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Review on Optimization Techniques such as DOE and GRA used for Process Parameters of Resistance Spot Welding

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Abstract: ***In order to maintain the optimum utilization of the resources, time and economy, the various process parameters and their levels are optimized in order to get the output quality product or process. Many industries such as automobiles, domestic appliances, air craft and space craft fabrication having the resistance spot welding as a major sheet metal joining process. As the spot welding involves interactions of thermal, mechanical, electrical and metallurgical phenomenon, controlling the welding parameters plays an import role on the quality of the weld. Resistance spot welding is a high speed process, where in the actual time of welding is a small fraction of second and it is one of the cleanest and most efficient welding processes. Resistance spot welding has ability to join the variety of materials and complicated shapes with high accuracy and great precision. The Taguchi Method is used to determine the optimum process parameters. At the design stage, for the purpose of designing and improving product quality, the Taguchi Method is a systematic application of design and analysis of experiments.***

Keywords: Resistance spot welding (RSW), Taguchi Method, Design and Analysis of Experiments, Grey system Theory, Optimization

1. Introduction

Resistance spot welding process in which coalescence of metal is produced at the faying surface by the heat generated at the joint by the contact resistance to the flow of electric current. The materials to be joined are brought together under pressure by a pair of copper electrodes of the require tip diameter. The amount of heat produced is of current, time and resistance between the workpieces. It is desirable to have the maximum temperature at the interface of the parts to be joined. The process uses resistance of the materials to the flow of current that causes localized heating between the parts to be joined. Electrode cap life gets reduced and deteriorates the weld quality due to excessive heat in the electrodes.

The strength of the weldment is measured by certain standardized destructive tests by the application of different types of loading. Some of these are tension-shear, torsion, tension, hardness, fatigue and impact. The welding parameters significantly affect the stiffness and the operating strength of sheet metal parts. [1]

Recently, for analyzing multivariate time series data (MTS) the multi objective technique Grey relational analysis (GRA) has been widely applied as a solution to the conventional statistical limitations. For analyzing relationships in MTS, GRA has been proven to be simple and accurate method in various disciplines such as engineering, economics and sociology. Grey relational analysis is used to search for grey relational grade, which can be used to describe the relationships among the factors and to determine the important factors that significantly influence some define objective. [2]

Spot Weld Parameters:

The determination of appropriate welding parameters for spot welding is a very complex phenomenon. A small change of one parameter will affect all the other parameters.

1. Electrode Force

The purpose of electrode force is to squeeze the metal sheets to be joined together. This requires a large electrode force otherwise the weld quality will not be good enough. When electrode force is increased the heat energy will decrease. This indicates that higher electrode force requires a higher weld current. An adequate target value for electrode force is 90N per mm^2.

2. Squeeze Time

Squeeze time is the time interval between the initial application of the electrode force on the work and the first application of current. Squeeze time is necessary to delay the weld current until the electrode force has attained the desired level.

3. Weld Time

Weld time is the time during which welding current is applied to the metal sheets. The weld time is measured and adjusted in cycles of line voltage as with all timing functions. Weld time should be as short as possible. The weld time shall cause the nugget diameter to be big when welding thick sheets.

4. Hold time

Hold time is the time, after the welding has occurred when the electrodes are still applied to the sheet to chill the weld. Considered from a welding technical point of view, the hold time is the most increasing welding parameter. Hold time is necessary to allow the weld nugget to solidify before releasing the welded parts. If hold time is too long and carbon content of the material is high (more than 0.1%), there is a risk the weld become brittle.

5. Weld Current

The weld current is the current in the welding circuit during the spot welding process. The amount of weld is controlled by two things, first the setting of the transformer tap switch determines the maximum amount of weld current available; second the percent of current control determines the percent of the available current to be used for making the weld. Weld current should be kept as low as possible. When the weld current becomes too high, spatter will cause the electrodes to get stuck to the sheet. [3]

Two Multi- Objective Optimization Techniques are described as follows

A) Design Of Experiments (D.O.E)

Design of experiments is a series of steps arranged in a certain sequences for the experiment to achieve an improved understanding of product or process. The process is made up of three main phases such as planning phase, the conducting phase and the analysis/interpretation phase. Experimental design methods have found broad application in the scientific and engineering field for improving the product realization process. The application of experimental design techniques early in process development can results in:

1 Improved process yields
2 Reduced variability and closer conformance to nominal or target requirements.
3 Reduced development time
4 Reduced overall costs

The use of experimental design in product realization can result in products that is easier to manufacture and that have enhanced field performance and reliability, lower product cost and shorter product design and development time.

