A REVIEW ON DESIGN OF EXPERIMENTAL ANALYSIS

Shrikant U. Gunjal[1], Rahul Dabhade[2], Vishal Dabhade[3]

[1]Assistant Professor, [2, 3]UG Student, Department of Mechanical Engineering

Sandip Foundations- SITRC, Mahiravani, Trimbak Road, Nashik, Maharashtra,

Savitribai Phule Pune University (SPPU), Maharashtra, India

ABSTRACT

Experimental design is a critically important tool in engineering for continuous improvement of the performance of manufacturing process. It is essentially a strategy of planning, designing, conducting and analyzing experiments so that valid and reliable conclusions can be drawn in the most effective manner. Statistical experiments are generally carried out to explore, estimate or confirm. Experimental design has proved to be very effective for improving the process performance and process capability. Experimental procedures require a structured approach to achieve the most reliable results with minimal wastage of time and money. Experimental design, based on sound statistical principles, can be used to give an overall view of a manufacturing process using a limited number of experiments. The information gained can be used to optimize a process and define which parameters need to be placed under the most influencing in order to maintain the repeatability of a process. A mathematical model of the process can also be developed so that it can help in predicting the results which are expected when parameters are changed.

Keywords: Continuous Improvement, Experimental Design, Manufacturing Process, Minimal Wastage, Optimize.

I. INTRODUCTION

The basic concepts of the statistical design of experiments and data analysis were developed in the early part of the 20th century as a cost effective research design tool to help in improving the yields in farming. Since then, many types of designed experiment and analysis techniques have been developed to meet the diverse needs of researchers and engineers. The first statistician to consider a formal mathematical methodology for the design of experiments was Sir Ronald A. Fisher. Exploration consists of gathering and understanding data to learn more about the process or product characteristics. Estimation refers to determining the effects of process variables or factors on the output performance characteristic. This information is used to estimate the settings of factors to achieve maximum output. Confirmation implies verifying the predicted results obtained from the experiment. The application of experimental design is useful in all the above phases [1]. A well designed experiment can ensure improved process outputs, reduced variability and closer conformance to nominal or target requirements, reduced development time and reduction in overall cost.

The traditional approach of experimental design is empirical in nature. In this approach one factor is varied at a time keeping all other variables in the experiment fixed. This approach depends upon guesswork, luck, experience and intuition for its success. Moreover, this type of experimentation requires large resources to obtain a limited amount of information about the process [2]. One Variable-At-a-Time experiments often are unreliable, inefficient, time consuming and may yield false optimum condition for the process. Statistical thinking and statistical methods play an important role in planning, conducting, analyzing and interpreting data from engineering experiments. When several variables influence a certain characteristic of a product, the best strategy is then the statistical design of experiment which can give valid, reliable and sound conclusions that can be drawn effectively, efficiently and economically.

II. BASIC ELEMENTS OF EXPERIMENTAL DESIGNS

2.1 Randomization

The first principle of an experimental design is randomization, which is a random process of assigning treatments to the experimental units. The random process implies that every possible allotment of treatments has the same probability. An experimental unit is the smallest division of the experimental material and a treatment means an experimental condition whose effect is to be measured and compared. The purpose of randomization is to remove bias and other sources of extraneous variation which are not controllable [2, 3]. Another advantage of randomization is that it forms the basis of any valid statistical test. Hence the treatments must be assigned at random to the experimental units. Randomization is usually done by drawing numbered cards from a well-shuffled pack of cards or by drawing numbered balls from a well-shaken container or by using tables of random numbers.

2.2 Replication

The next principle of an experimental design is replication; which is a repetition of the basic experiment. In other words, it is a complete run for all the treatments to be tested in the experiment. In all experiments, some variations are introduced. This type of variations can be removed by replication. The experiments are to be performed more than once. An individual repetition is called a replicate. The number of replicate depends upon the nature of the experimental material. Replication of experiments can fetch the following benefits (i) It will secure more accurate estimate of the experimental error, thereby calculated values will tend to be closer to the true factor effects [4]; (ii) In un- replicated experiment, a single erroneous sample value can distort the whole analysis which will not be the case in replicated experiments; (iv) Considerable confidence is added if an experiment is replicated; (v) It will increase precision, which is a measure of the variability of the experimental error; and (iii) It will give more precise estimate of the mean effect of a treatment.

2.3 Local Control

It has been observed that all extraneous sources of variation are not removed by randomization and replication. This necessitates a refinement in the experimental technique. In other words, a design is to be selected in such a manner that all extraneous sources of variation are brought under control. For this purpose, one has to make use of local control, a term referring to the amount of balancing, blocking and grouping of the experimental units. Balancing means that the treatments should be assigned to the experimental units in such a way that the result is a balanced arrangement of the treatments. Blocking means that similar experimental units should be collected together to form a relatively homogeneous group [5]. Blocking reduces known but irrelevant sources of variation between units and thus allows greater precision in the estimation of the source of variation under study. The main purpose of the principle of local control is to increase the efficiency of an experimental design by decreasing the experimental error. Control in experimental design is used to find out the effectiveness of other treatments through comparison.

