Taguchi Method Experimental Design Technique

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Abstract

In this recent global competitive market, it is desired to produce high level of quality products and the services to sustain in this competitive market of manufacturing. For this process optimisation, manufacturer has to focus on design optimisation in order to compete in this market. This paper presents the philosophy and method applied for Taguchi method design of experiment. This includes quality loss function, signal to noise ration, influence of uncontrollable parameters, orthogonal arrays are the important terms in defining Taguchi method design of experiment

Keywords: Design of Experiment (DOE), Orthogonal Arrays, Quality loss function, S/N ratio, Taguchi.

1.Introduction:

The Taguchi method is one of the most well-known robust design methods. The basic intention of the Taguchi approach is to develop an understanding of the individual and combined effects of various design parameters from a minimum number of experiments. The objectives of the Taguchi method for parameter design are to establish the optimal combination of design parameters and to reduce variations in the product quality by rendering the parameter design robust to the effects of noise [1]

The full factorial design is referred as the technique of defining and investigating all possible conditions in an experiment involving multiple factors while the fractional factorial design investigates only a fraction of all the possible combinations. Although these approaches are widely used, they have certain limitations: they are inefficient in time and cost when the number of the variables is large; they require strict mathematical treatment in the design of the experiment and in the analysis of the results; the same experiment may have different designs thus produce different results; further, determination of contribution of each factor is normally not permitted in this kind of design [2].

The Taguchi method has been proposed to overcome these limitations by simplifying and standardizing the fractional factorial design. The methodology involves identification of controllable and uncontrollable parameters and the establishment of a series of experiments to find out the optimum combination of the parameters which has the greatest influence on the performance and the least variation from the target of the design. The Taguchi methodology has been successfully applied in the automobile industries [2].

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2. Taguchi Background:

Genichi Taguchi, a Japanese engineer, laid out the theoretical foundations of the Taguchi Method. In the 1950's, Taguchi began working for ECL (Electrical Communications Lab, a part of NT&T), a telecommunications company. After the end of World War II, Taguchi's team was involved in the designing of components of telephone systems. Bell Labs of the US were their main rivals, and Taguchi's team successfully produced better performing designs. What do we mean by "performed better"? Taguchi found the traditional definitions of quality to be inadequate and perhaps, vague. Over years of working with various projects on process and product design, Taguchi developed his own definitions of the concept of quality and better performance.

Robustness: Taguchi defined a robust design as "a product whose performance is minimally sensitive to factors causing variability (at the lowest possible cost)".

Taguchi's view was that the traditional systems used some performance criteria for measurement of robustness (or in general, quality), such as:

- meeting the specifications
- % of products scrapped
- Cost of rework
- % defective
- failure rate

However, make-and-measure policies formed the basis of these measures of performance. They all came in at the later stages of the product development cycle. Robust design is a systematic methodology to design products whose performance is least affected by variations, i.e. noise, in the system (system variations here means variations due to component size variations, different environmental conditions, etc.). Some statistical tools are necessary to generate robust designs. These are broadly covered in standard courses on Design of experiments.

2.1 Milestones of Taguchi method:

The use of the parameter design of the Taguchi method to optimize a process with multiple performance characteristics includes the following:

- The performance characteristics are identified, and the process parameters to be evaluated are selected.
- The number of levels for the process parameters and the interactions possible amongst the process parameters are determined.
- The appropriate orthogonal array is selected, and the process parameters are assigned to the orthogonal array.
- Experiments based on the arrangement of the orthogonal array are conducted.
- The total loss function and the S/N ratio are calculated.

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- The experimental results are analysed using ANOVA and the S/N ratio.
- The optimal levels of process parameters are selected.
- The confirmation experiments are conducted to verify the optimal process parameters.

Figure 1 shows the flowchart of the Taguchi Design.

