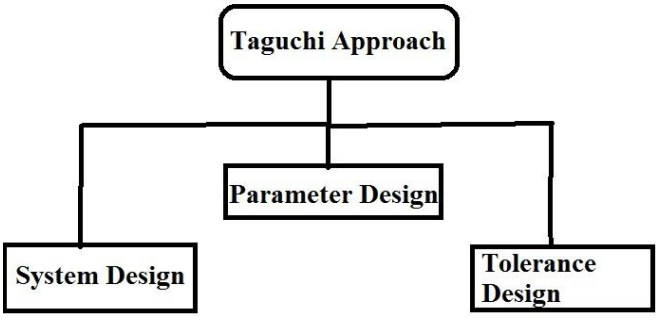

Figure 2. Different types of Taguchi approaches

System design includes developing basic design i.e. evaluating and comparing basic design configuration, material specification etc. On the other hand, parameter design includes optimization of process parameters to minimize its sensitivity to noise ratio while tolerance design deals with the upper and lower limit of tolerances.

The main objective of Taguchi method of optimization of process parameters are mentioned below;

- Making a robust design
- Identification of controllable factors, which minimize the effect of noise factors.
- Signal to noise (S/N) ratio

2. Methodology of Taguchi Technique

Taguchi method is broadly divided into three sections i.e. system design, parameter design and tolerance design. Figure 3 shows the various internal steps of Taguchi techniques, which are used in the optimization of process input parameters. The main task is to determine the various input (control factors) and output (quality characteristics) process parameters and their respective levels. Secondly, selection of suitable orthogonal array (OA) is carried out, on the basis of which experimental trials are performed. Finally confirmatory test will be performed on optimal conditions, which is obtained by taguchi method.

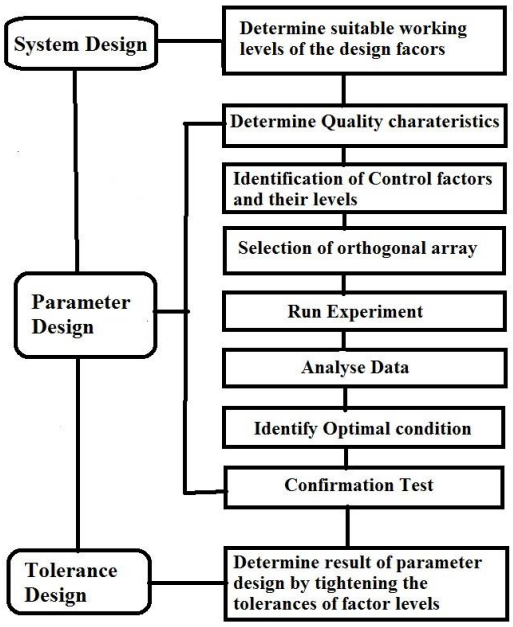

Figure 3. Various steps of Taguchi method

3. Plan of Experiment

In this research paper, an example of process of friction welding of two metal pieces is studied. Table 1 indicates the various input and output process parameters with their levels.

Table 1. Input and output process parameters

S. No.	Output Parameter	Input Parameters	No. of Levels		
			1	2	3
1	Welding strength of joint	Profile	A	B	C
2		Revolution of tool	(R_1)	(R_2)	(R_3)
3		Welding speed	(W_1)	(W_2)	(W_3)

A. Orthogonal array (OA) of taguchi

Taguchi design of experiment is based on orthogonal array. It is a type of a fractional factorial design. Orthogonal array (OA) includes subsets of combination of multiple factors at multiple levels. It is generally expressed in terms of L_8, L_9 etc.

General expression for orthogonal array can be expressed as;

$L_{runs} = (\text{Level})^{\text{Factor}}$

Where, Run (N) = Number of rows in array

Level (V) = Maximum number of values that can be taken in single factor.

Factor (K) = Number of column

In this research paper, our focus is towards only L_9 (3^3) orthogonal array proposed by Taguchi. It has 9 rows and 3 columns, which represent the number of experiments. In Taguchi orthogonal array (OA) design, main effect and two factors interactions are considered and higher order interaction are assumed to be non-existent. Table 2 shows the layout of L_9 (3^3) orthogonal array.