2.4 Orthogonality

Orthogonality concerns the forms of comparison (contrasts) that can be legitimately and efficiently carried out. Contrasts that can be represented by vectors and sets of orthogonal contrasts are uncorrelated and independently distributed if the data are normal [6]. Because of this independence, each orthogonal treatment provides different information to the others. If there are T treatments and T - 1 orthogonal contrasts, all the information that can be captured from the experiment is obtainable from the set of contrasts.

2.5 Comparison

In many fields of study it is hard to reproduce measured results exactly. Comparisons between treatments are much more reproducible and are usually preferable. Often one compares against a standard or traditional treatment that acts as baseline.

III. STEPS INVOLVED IN EXPERIMENTAL DESIGN

The following steps are involved in the design of experiment:

1. Definition of the objective of the experiment.
2. Selection of the response or output.
3. Selection of the process variables or design parameters (control factors), noise factors and the interactions among the process variables of interest. (Noise factors are those which cannot be controlled during actual production conditions, but may have strong influence on the response variability). The purpose of an experiment is to reduce the effect of these undesirable noise factors by determining the best factor level combinations of the control factors or design parameters.
4. Determination of factor levels and range of factor settings.
5. Choice of appropriate experimental design.
6. Experimental planning.
7. Experimental execution.
8. Experimental data analysis and interpretation.

IV. BENEFITS OF EXPERIMENTAL DESIGN

Experimental design enables industrial engineers to study the effects of several variables affecting the response or output of a certain process. Experimental design methods have wide potential application in the engineering design and development stages [6, 8]. It is the strategy of the management in today's competitive world to develop products and processes insensitive to various sources of variations. The potential benefits of experimental design are as under:

1. Reduction of product and process design and development time.

2. Possibility to study the behavior of a process over a wide range of operating conditions.
3. Minimizing the effect of variations in manufacturing conditions.
4. Understanding the process under study and thereby improving its performance.
5. Increasing process productivity by reducing scrap, rework etc..
6. Improvement in the process yield and stability of an on-going manufacturing process.
7. Making products insensitive to environmental variations such as relative humidity, vibration, shock and so on.
8. Studying the relationship between a set of independent process variables (i.e., process parameters) and the output (i.e. response).
9. It offers a framework where a researcher performs an experiment to confirm or deny certain allegations.
10. The experimental design gives investigators or researchers adequate control to analyze and establish the cause-effect relationships.
11. A researcher can be assured that the outcomes obtained are essentially true representations of the actual events.
12. An extra advantage is that experimental design enables the generalization of results.

V. TAGUCHI'S APPROACH

Taguchi's experimental methods are now widely used in many industries and in research to efficiently optimize the manufacturing process. It is an iterative approach which allows a statistically sound experiment to be optimized at minimal cost while investigating a minimum number of possible combinations of parameters or factors (Park, 1996). Taguchi's parameter design is an important tool for robust design. By applying this technique one can significantly reduce the time required for experimental investigation as it is effective in investigating the effects of multiple factors on performance as well as to study the influence of individual factors to determine which factor has more influence and which has less influence [9]. This method employs orthogonal arrays which reduce the number of trials and at the same time all factor effects are given equal importance and determine the effect of process parameters upon performance characteristics. Orthogonal arrays allow the simultaneous effect of several process parameters to be studied efficiently. Taguchi's technique effectively separates many trivial design parameters from the few vital ones making the design robust. Hence maximum information can be derived in minimum number of trials. Orthogonal arrays allow the simultaneous effect of several process parameters to be studied efficiently. Thus Taguchi contributed discipline and structure to the design of experiments. This standardized design methodology can be easily applied by investigators.

Its results are comparable to a full factorial experiment. Techniques such as fractional factorial experiments are used to simplify the experiment. Fractional factorial experiments investigate only a fraction of all the possible combinations. This approach saves considerable time and money but requires rigorous mathematical treatment both in the design of the experiment and in the analysis of the results. Each experimenter may design a different set of fractional factorial experiments. Taguchi simplified and standardized the fractional factorial designs in such a manner that two different persons conducting the same tests thousand of miles apart, will always use similar designs and tend to obtain similar results. Therefore, factorial and fractional factorial designs of experiments are widely and effectively used (Ranjit K. Roy, 2010). Taguchi's technique addresses the following limitations of full factorial experiments.

