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Technical Paper

Experimental design in soap manufacturing for optimization of fuzzified process capability index

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ABSTRACT

In manufacturing industries, the quality of a product depends on the combined effect of multiple input variables working singly or together and therefore attention has been given on process capability indices to shift from single to multivariate domain. In case of multivariable domain the capability to incorporate uncertainties at the time of decision making becomes necessary. Fuzzy system is introduced to take care of this requirement. In this article the process parameters of soap manufacturing industries have been analyzed. The process capability is determined using Fuzzy Inference System rule editor based on a set of justified if then statements as applicable for the process. The data has been collected in linguistic form to derive its process capability, using a set of justified rules and the effect of each factor has been determined using Design of Experiments (DoE) and analysis of variance technique (ANOVA) for improving the soap quality from perspective of its softness. This article ventures to propose a new methodology by integrating Fuzzy with DoE providing better result followed by DoE and Fuzzy Inference system in isolation.

1. Introduction

Quality of a product is measured in terms of total loss to the society due to functional variation and harmful side effects. Greater the loss is, lower the quality is. This loss occurs due to the failure of the product to deliver the target performance and due to harmful side effects of it including its cost. It is not possible to achieve zero loss or ideal quality condition, but using robust design engineering methodology we can improve the quality of a product by minimizing the effect of the causes of variation without eliminating the causes. This is achieved by optimizing the product and process design to make the performance minimally sensitive to causes of variation. Robust design broadly can be divided into two steps–planning the experiments and perform them. The data is disguised to conceal the identity of the manufacturing company and the data has been modified suitably for obvious reason. This however has not affected the treatment in the present article as the data presented here are quite representative of the actual operation. They are defined in linguistic form that is a particular range has been taken for each variable as these variables are always subjected to change and so defining them in this way is much more reliable. This article demonstrates the fact that integration of Fuzzy with DoE has not been shown in articles published previously. It ventures to propose a new methodology by integrating Fuzzy with DOE providing better result followed by DoE and Fuzzy Inference system in isolation.

The main factors and noise factors are identified, and also conditions are tested for evaluating quality loss. The control factors and their levels are recognized and then Design of Experiment matrix formed. Matrix experiment is conducted and then we analyze the results through ANOVA to determine which factor is putting emphasis most on whole soap making process and then plan for future. This is Robust Design Cycle through which soap quality can be improved. DoE is done to obtain data to quantitatively estimate the effects of factors on system responses without having to measure system response at every point in its operating space. Quality analysis is done to obtain predictive optimal level of the system.

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1.1. Literature review

Process capability is defined as the capability of the process to produce its output response within its specification limits [18]. It provides numerical measures on whether a process conforms to the defined manufacturing capability prerequisite [19]. Process capability indices are summary statistics which measure the actual or the potential performance of process characteristics relative to the target and specification limits. In most traditional methods, precise estimation is used to assess the capability of manufacturing processes [20]. Fuzzy allows a realistic approach that allows the consideration of imprecise output data resulting from measurements of quality product. Fuzzy inference procedure helps to assess process capability considering certain degree of imprecision on the sampled data leading to decision rule with four quadrants decision making plot [15]. Most of the traditional methods for assessing the capability of manufacturing processes are dealing with crisp quality. Therefore, classical statistics have been combined with fuzzy theory [16]. Fuzzy process capability indices are introduced, where instead of precise quality we have membership functions for specification limits. These indices are necessary when the specification limits are fuzzy and they are helpful for comparing manufacturing processes with fuzzy specification limits [17].

Fuzzy approach has been proved to be helpful to select parameters, for example, machining parameters such as Electronic Discharge Machining (EDM). Condition monitoring of the machining process is very important in today's precision manufacturing, especially in EDM. A fuzzy-based algorithm can be used for prediction of material removal rate (MRR), tool wear ratio (TWR), and surface roughness [14]. Reconfigurable machine tools (RMTs) are synthesized using the principles of modular design in order to achieve the required structural design for a particular part to be manufactured. A method that uses multi-level fuzzy decisions to create dynamic optimal configurations of machine structures with respect to a given part geometry can be presented [13].

