Application of Grey Based Taguchi Method in Optimization of Process Parameters- A Review

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Abstract— Over the years, optimization of process parameters of various engineering process has been the challenge for the researchers. Process outcomes depend upon the process parameters so optimization of process parameters is necessary. Single output problems can be solved by various conventional optimization methods but multi-objective optimization problems are critical to solve and hence to achieve optimal process parameters is a challenge. Taguchi method is a popular approach to optimize the process parameters of any process. But for multi-objective optimization, Grey based Taguchi method is utilized to achieve the optimal process parameters and ANOVA is used to validate the results. In this article, review of optimization of various processes using grey relational analysis is employed. It is found in this review article that grey relational analysis is the competent optimization approach to achieve the optimal process parameters.

Key words: Taguchi Method, Optimization, Grey Relational Analysis (GRA)

I. INTRODUCTION

Quality has become vital in today's manufacturing world. Quality is the level of customer satisfaction provided from the product. Any product must meet the functional requirement of the customer for which it is procured. [1] For gaining the better product's quality, continuous research is going on to achieve it. For any process, objective parameters depend on the input parameters of that process. For example, in plastic injection molding, various objective parameters are improved mechanical strength, low shrinkage and warpage etc. Injection molding process depends upon the various input parameters like melt temperature, mold temperature, injection pressure, packing pressure, packing time etc. The input process parameter must be set such that objective function of the process may be achieved. To achieve the optimal set of process parameters, very experimenter needs proper planning to obtain adequate, relevant and reliable data. Experimenter performs a string of experiments, which requires series of calculations after every experiment so that analysis of observed data gives the answer to the question "Which parameters should be varied and to what extent". In these attempts, a long series of experiments doesn't yield any fruitful results.

Design of Experiment (DOE) is a popular approach for investigation of a system. [2] A series of structured tests are considered in which planned changes are made to the input variables of a system. The effects of these changes on objective functions are then assessed. DOE is important as a recognized way of maximizing the information gained, while minimizing the resources required. It gives a conclusion on the significance to the objective function of input variables acting alone, as well input variables acting in combination with one another. DOE identifies the input variables and the objective functions that are to be measured. For each input variable, a number of levels are defined over the range for which the effect of that variable is to be known. A proper plan is produced which tells the experimenter where to set each parameter for each run of the experiment. The output responses is then measured for each experiment Proper planned experiments produces significant information and often require less runs than what haphazard or unplanned experiments do require.

II. TAGUCHI DESIGN

Dr. Genichi Taguchi has developed a method based on "Orthogonal Array" experiments which gives much reduced "variance" for the experiment with "optimum settings" of control parameters. Thus the DOE with optimization of process parameters to obtain the 'best' results is achieved through the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of minimum experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), serve as objective functions for the optimization of the process parameters and helps in data investigation and prediction of optimum results.

Taguchi method is applicable only for the single objective optimization problem. For multi-objective optimization, grey based Taguchi method, popularly known as grey relational analysis is employed. [3]

III. GREY RELATIONAL ANALYSIS (GRA)

Many researchers have utilized grey based Taguchi method to optimize process parameters of a process.

P. Sahoo et al [4] done experimental study of tribological performance of electroless Ni–P coatings and optimization of tribological test parameters using grey relational analysis. Based on L_{27} Taguchi orthogonal design, experiments were carried out by utilizing the combination of tribological test paremeters. The three test paremeters in the study were load, speed and time. Study shows that test parameters significantly improve friction and wear behaviour of Ni-P coating.

Hakan Aydin et al [5] studied welding process of welded AA1050-H22 aluminum alloy and found that Taguchi method is a very useful tool for process optimization. The objective functions of the study were higher tensile strength with lower elongation. They applied Taguchi method coupled with Grey relation analysis for solving multi criteria optimization problem in the field of friction stir welding process. Experimental results of the study reveals that tensile strength and elongation of welded AA1050-H22 aluminum alloy are higly improved by using Grey based Taguchi method.

Sadasiva Rao T. et al [6] utilized Taguchi based Grey relational analysis for multi-objective optimization of process parameters in Face milling Inconal 718 metal based super alloy. The input variables in the study were cutting speed, feed, depth of cut and approach angle. The response variables of the study were force, tool life and surface roughness. The optimal combination of control factors and their levels were found to be 40 m/min cutting speed, 0.16 mm/rev feed, 0.1 mm depth of cut and approach angle of 350. Using ANOVA, it was shown that the cutting speed is the most influential control factor among the four face milling process parameters investigated in the work, when minimization of cutting forces, maximization of tool life and minimization of surface roughness were considered simultaneously.