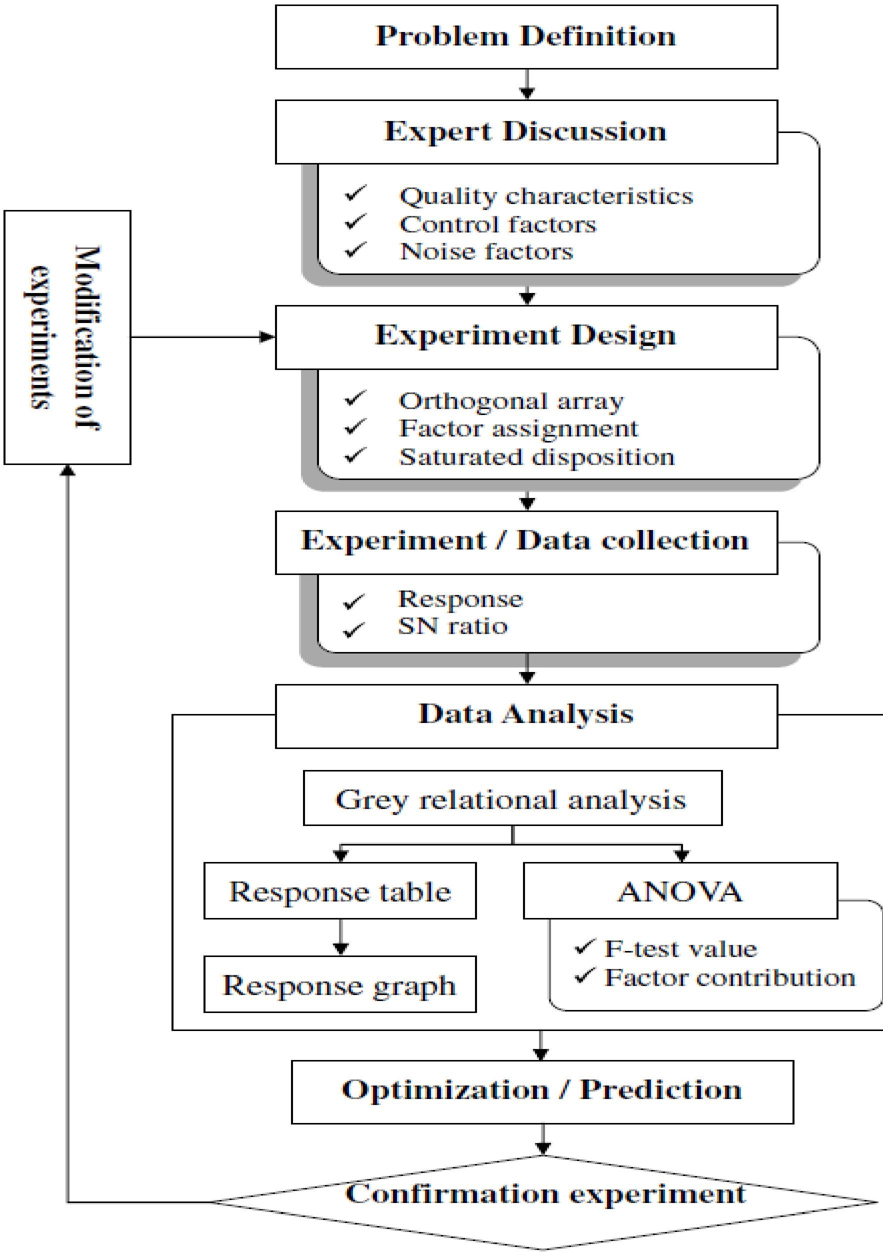

Figure1- Flowchart of the experiment design [3]

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3. Taguchi Quality Loss Function:

Nalbant [4] says that, basically, classical parameter design, developed by Fisher, is complex and hence, difficult to use. Especially, when the number of the process parameters increases, a large number of experiments have to be conducted. Easing this task, the Taguchi method uses a unique design of orthogonal arrays in only a small number of experiments are used to study the entire parameter space. The deviation between the experimental value and the desired value is then calculated by defining a loss function. As recommended by Taguchi, for measurement of the performance characteristic deviating from the desired value, the loss function is made use of. A signal-to-noise (S/N) ratio is obtained by transforming the value of the loss function. Usually, for the analysis of the S/N ratio, three categories of the performance characteristic are there, that are,

(a) the lower, the better;

(b) the higher, the better, and

(c) the nominal, the better.

4. Taguchi's contribution to quality engineering and design of experiment:

Taguchi quantified the definition of quality using Karl Gauss's quadratic loss function. He introduced orthogonal arrays (OAs), although almost half of them are classical fractional (or factorial) design developed by Sir Ronald A. Fisher, G.E.P. Box and J.S. Hunter, F. Yates, O. Kempthorne, S. R. Searle, and countless others. Taguchi's orthogonal arrays, however are already in developed format so that the engineer does not have to design the experiment from scratch, even though the engineer should have knowledge of their development to make, the contribution Dr. Taguchi has made in this area is simply making it easier for an engineer to use design of experiments (DOE).

Taguchi introduced a robust (i.e., parameter and tolerance) designs. He defined a set of measures called signal to noise (S/N) ratios that combine the mean and standard deviation into one measure in analyzing data from a robust design[5].

5. Orthogonal Array:

In1956, a catalogue consisting of orthogonal array tables was developed by Taguchi for producing fractional and fractional factorial designs. Taguchi took the following steps while constructing his design of experiments:

1. From the catalogue of orthogonal arrays, a suitable orthogonal array was chosen.

2. Triangular tables and linear graphs were used for the assignment of orthogonal arrays to the columns, and for the estimation of the interactions in the experiments.

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An appropriate orthogonal array is selected depending upon the total degrees of freedom of an experiment. The number of comparisons to be made between process parameters, that are needed to determine the best level and particularly how much better it is as compared to other levels, are known as the degrees of freedom of an experiment. For example, a single degree of freedom is deemed for a two-level process parameter. When interaction between two process parameters is considered, the degree of freedom is given as the product of the degrees of freedom for the two process parameters [6].