Some applications of experiment design in engineering design include:

1. Evaluation and comparison of basic design configurations
2. evaluation of material alternatives
3. Selection of design parameters so that the product will work well under a wide variety of field conditions for achieving robustness in the product.
4. Determination of key product design parameters that impact product performance.
5. Formulation of new products. [4]

Steps for DOE are as follows

1. Orthogonal Array Selection and utilization

A major step in the DOE process is the determination of the combination of factors and levels which will provide the experimenter with the desired information. One approach is to utilize a fractional-factorial approach whenever there are several factors involved and this may be accomplished with the aid of orthogonal arrays.

Many times, discrete variables such as different materials cause a portion of the experiment to be unable to be exposed to the variation of other factors. This situation requires the use of a nested experiment to allow easy analysis of the data.

2. Conducting Tests

Two Statistical aspects of conducting tests, sample size and randomization are addressed. The sample size affects the sensitivity of the experiment and the randomization protects the experimenter from unknown influences which may bias the experimental results and subsequent decisions.

Different randomization strategies are applied to typical product, process and production situations.

3. Analysis and Interpretation Methods for Experiments

More sophisticated methods, starting with the basics of conducting an analysis of variance for a particular set of data. Analysis of variance is applied to the orthogonal array type of designed experiment. Polynomial decomposition of variance is necessary with the information is gained when running a multiple level experiment.

4. Confirmation Experiment

Two methods of estimating the mean are used: standard and omega. These estimates are used as predictions of the results of a confirmation experiment which validates the conclusions drawn from previous round of experimentation.

5. Parameter Design

The main thrust of Taguchi methods is the use of parameter design, which is the ability to design a product or process to be resistance to various environmental factors that change continuously with the customer use. To determine the best design of a product or process requires the use of strategically designed experiment which exposes the product or process to the varying environmental conditions.

Taguchi refers to these variations in customers use as noise factors. The analysis of the experimental results uses a signal to noise ratio to aid in the determination of the best product or process design. Nonlinear response characteristics of products or processes can be used to the engineer's advantage if the proper design philosophy is employed.

6. Tolerance Design

Tolerance design is to achieve high quality at some cost in the product or process by tightening tolerance on specifications. This approach is used when parameter design has not achieved the quality level desired by the customer. Tolerance design utilizes information from the ANOVA of the experiment to determine which specifications are most appropriate to tighten.[5]

Engineers and Scientists are most often faced with two product (or process) development situations. One development situation is to find a parameter that will improve some performance characteristic to an acceptable or optimum value. A second situation is to find a less expensive, alternative design, material, or method which will provide equivalent performance.

No. of Experiments= (No. of Level) $^{\text{No. of factors}}$

The selection of which orthogonal Arrays to use predominantly depends on the following items:

1. The number of factors and interactions of interest.
2. The number of levels for the factors of interest.
3. The desired experimental resolution or cost limitations.

Two level arrays are:

L_4, L_8, L_{12}, L_{16}, L_{32}

Three level arrays are:

L_9, L_{18}, L_{27}

In order to improve productivity during research and development. Robust Design is an engineering methodology. Through his research in 1950's and early 1960's, Dr. Genichi Taguchi developed the foundations of Robust Design and validated the basic underlying philosophies by applying them in the development of many products.

Sir Ronald Fisher's work on the basic principles of experimental design along with data analysis technique called analysis of variance (ANOVA) for improving the yield of agricultural crops showed the significant effects in England in the 1920's. Fisher founded the science of statistical experimental design to plan experimental design to plan experiments for obtaining dependable information about variables involved in making engineering decisions. Robust Design method can be applied to a wide variety of problems in electronics, automotive products and many other industries.