1. The experiments become unwieldy in cost and time when the number of variables is large.
2. Two designs for the same experiment may yield different results.
3. The designs normally do not permit determination of the contribution of each factor.
4. The interpretation of experiments with a large number of factors may be quite difficult.

In full factorial design if there are k factors at n levels, one requires nk trials. But in Taguchi's approach the influence of k factors could be found using k+1 trials. As a result, a drastic reduction in the number of experimental trials is possible. Considering the above factors, Taguchi's concept of 'Robust design' is extensively used in this investigation for designing the experiments.

Taguchi suggests signal-to-noise (S/N) ratio as the objective function for matrix experiments. The S/N ratio is used to measure the quality characteristics as well as the significant machining parameters through analysis of variance (ANOVA). Taguchi classifies objective functions into three categories such as smaller the better type, larger the better type and nominal the best type. The optimum level for a factor is the level that results in the highest value of S/N ratio in the experimental region (Gaitonde et al., 2008). Taguchi's approach for creating robust design is through a three-step method consisting of system design, parameter design, and tolerance design.

¾The focus on system design phase is on determining the suitable working levels of design factors. It includes designing and testing a system based on the engineer's judgment of selected materials, parts, and nominal product/process parameters based on current technology. Most often it involves innovation and knowledge from the applicable fields of science and technology. ¾Parameter design helps to determine the factor levels that produce the best performance of the product/process under study.

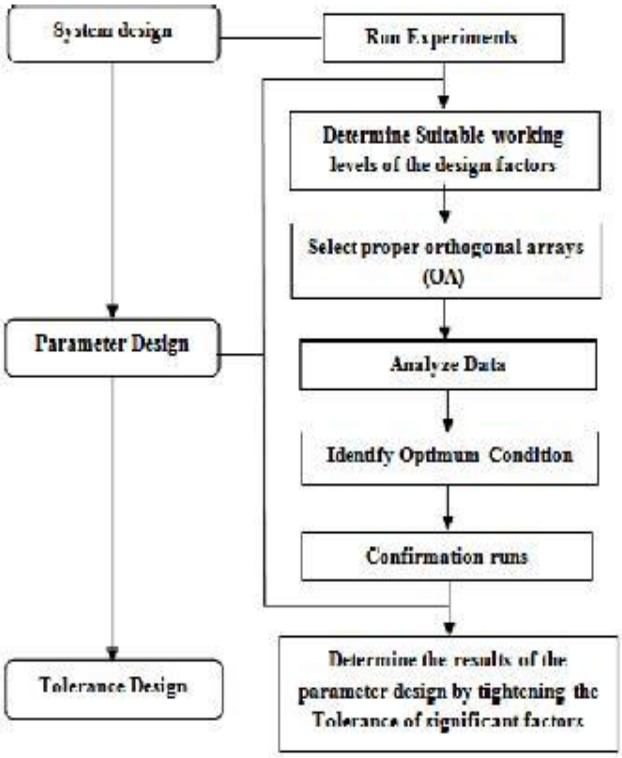

Fig.1 Taguchi Design Procedure

The optimum condition is selected so that the influence of the uncontrolled factors (noise factors) causes minimum variation of system performance. ¾Tolerance design is a step used to fine tune the results of parameter design by tightening the tolerance of factors with significant influence on the product. Such steps will normally lead to identify the need for better materials, buying newer equipments, spending more money for inspection, etc.

5.1 Steps Involved in the Taguchi Approach

Following are the steps to be followed during the Taguchi approach:

1. Identify the main function.
2. Determine the de sign parameters affecting the process. Parameters are variables within the process that affect the performance measure.
3. Identify the objective function to be optimized or more specific ally a target value or a performance measure of the process.
4. Identify the control factors and their levels.
5. Create orthogonal arrays for the parameter design indicating the number of experiments and conditions for each experiment. The selection of orthogonal arrays is based on the number of parameter s and the levels of variation for each parameter.
6. Conduct the experiments indicated in the completed array to collect data.
7. Analyze the data, predict the optimum levels and performance.
8. Perform the verification experiment and plan the future action.

5.2 Experimental Design Strategy of Taguchi Technique

Taguchi constructed a special set of orthogonal arrays to lay out his experiments. By combining the orthogonal Latin squares in a unique manner, Taguchi prepared a new set of standard orthogonal arrays to be used for a number of experimental situations. This array, designated by the symbol L8, is used to design experiments involving up to seven 2-level factors. The array has 8 rows and 7 columns. Each row represents a trial condition with factor levels indicated by the number of each row.

Each column contains four level 1 and four level 2 conditions for the factor assigned to the column. The orthogonal array facilitates the experiment design process. To design an experiment one has to select the most suitable orthogonal array, assign the factors to the appropriate columns and finally describe the combinations of the individual experiments called the trial conditions. The table identifies the eight trials needed to complete the experiment and the level of each factor for each trial run. The experiment descriptions are determined by reading numerals 1 and 2 appearing in the rows of the trial runs. A factorial experiment on the other hand would require 27 or 128 runs but would not provide appreciably more information.