The catalogue of Taguchi consists of 18 orthogonal arrays. These orthogonal arrays are denoted by L_N (s^k) or simply by L_N. Here, L_N (s^k) is a matrix with dimension N × k, s distinct elements. Every pair of columns of the L_N (s^k) matrix contains all possible s^2 ordered pairs of elements with the same frequency. Particularly, in the orthogonal array, the number of rows is N and the number of columns is k. Letters, numbers or symbols can be the elements of an orthogonal array. Since in this article, only 2-element orthogonal arrays are to be discussed, the orthogonal arrays L_N (s^k) discussed here have the following properties:

$N = 2r$: number of rows, r = 2, 3, 4,….and so on

$k = N - 1$: number of columns

$s = 2$: number of distinct elements.

As recommended by Taguchi, (- , +), (0, 1) or (1, 2) can be used for the elements of the orthogonal arrays. The smallest of the 2-element orthogonal arrays, L_4 (2^3), is given in Table1

	COLUMN		
ROW	1	2	3
1	1	1	1
2	1	2	2
3	2	1	2
4	2	2	1

Table 1: The Orthogonal Array L_4 (2^3)

As can be seen from Table 1 , the orthogonlity constraint is confirmed, as in every pair of columns, the 4 ordered pairs (1, 1), (1, 2), (2, 1) and (2, 2) appear exactly once. Also, this implies that elements 1 and 2 occur twice in each row.

Considering that in the orthogonal arrays, the columns represent factors and interactions, the elements in the columns represents the levels of the factors and the elements in the rows represent the runs, the orthogonal arrays can be taken as factorial experiments. A distinguishing feature of the orthogonal arrays is that upon deleting some columns and interchanging columns or rows, a submatrix, which is also an orthogonal array, can be formed.

The 2-level orthogonal arrays appearing in the catalogue of Taguchi, factors and interactions (columns) , and the number of runs (rows), are given in Table 2

ORTOGONAL ARRAYS	NUMBER OF ROWS	NUMBER OF COLUMNS
L_4 (2^3)	4	3
L_8 (2^7)	8	7
L_{12} (2^{11})	12	11
L_{16} (2^{15})	16	15
L_{32} (2^{31})	32	31
L_{64} (2^{63})	64	63

Table2 : The 2-Level Orthogonal Arrays of Taguchi

In 2-level orthogonal arrays, each column has only one degree of freedom, and the number of rows must be at least equal to the degree of freedom of the experiment.

For example, if only the main factors are to be determined in an experiment with 7 factors each having 2 levels, the total degree of freedom of the experiment is 8. That is, 7 for the 7 factors each having 2 levels, and 1 for the average. Hence, L_8 (2^7) having 8 rows and 7 columns, can be used as the smallest orthogonal array. A N/2k fraction of a complete factorial plan in k factors, each having 2 levels, can be considered as the orthogonal array L_N (2^k). For example, in the Table, the 4/8 = 1/2 fraction of the complete 2^3 factorial experiment is the orthogonal array L_4 (2^3).

5.1 Triangular Tables:

Triangular tables were developed by Taguchi. These tables give valuable information about the columns of orthogonal arrays in interaction, thereby, helping with the design of experiments where estimation of interactions can be done. In the Table, the triangular table corresponding to the orthogonal array L_4 is given. The numbers in each row and column depict the column numbers in L_4 (See Table 3). The triangular table is a symmetric matrix because there is commutative interaction between the two columns a and b. Hence, lower triangular part is left blank and only the upper triangular part of the matrix is given in the representations.

	COLUMN		
COLUMN	1	2	3
1	(1)	3	2
2		(2)	1
3			(3)

Table 3: The Triangular Table for L_4

For example, using Table, in L_4, let column 1 be assigned factor A and the column 2 be assigned factor B. Then, from the triangular table of L_4, we observe that the interaction between columns 1 and 2 is contained in the column 3. A triangular table supplies all the information essential for assigning factors to an orthogonal array such that estimations of all the major effects and some of the required interactions are obtained. Taguchi provided the triangular tables for all 2nd order orthogonal arrays.

In the same manner as described for L_4, the triangular tables are used for the orthogonal arrays of higher dimensions. In fact, the triangular tables for lower dimensional orthogonal arrays are extended to obtain the triangular tables for the higher dimensional orthogonal arrays. For example, from Table 4, we observe that the triangular table for L_4 is extended to obtain the triangular table for L_8.

	COLUMNS						
COLUMNS	1	2	3	4	5	6	7
1	(1)	3	2	5	4	7	6
2		(2)	1	6	7	4	5
3			(3)	7	6	5	4
4				(4)	1	2	3
5					(5)	3	2
6						(6)	1
7							(7)

Table 4: The Triangular Table for L_8

6. Conclusion:

In this paper, we have discussed in detail, the working of the Taguchi methodology, its background and milestones, and its most distinguishing feature of the usage of Orthogonal Arrays, to which the Taguchi method owes its popularity. Using this popular algorithm, we will endeavour to find a solution to the problem undertaken .

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