Dynamic systems are those in which system's response follows the levels of the signal factors in a prescribed manner. The changing nature of the levels of the signal factor and the response make designing a dynamic system more intricate than designing a static system.

A complicated non linear function is obtained by relating product's quality characteristic to the various product parameters and noise factors. Quite different variations in the quality characteristic are caused by non linearity, these different product parameter combinations. By exploiting the non linearity for finding the combinations of product parameter values which gives smallest variation in the value of the quality characteristic around the desired target value.

Mathematically the response is expressed as

y = f (x, z)

The deviation Δy, of the quality characteristic from the target value caused by the deviations, Δx_i , of the noise factors from their respective nominal values can be approximated by the following formula:

$$\Delta y = \left[\frac{\partial f}{\partial x_1}\right]\Delta x_1 + \left[\frac{\partial f}{\partial x_2}\right]\Delta x_2 + \ldots\ldots\ldots + \left[\frac{\partial f}{\partial x_n}\right]\Delta x_n$$

Further, if the deviations in the noise factors are uncorrelated, the variance, σ_y^2 of y can be expressed in terms of variances, $\sigma_{x_i}^2$ of the individual noise factors as

$$\sigma_y^2 = \left[\frac{\partial f}{\partial x_1}\right]^2 \sigma_{x_1}^2 + \left[\frac{\partial f}{\partial x_2}\right]^2 \sigma_{x_2}^2 + \ldots + \left[\frac{\partial f}{\partial x_n}\right]^2 \sigma_{x_n}^2$$

Thus, the σ_y^2 is a sum of products of the variances of the noise factors $\sigma^2 x_i$ and the sensitivity co-efficient $\left[\frac{\partial f}{\partial x_i}\right]^2$. A robust product (or robust process) is one for which the sensitivity coefficients are the smallest.

Robust Design is a methodology for finding the optimum settings of the control factors to make the product or process insensitive to noise factors. It involves eight steps that can be grouped into three major categories of planning experiments, conducting them and analyzing and verifying the results.

Planning the Experiment:

1. The main function, side effects and failure modes are to be identified.
2. For the evaluation of the quality loss, noise factors and testing conditions need to be identified.
3. The required quality characteristics to be identified and the objective function to be optimized.
4. Control factors with their alternative levels must be identified.
5. The matrix experiment is to be designed and the data analysis procedure is to be defined.
6. Performing the Experiment:
7. Conducting the matrix experiment.
8. Analyzing and verifying the experiment results:
9. By the analysis of the data, determine optimum levels for the control factors and the performance under these levels must be predicted.
10. Conduct the Verification experiment and plan future actions.

The two major tools used in Robust Design are:

i. Signal to noise ratio which measures quality.
ii. Orthogonal arrays which are used to study many design parameters simultaneously. [5]

B) Grey Relational Analysis

In order to study certain problems with less data and poor information Grey System Theory is a new methodology. This Grey System studies on the "poor information", "small sample" systems with partial information unknown and partial information known. By extracting valuable information, It describes correctly and the system's operation and evolution is monitored effectively. [7]

The Grey relational analysis uses information from the Grey system to dynamically compare each factor quantitatively. This approach is based on the level of similarity and variability among all factors to establish their relation. The Grey relational analysis is a method to analyze the relational grade for discrete sequences. This is unlike the conventional statistics analysis handing relation between variables. Grey relation analysis is used to perform multiple attributes overall evaluation, the measurement unit is not necessarily be the same. It can easily determine the overall index without consulting utility functions. [10]

GRA is a method for identifying and prioritizing the key factors of a system. It quantifies the influence that an input variable exerts to the output variable by computing the Grey Relational Grades. Grey relation grades are numerical measures of the impact of the influencing variables on the target variables. The larger the grey relational grade the more significant impact the influencing variable (input) has on target variable (output). GRA is described as an alternative method of variable independence analysis. The main advantages of GRA are its comparative simplicity and its ability to deal with small sets of data that do not have typical probability distribution. [9]

For analyzing undeveloped and complicated systems, Grey System Theory provides understanding, techniques and ideas.