The objective of Taguchi's robust design method is to reduce the output variation from the target (the desired output) by making the performance insensitive to noise, such as manufacturing imperfections, environmental variations and deterioration. However it has some limitations that can lead to non-optimal solutions. In addition, since his modeling loss approach requires a special experimental format that contains a cross-product of two separate arrays for control and noise factors, this leads to less flexible and unnecessarily expensive experiments. The response model approach, an alternative approach does not have these problems. However, this alternative approach also has its own problems. This paper reviews and discusses the potential problems of Taguchi's modeling approach [1]. Taguchi's method appears to be an ideal statistical tool for the post-analysis correct determination of chemical composition in marine sediment samples. Using Taguchi's method in the chemistry laboratory, controllable factors can be isolated to provide centering and variance control in sediment concentration minimizing the effect of noise factors. Statistical analysis is performed to identify the effect of parameters and their interactions. Also the expected cost savings under optimum condition is calculated [2]. Optimization of the gear blank casting process is possible by using Taguchi's Robust Design technique. The metal casting process involves a large number of parameters affecting the various casting quality features of the product [3]. Taguchi's robust parameter design (RPD) has its application in the design of a motor in a large electrical company in India. There used to be specific customer requirements related to temperature rise and low efficiency of the existing model of motor, which the organization was unable to meet. The experimentation was carried out by a computer simulation [MINITAB] and the data were analyzed using signal-to-noise ratio method. From the analysis of variance along with main effect plots, the optimum factor level combination for the new product was reached [4]. The expanding use of experimental design techniques for statistical tolerance is primarily due to their simplicity. They can be understood easily and implemented by engineers and scientists having only a limited knowledge of statistics and experimental design. But there are some limitations that do not give always a true optimal condition [5]. Magneto-optic/eddy current imaging (MOI) is becoming widely used for aging aircraft inspection for cracks and corrosion. The optimization of the parameters is extremely crucial in enhancing the performance of MOI system. Taguchi method can be used to change parameter values simultaneously to search for the optimum set of test parameters for maximizing system performance for a given sample geometry and critical crack [6]. If we compare classical ANOVA with Taguchi's method, the 2nd one is found to be better in functioning. After observing the robustness of the classical ANOVA techniques and the use of Taguchi's signal-to-noise ratio coupled with the proposed pooling of the error variances under various simulated experimental conditions it was found that under the null conditions, the classical ANOVA maintained a probability of the Type I error for main, two-factor, and three-factor interactions which Taguchi did not. This is why the use of the S/N ratio exhibited a disappointing performance and was found to be inferior to the classical ANOVA for the purposes of significance testing under all conditions examined in this study [7]. Taguchi's DoE finds its application in yield of paraffin wax through determination of optimum performance condition of factors and also determination of most significant factor [8]. An integrated approach, involving statistical experimental design and the quality loss function can be applied by which variability of a product performance and quality loss are reduced. The method is implemented using a case study from the electromechanical product industry [9]. Statistical experiment design can be used to efficiently select experimental runs to achieve a given experimental purpose. However, uncertainty is a fact of life in experimentation. The experimenter is faced with uncertainty in inputs, uncertainty in outputs from both random variability and uncertainty in measurement processes, etc. In the face of all this uncertainty, the experimenter must try to collect and analyze data [10]. Grinding is one of the most important processes as it accounts for about 20–30% of the total expenditure on machining operations in industrialized nations. So, it becomes imperative to determine of optimum grinding conditions. This is another application of DoE [11]. In many experimental designs, the standard procedure involves randomization of the factor-level combination run order. There are cases, however, where it is known that a time or position trend that can seriously compromise the results of the experiment may be present. These trends include wear of tooling and equipment, learning curves, change in temperatures, etc. The objective of this work is to establish the foundations of a method for constructing linear and quadratic trend-resistant plans in two-level split-plot designs. An experimental plan that is robust against all linear trends and most quadratic trends was achieved [12]. Taguchi optimization methodology is applied to optimize cutting parameters in turning extra low interstitial with coated and uncoated cemented carbide tools under dry cutting condition and high cutting speed [21]. Taguchi also finds its applications in the design of a motor in a large electrical company in India. There used to be specific customer requirements related to temperature rise and low efficiency of the existing model of motor, which the organization was unable to meet. Taguchi's parameter design approach was successfully applied to derive the optimum design [23]. Optimum energy consumption and prevention of energy losses are important issues in various fields including agricultural engineering. Mower is one of the agricultural machineries that can waste too much energy if does not function properly. The performance of a single disk rotary mower was studied and optimized by measurement