ROBUST ENGINEERING APPROACHES TO MAXIMIZE RESULTS

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Abstract

The paper approaches the new branch of engineering, Robust Engineering, developed by G. Taguchi. His main contribution to engineering was the proposition of a given design plan subject to a set of uncontrolled variables that affect the process or product performances. The new levels of the controlled variables are set after estimating of the effects of the uncontrolled variables on the responses, via mathematical transform signal-to-noise ratio. An application was shown.

Keywords: robust engineering; process control

Introduction

Robust Engineering is a branch of engineering techniques developed by Genichi Taguchi, since the early fifties in Japan, and now widely applied in the western world, after successfully utilized in several industrial applications. Theses successes may be grasped via quick look at the home page of the American Supplier Association: http://www.amsup.com/TAGUCHI.

The basic ideas of Taguchi are well described in several texts and articles published elsewhere (Taguchi, 1987; Taguchi and Yockeyama, 1994) and consist in taken care of a product or a process from the very beginning; i.e., when the product or process concepts are being idealized, even well before production or manufacture starts, paying attention to avoid conducting a manufacturing route or process development just to be within the technical tolerances here established. Therefore, according to Taguchi you, as a researcher engineer, have to force your product or process to be as narrowly as possible targeting the value and not the acceptable range of variation.

A very interesting feature when designing for competitive advantage is that value is defined as the measure of choice; see Dean, E.B. at http://mjuno.larc.nasa.gov/dfe/value.html. Moreover, robust products or projects do have strong signals, whatever external noises they might be subjected to!

These thoughts are well illustrated in every day practice, when a given product or process, being constituted of several paths or parts (or unit operations for the processes), is to be manufactured or run and since every part or unit operation has its own tolerances. The couplings of these may result, as it does, in the summation of all the parts or unit operations variances, resulting, as it can see everyday, when slipping yours car door, in a product or process of bad performance or even failure.

The basis of Robust Engineering is D.O.E., i.e., Design of Experiments, a set of mathematical tools, well established in the literature as well, that maybe looked as devised for competitive advantage.
The originality of Taguchi was utilizing fractional factorial designs arrays that could provide the performance and endurance of a product or process, when subjected to the controlled and uncontrolled variables that affect such performance and endurance! As it is well known, the utilization of fractional factorial designs for the sake of controlled variables is not a Taguchi’s achievement; his main contribution to engineering was the proposition of a given design plan subject to a set of uncontrolled variables that affect the process or product performances. Such uncontrolled variables might be humidity, temperature, cultural habits in utilizing a given process or product, the lack of given expensive equipment for better performance of the results, etc.

The statistical analysis that he proposed, and that is being used, by engineering users, worldwide is very simple, although heavily criticized by statisticians worldwide (Box, 1988; Berk and Picard, 1991; Lucas, 1994). Nevertheless, although lacking real statistical grounds, the analysis does work in the real world and all the better statistical approaches that have been proposed reach about the same conclusions!

A short discussion on some topics of interest in Robust Engineering is fundamental for the reader’s understanding of the overall issue.

**Robust designs**

Robust designs are conducted for optimization. A mathematical transform is utilized by achieving this; this transform is the signal to noise ratio, quite arbitrarily imposed by Taguchi as the transform to be always used.

Such a ratio gives an indication of how close the design is to the optimum performance of a given process or product. For a discussion on the measurement of robustness, see [http://www.ansap.com/TAGUCHI/ROBUSTY/](http://www.ansap.com/TAGUCHI/ROBUSTY/).

The interesting proposal is that the research engineer may choose a variety of designs that best suit his engineering goals. These designs, called Taguchi arrays, are fractional factorials and may be derived from the application of the principles of constructions of such factorials (Kacker, 1991; Villas Boas, 1996). The literature brings several of these arrays (Taguchi, 1994; Taguchi and Yokoyama, 1994; Fowlkes and Crevibg, 1995) and they are represented by the letter L, sometimes A, followed by a subscript indicating the number of actual runs of the experiment, and that may be, also sometimes, depending on the source of the plan, followed by a parenthesis and inside it the original basic design that was fractionalized. An indication of how many variables and levels of such variables is also given in the plan; such a plan is an orthogonal array and the computation of the effect of that particular variable when subjected to the variations of the levels that are studied is very simple.