The main objectives of the Grey System theory are as follows:

1. In case of regression technique, a non functional model is established.
2. Using grey generating techniques, the disorderly raw data is turned into more regular series for the benefit of modeling instead of modeling with original data.
3. Building a grey model (GM)- by using the least 4 data to replace difference modeling in vast quantities of data.
4. The Grey process is defined and constituted replacing the stochastic process and to find the real time techniques.
5. To set up an approach to modeling with few data, avoiding searching for data in quantities.
6. For grey decision making, innovational techniques and concept are developed.
7. To develop novel control techniques eg. The grey forecasting control replacing classical control which is referred to as afterward control, also relational control, generating control and programming control.
8. To study feeling and emotion functions and fields with whitening functions.
9. To study the mechanism theory, along with grey sequence theory and grey structure theory.
10. Based on grey relations, grey elements and grey numbers to be used to study grey mathematics in place of classical mathematics study.

The essential topic of Grey system theory includes the following areas:

Grey relational space
Grey generating space
Grey decision making
Grey forecasting
Grey mathematics
Grey control
Grey theory
Grey programming [10]

For the Grey Relational Generation the quality characteristics are first normalized, ranging from zero to one. Based on normalized experimental data, the Grey Relational coefficient is calculated for representing the correlation is calculated for representing the experimental data. Corresponding to selected response, overall Grey Relational Grade (GRG) is determined by averaging Grey Relational Coefficients.

The overall performance characteristic of the multiple response process depends on the calculated GRG. This is the conversion of a multiple response process optimization problem into a single response optimization problem. The combination of optimal parameters is then evaluated obtaining the highest Grey relational grade. The Taguchi method is used for the optimal factor setting to maximize the overall Grey relational grade.

Higher the better criterion can be expressed as:

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

Lower the better criterion can be expressed as:

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

Where x_i (k) and x_j (k) are the value after Grey Relational Generation for HB and LB criteria. Max y_i (k) is the largest value of y_i (k) for k^{th} response and **min** y_i (k) is the minimum value of y_i (k)for the $\mathbf{k^{th}}$ response.

The Grey relational coefficient ξi**(k)** can be calculated as:

$$\xi i(k) = \frac{\Delta \min - \psi\,\Delta max}{\Delta O_i(k) + \psi \Delta max}$$

And $\Delta o_i = ||x_o\ (k) - x_i\ (k)||$

Where $\Delta \mathbf{o_i}$ is the difference between absolute value $x_o\ (k)$ and $x_i\ (k)$, ψ is the distinguishing coefficient $0 \leq \psi \geq 1$, Δmin and Δmax are the minimum and maximum value among the for corresponding k^{th} response. Now the Grey Relational Grade can be calculated as:

$$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi i(k)$$

Where **n** is the number of process responses. The higher value of the GRG corresponds to a relational degree between the Reference sequence $x_o\ (k)$ and the given sequence $x_i\ (k)$. The Reference sequence $x_o\ (k)$ represents the best process sequence. Therefore, a higher GRG means that the corresponding parameter combination is closer to the optimal. The mean response for the GRG and the main effect plot of the GRG are very important. [11]

2. Conclusions

From the above study of tools and techniques used for Multi-objective optimization of processes and its parameters, it is come to know that,

1. With the consideration of multiple responses, the Design of experiments techniques has been applied using Taguchi Method.
2. Analysis of variance technique is used for determining the level of importance of welding parameters on the response variables.
3. The analysis of S/N ratio used for obtaining an optimum parameter combination for the required response variable characteristic.
4. For the optimization process parameters, Taguchi Method is efficient, close to target and economical.
5. The grey system theory is pioneered by Prof Deng Julong in 1982. Many scientific and technological theories require the continuous efforts of several generations of people and have gone through hundreds of years before reaching maturity and perfection.
6. Grey system Theory is 30 years old and still there is a wide scope to explore it for the applications in the science and Technology.
7. Engineers and Scientists engaged in the Advances of the Grey system Research should take serious in all criticisms.
8. Then the problems and flaws can be overcome, the new growing point be excavated, exploring and innovating with the modern computerized techniques for the analysis and Computations. Thus making the grey system theory, originated by Chinese Scholars goes forward significantly.
9. There is a wide scope for the development of Grey Relational System software for the applications in Engineering Field.

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