Ali M. Hatab et al [7] revealed the application of grey relational approach for determining optimum friction welding parameters for multiple performances more effectively than single objective problem. The responses of the study were metal loss length or the joint hardness measurements as a single quality characteristic to efficiently establishing optimal friction welding parameters for joining similar aluminum alloy. The optimum parameters of the friction welding process were found to be rotational speed of 164.93 m/min, friction pressure of 42 bar, and forge pressure of 100 bar with 81.94% contribution. The hardness of the produced welding joint was in the range of 75 to 95% of the base metal hardness.

Shun-Te Lin et al [8] proposed grey-relational analysis for supporting a water- marking scheme By using grey-relational analysis for the watermarking schemes in audio, 2D images and 3D images, based on the grey-level degree, a relatively better watermarking scheme for each medium was found.

Saurav Datta et al [1] studied multi-objective optimization problem to get the optimal parametric settings to yield bead geometry of submerged arc bead-on-plate welding. The study utilized Taguchi's L_{25} orthogonal array design and derived the objective functions. The input variables were bead width, beadreinforcement, depth of penetration and depth of HAZ. The grey relational analyses were performed to solve the multi-objective optimization problem. The study reveals that Taguchi based grey relational analysis improves the product quality in bead-on-plate welding.

Chung-Feng et al. [9] studied PEEK injection molding process using the Taguchi method and to make the experimental plan with the minimum number of runs. However, the Taguchi method was used for obtaining the optimum parametric combination for a single quality characteristic only, and did not give any concern to the relationship between multiple quality characteristics and parametric settings. Therefore, the grey relational analysis was utilized to overcome the drawback of the Taguchi method and to achieve the desired outcomes of optimization for multi-objective optimization. In this study of the optimization of multiple responses, the dimensional deviation of the injection molded screw's outer diameter was minimized successfully, and the tensile strength and twisting strength of the screw were maximized. The study utilized grey relational analysis with the Taguchi method for the optimization of the PEEK injection molding. The efficient optimization model had been successfully proven by experiments. L18 orthogonal array were used to get the target value of the hexagonal screw's outer diameter and the maximum mean values of the tensile strength and twisting strength.

The optimal parametric settings of the PEEK injection molding for the hexagonal screw were found to be mold temperature of 1600C, pre-plasticity amount of 5 cm, injection pressure of 250 bar, injection speed of 15 cm/sec, screw speed of 25 m/min, packing pressure of 600 bar, packing time of 3 sec and a cooling time of 15 sec.

IV. METHODOLOGY OF GRA

In this grey relational analysis, the normalized data processing for a minimized response corresponding to lower- the-better criterion can be expressed as

$$x_i(k) = \frac{x_i(k) - \min\ x_i(k)}{\max\ x_i(k) - \min\ x_i(k)}$$

The first standardized formula is suitable for the benefit – type factor.

$$x_i(k) = \frac{\max\ x_i(k) - x_i(k)}{\max\ x_i(k) - \min\ x_i(k)}$$

The second standardized formula is suitable for defect – type factor.

$$x_i(k) = \frac{|x_i(k) - x_0(k)|}{\max\ x_i(k) - x_0(k)}$$

The third standardized formula is suitable for the medium – type factor.

The grey relation degree can be calculated by steps as follows:

A. The absolute difference of the compared series and the referential series should be obtained by using the following formula:

$$\Delta x_i(k) = |x_0(k) - x_i(k)|$$

and the maximum and the minimum difference should be found.

B. The distinguishing coefficient p is between 0 and 1. Generally, the distinguishing coefficient p is set to 0.5.

C. In Grey relational analysis, Grey relational coefficient (ξ) can be expressed as follows:

$$\xi_i(k) = \frac{\Delta\min + p\Delta\max}{\Delta x_i(k) + p\Delta\max}$$

and then the relational degree follows as:

$$r_i = \sum [w(k)\xi(k)]$$

In equation (6), ξ is the Grey relational coefficient; w (k) is the proportion of the number k influence factor to the total influence indicators.

V. OPTIMIZATION OF TAGUCHI METHOD AND GREY RELATIONAL ANALYSIS

Based on the above discussion, the use of the Taguchi method with grey relational analysis to optimize the multi-objective optimization includes the following steps:

1) Identify the response characteristics and process parameters to be considered for the process.
2) Determine the number of levels for the experiment.
3) Select the appropriate orthogonal array.

4) Conduct the experiments based on the chosen orthogonal array.
5) Normalize the experimental results between 0 and 1 to perform grey relational analysis.
6) Calculate the grey relational coefficient
7) Convert the grey relational coefficient to grey relational grade.
8) Convert the multi response grey relational grade into single grey relational grade.

VI. CONCLUSION

From the literature survey it is concluded that grey based Taguchi method is very popular and effective method for optimization of multi-objective optimization problems. It gives the optimal process parametric combination of any process efficiently and hence is helpful in achieving the product quality of procured products.

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