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A procedure based on robust design to orient towards reduction of information content

Sergio Rizzuti*

Università della Calabria, Ponte Pietro bucci 46/C, Rende 87036 (Cosenza) Italia

* Corresponding author. Tel.: +39-0984-494601; fax: +39-0984-494673. *E-mail address:* sergio.rizzuti@unical.it

Abstract

To manage the design matrix is an apparently easy thing to do. Discovering incongruences and converging at least towards a decoupled structure could suggest to designers that they have reached a sufficiently good starting point for the product under development. This is not sufficient. To be able to evaluate the information content of that solution is on the contrary an almost difficult activity because many relations between Functional Requirements and Design Parameters may not be completely defined deterministically. Eliminating bias and reducing variance remain the objective to be pursued. The paper discusses a procedure based on the Taguchi method to orient designers when verifying the influence that each design parameter has on the functional requirements. After the association of an Objective Function with one functional requirement or with a macro-functional requirement, the relation between the Objective Function and a set of design parameters can be identified from the Design Matrix. This can allow the designer to discern the best range of each parameter, analysing the Mean Value of the Objective Function and Signal to Noise Ratio. In the case of a conjoint influence of many design parameters on the functional requirement, it is important to verify the mutual interaction among the design parameters and evaluate the kind and level of interaction.

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1. Introduction

The measure of the robustness of an engineering device can be computed knowing the probability of satisfaction of its main characteristics. The information axiom [1] has been introduced, on the basis of the Shannon assumption [2], to evaluate the level of robustness of a design solution. The main difficulty during the product design phases is gathering this kind of data, in general at least a prototype being required on which to evaluate these performances and to measure the corresponding probabilities. Along all the phases of product development it is extremely useful to have data on which to base the right choice of the most promising design solution. Computer simulation by means of CAE systems gives designers many insights into the product behavior and can assist the right choices.

A further task would be to compare two or more alternative solutions, in order to decide which solution has the greater chance of solving the problem for which it has been developed. This latter problem is more complex, since not only technical data but also economic, marketing, and technological evaluations are involved. Multi-Criteria Decision Making techniques are generally employed for this kind of evaluation and many more people or stakeholders must share the responsibility for the final choice. Among the wide literature on this topic [3-5] can be indicated.

The main task of the design phase is to assure that each design alternative has reached the best configuration. Both axioms of Axiomatic Design can guide designers to improve a design solution. Both axioms must be managed with care. The first axiom is strictly related to the form of the design matrix, and the latter must be continuously updated and verified. However, it is not generally evident which kind of form it assumes, because many of the relations between functional requirements and design parameters might not be declared. The second axiom is really more difficult to apply

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when the design matrix has a triangular form and the terms outside the diagonal are not identified by deterministic relations.

The search for a robust solution requires verification that the performance of the design system must be contained inside the design range. This requires that the eventual bias between the mean values of domain range and system range must be removed, or at least reduced, and that the variance of the probability density function (pdf), which describes the performance of a design alternative, becomes smaller than the design range. The smaller the variance the more robust the system.

In order to guarantee these conditions designers must pursue a strategic design activity that integrates robust design into axiomatic design. Establishing a proper objective function associated with the main functional requirement or to a macro-functional requirement the design of an experiment, planned in terms of the Taguchi method, can be organized identifying the design parameters involved in the analysis. Having previously studied the design solution by axiomatic design this type of identification is done almost straightaway. The discussion of the results highlights the type of interaction between design parameters and the functional requirements associated with the objective function and suggests the nature of the design matrix, which could be unknown from the beginning.

In a certain sense the discussion of the results of a design of experiment gives many insights into the nature of the design matrix. The employment of the Taguchi method offers a more flexible investigative tool, in that the comparison between the influence of each design parameter on the Objective Function and the associated values of the Signal to Noise Ratio allows designers to understand the kind of relation among design parameters and functional requirements [6-9]. This kind of study details better the kind of design matrix structure because the presence of interaction among design parameters suggests the presence of off-diagonal terms.

The paper describes a procedure that introduces how to take into account the results obtained by the Taguchi method for the reduction of the information level of design solution and at the same time identify better the form of the design matrix. The main intent is to give the designer a tool by which to study the nature and the behavior of one design solution and to lower the information level that characterizes it.

2. The related literature

Many researchers have investigated the relation between axiomatic design and Robust Design [10-15] suggesting coherent strategies to support the identification of the best design solution. Bras and Mistree [10] introduced the compromise Decision Support Problem as a method to combine Axiomatic and Robust design by the Taguchi approach. They demonstrated how to determine the most suitable values and tolerances for a given set of parameters, and to identify the most suitable principal design parameters. This approach requires the definition of all the relations among Functional Requirements and Design Parameters. They also used reangularity and semangularity to establish the degree of independence of a design solution, even though it must be underlined that these two quantities were no longer employed by Suh after 2001. Gu et al [11] integrated the analysis of independence of Axiomatic design with Robust design and used the condition number of the sensitivity matrix, related to the design matrix, as a means to evaluate the degree of independence of a design solution. The design matrix, also in this case, must be fully determined in each component. Xiao and Cheng [12] developed an analytic approach to demonstrate the relation between Axiomatic Design and Robust Design. They used the new insight by Suh [1] and studied the uncoupled and decoupled design matrices. They demonstrated on the basis of some case studies, and with properly probability density functions, why an uncoupled design is more robust than a decoupled design and why the latter is better than a coupled one. More recently Lijuan et al. [13] used the concept of optimization framework to integrate axiomatic design, robust design and reliability-based design, even though they needed to use again reangularity and semangularity to configure the optimization framework. Kar [14] underlined the strict relation between axiomatic design and the Taguchi method. Frey et al. [15] proved that simple summation of information levels cannot be performed for decoupled designs and offered a method for computing the information content. They also suggested that decoupled designs can have a higher probability of success with respect to uncoupled designs and that a decision made only on the basis of the first axiom might not necessarily be a guide towards the solution with the lowest information content.

Suh in [1], and mainly in Chapters 2 and 3, explored more contexts and suggested many ways to guide designers towards elimination of bias and reduction of variance, in order to arrive at design solutions that can be considered robust for the purposes for which they were designed. The way followed in this paper is based on the employment of the Taguchi method and can be considered a reverse road map to be followed, without a previous deep knowledge of the relation among functional requirements and design parameters.

3. The information axiom through the insight of the Taguchi method.

The analysis carried out by means of the Taguchi method is performed comparing how each design parameter employed in the modeling has influenced the objective function, both in terms of the Mean Value (MV) and in terms of Signal to Noise Ratio (SNR).

The comparison of both results gives useful elements in order to correct the solution, modifying the range of variation of the design parameters, either trying to eliminate the bias or reducing the variance.

The evaluation of the performance in terms of Mean Value is obtained in strict relation to the law used to describe the objective function. This is associated with the loss function in one of the criteria: lower is better or higher is