The array forces all experimenters to design almost identical experiments [10]. Experimenters may select different designations for the columns but the eight trial runs will include all combinations independent of column definition. Thus the orthogonal array assures consistency of design by different experimenters.

5.3 Analysis of Results

In the Taguchi method, the results of the experiments are analyzed to achieve one or more of the following three objectives:

1. To establish the best or the optimum condition for a product or a process
2. To estimate the contribution of individual factors
3. To estimate the response under the optimum conditions.

The optimum condition is identified by studying the main effects of each of the factors. The main effects indicate the general trend of the influence of the factors. Knowing the characteristic, i.e., whether a higher or lower value produces the preferred result, the levels of the factors which are expected to produce the best results can be predicted. The knowledge of the contribution of individual factors is a key in deciding the nature of the control to be established on a production process. The analysis of variance (ANOVA) is the statistical treatment most commonly applied to the results of the experiment to determine the percent contribution of each factor. Study of the ANOVA table for a given analysis helps to determine which of the factors need control and which do not.

Once the optimum condition is determined, it is usually a good practice to run a confirmation experiment. It is however possible to estimate performance at the optimum condition from the results of experiments conducted at a non-optimum condition. Qualitek-4 software is used to easily accomplish experiment design and analysis tasks [11, 12]. Qualitek automatically designs experiments based on user-indicated factors and levels. The program selects the array and assigns the factors to the appropriate column. For complex experiments a manual design option is also included in the software. The program performs three basic steps in the analysis: main effect, analysis-of variance and optimum studies. Analysis can be performed using standard or signal-to-noise ratios of results for smaller, bigger, nominal or dynamic characteristics. Results can be displayed using pie-charts, bar charts or trial-data-range graphs.

VI. CONCLUSION

In the design of engineering products and processes, analytical simulation plays an important role by transforming a concept into the final product design. The Taguchi's approach can be utilized to arrive at the best parameters for the optimum design configuration with the least number of analytical investigations. Taguchi's method is the method that treats factors at discrete levels. Frequently this approach significantly reduces computer time.

REFERENCES

[1] Astakhov, V.P. (2010) "Metal cutting theory foundations of near-dry (MQL) machining", International Journal of Machining and Machinability of Materials 7,

[2] Rahim, E.A. and H. Sasahara, H. (2011) "A study of the effect of palm oil as MQL lubricant on high speed drilling of titanium alloys", Tribology International 44, 309–317.

[3] Tasdelen, B., Thordenberg, H. and Olofsson, D. (2008) "An experimental investigation on contact length during minimum quantity lubrication (MQL) machining", Journal of Materials Processing Technology 203, 221-231.

[4] Tasdelen, B., Wikblom, T. and Ekered, S. (2008) "Studies on minimum quantity lubrication (MQL) and air cooling at drilling", Journal of Materials Processing technology 200, 339-346.

[5] Suresh Kumar Reddy, N., Nouari, M. and Yang, M. (2010) "Development of electrostatic solid lubrication system for improvement in machining process performance", International Journal of Machine Tools and Manufacture 50 789-797.

[6] Weinert, K., Inasaki, I., Sutherland, J.W. and Wakabayashi, T. (2004) 'Dry machining and minimum quantity lubrication', Annals of the CIRP 53(2), 511–537.

[7] Aoyama, T., Kakinuma, Y., Yamashita, M. and Aoki, M. (2008) "Development of a new lean lubrication system for near dry machining process" Annals of CIRP - Manufacturing Technology 57, 125–128.

[8] Dhar, N.R., Ahmed, M.T. and Islam, S. (2007) "An experimental investigation on effect of minimum quantity lubrication in machining AISI 1040 steel", International Journal of Machine Tools and Manufacture 47, 748-753.

[9] Khan, M.M.A., Mithu, M.A.H. and Dhar, N.R. (2009) "Effects of minimum quantity lubrication on turning AISI 9310 alloy steel using vegetable oil-based cutting fluid", Journal of Materials Processing Technology 209, 5573-5583.

[10] Abukhshim, N.A., Mativenga, P.T. and Sheikh, M.A. (2004) "An investigation of the tool-chip contact length and wear in high-speed turning of EN19 steel", Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture 218, 889-903.

[11] Alberts, M., Kalaitzidou, K. and Melkote, S. (2009) "An investigation of graphite nano platelets as lubricant in grinding", International Journal of Machine Tools and Manufacture 49, 966-970.

[12] Dilbag, S. and Rao, P.V. (2008) "Performance improvement of hard turning with solid lubricants", International Journal of Advanced Manufacturing Technology 38, 529-535.