Table 2. Layout of L9 (3^3) orthogonal

No. of Experiments	Input parameter	Output parameter

	Profile		Revolution of tool (rpm)	Welding speed (mm/min)	Welding strength (Newton)
1	A		R_1	W_1	X_1
2	A		R_2	W_2	X_2
3	A		R_3	W_3	X_3
4	B		R_1	W_2	X_4
5	B		R_2	W_3	X_5
6	B		R_3	W_1	X_6
7	C		R_1	W_3	X_7
8	C		R_2	W_1	X_8
9	C		R_3	W_2	X_9

B. S/N ratio calculation

Robust design of product is essential to satisfy the customer demand of high quality product with lowest cost and the main tool for robustness method is signal to noise (S/N) ratio. Basically signal to noise (S/N) ratio is used to measure quality characteristic deviation from the desired value. Minitab software is used to calculate the S/N ratio at different combination.

$$\text{S/N ratio} = \frac{\text{Signal (controllable factor)}}{\text{Noise (Uncontrollable factor)}}$$

$$\text{S/N ratio} = \frac{\text{Desirable value (mean) for output characteristic}}{\text{Undesirable value (standard deviation) for output characteristics}}$$

$$\text{S/N ratio} = \frac{\text{Mean}}{\text{Standard Deviation}}$$

However, signal factors are those factors which can be controlled by operator, to get desirable output while Noise factors are those that are uncontrollable factors. Noise factors are classified into two parts;

- Internal Noise
- External Noise

Internal Noise are due to internal wear, change in materials etc while external noise are the variations due to environmental condition like temperature, pressure etc. Signal by noise (S/N) ratio are divided into three parts. Figure 4 indicates the classification of signal by noise (S/N) ratio.

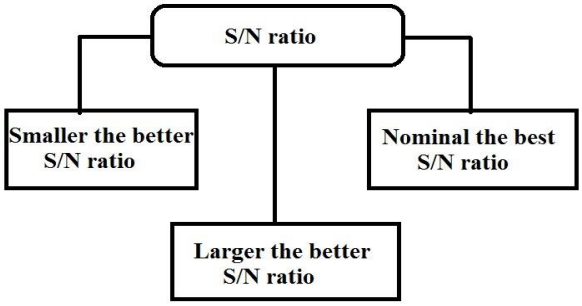

Figure 4. Types of signal to noise (S/N) ratio

- Smaller the best S/N ratio is used when we have to achieve the output parameter as smaller as possible. Like surface roughness of finished products. In this case the target value is zero.

  S/N ratio = $-10 \log_{10}$ [mean of sum of squares of measured data] = $-10 \log_{10} (1/n) \sum y^2$

- Larger the best criteria is used when the output shall be as larger as possible like metal removal rate (MRR) in machining. In this case the target value is zero.

  S/N ratio = $-10 \log_{10}$ [mean of sum of squares of reciprocal of measured data] = $-10 \log_{10} (1/n) \sum (1/y^2)$

- Nominal the best S/N ratio is used where nominal target value and variation is minimum. In this case target value is non-zero.

  S/N ratio = $-10 \log_{10}$ [square of mean variance] = $-10 \log_{10}(Y/S_Y)$

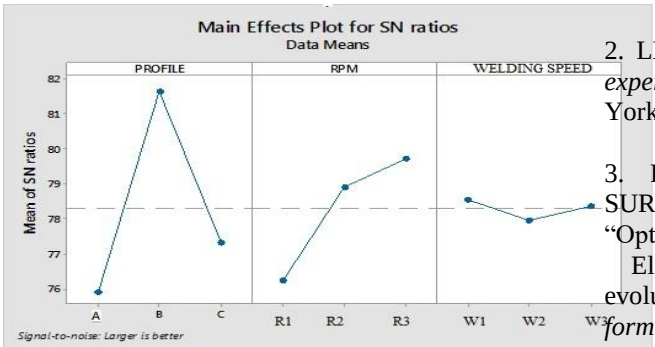

Figure 5. Mean effect plot for S/N ratio

Figure 5 gives the information regarding different values of S/N ratio with respect to various input process parameters.

4. ANOVA (Analysis of Variance)

The main aim of analysis of variance (ANOVA) is to find the role of input process parameters in affecting the output quality characteristics. This can be obtained by separating the total variability of S/N ratio. For the above example, larger the best criteria is chosen for S/N response table as the output parameter (desired quality characteristic) is taken as welding strength of weld.

5. Confirmation Test

After getting optimal solution in terms of combination of input process parameters, a confirmation test has been carried out to predict and verify the improvement of quality characteristics. This test gives the confirmation over the optimization process, which was carried out by Taguchi method.

6. Result and Discussion

In the above work, a brief introduction of various parameters and methodology of Taguchi technique is discussed and L_9 orthogonal array is used by considering three factors with their three levels to analyse the effect of input process parameters to get optimal results in the form of desired quality characteristics. Hence Taguchi method is one of the best and efficient methods as it based on mean performance characteristic value which is close to the target value rather than a value within specified limits. ANOVA is also used to investigate the significance of input process parameters, which affect the quality characteristics.

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