As mentioned earlier in this paper the real insight provided by Taguchi was not the application of fractional factorials to the design of engineering experiments, since many others did that; his contribution to the D.O.E. is the introduction of the uncontrolled variables within the proposed design. This is performed in the following sequence:

a) identifying the controlled variables for the process or product;

b) identifying the uncontrolled variables that affects the process or product performance;

c) choose, or construct, the arrays for the controlled and uncontrolled variables in such a way that the design plan for the controlled variables is obtained under the design plan for the uncontrolled ones, thus obtaining the desired responses for the problem;
d) via the mathematical transform, signal-to-noise ratio, i.e. the performance statistic that estimates the effect of the uncontrolled variables and their levels on the response(s), analyze the overall design and set the new levels of the controlled variables;
e) run it again and check if the new design satisfies the improving of the mathematical transform, i.e., the performance statistics.

The mathematical transform

Here lies one of the major criticisms of Taguchi's approach: the use of the so called signal-to-noise ratio, as the sole mathematical transform always; for a complete review on that see Box (1988). Three are the cases that the research-engineer will choose for his performance statistic:
a) the specific target value is the best;
b) the smaller, the better;
c) the larger, the better.

An experiment

For the sake of illustration let's perform an experiment according to the sequence suggested. Let's be interested in the use of zinc oxide as varistor, where the production of dense pieces are a must in order to enhance the electrical properties of the final product (Duarte, 1998); thus, the response sought is the real density of the produced piece.

Let's follow the sequence:
a) identifying the controlled variables:
   - temperature (°C) at three levels: 1,100; 1,200; and 1,300;
   - time (h) at three levels: 2; 3; and 4;
   - dispersant, oxalic acid (%) at three levels: 0; 7.5; and 15;
   - ligant, polyvinylalcohol (%) at three levels: 0; 1; and 2;

b) identifying the uncontrolled variable (a) furnace ventilation, at three levels: ambient, forced ventilation low, forced ventilation high;
c) the array:
   - a n 1,9 for the controlled variables was chosen;
   - taken at the three settings of the uncontrolled variables;
   - obtaining the real density (%) as the answer, for every setting thus defined; in replicates (that not necessary), the averages where assessed;
   - these averages were, following a n 1,9: 1 = 92.41%; 2 = 90.09%; 3 = 89.92%;
     4 = 91.74%; 5 = 91.72%; 6 = 92.17%; 7 = 91.69%; 8 = 93.04%; 9 = 91.88%;

d) the performance statistics (signal-to-noise ratio):
   - for the specific case study the chosen S/N was the larger, the better transform.
   - the computed S/N ratios were quite near one to the other, as follows:
     1 = 39.31%; 2 = 39.09%; 3 = 38.08%; 4 = 39.25%; 5 = 39.25%; 6 = 39.29%;
     7 = 39.25%; 8 = 39.37%; 9 = 39.26%;
   - therefore it was decided, by the research team, to compute the for each experimental unity: 1 = 0.078; 2 = 0.031; 3 = 0.22; 4 = 0.046; 5 = 0.083;
     6 = 0.007; 7 = 0.019; 8 = 0.013; 9 = 0.004;
   - and, the option for analyzing the data, was to determine the effect of each variable on the final response (average, S/N and variance), within their levels,
instead of recurring to the classical ANAVA; in fact, such analysis will give
the controlling levels for each variable that increments the average density,
decreases variances, and maximizes S/N, as follows: temperature at 1,300 °C
(increasing the average by 0.57%, decreasing var by 0.043 and increasing S/N
by 0.054); time at 2 h (increasing the average by 0.32%, decreasing var by
0.008 and increasing S/N by 0.030); dispersant, none (increasing the average
by 0.91%, decreasing var by 0.023 and increasing S/N by 0.086); ligant,
may be at 0.5% since the analysis showed that none increased the average
and S/N but had no influence on the variance and 1% showed a decrease in
average and S/N, but also a remarkable decrease in the variance;
- as for the uncontrolled variable, furnace ventilation, although level two is
indicated in the sense of a % increase in the average, it also introduces the
highest variance and a non significant S/N;
- running again: thus the experiment was performed with the new conditions set in
- d) and having no ventilation for the furnace, with the results showing an
improvement of the averages at minimum variance and maximum S/N.

Conclusions

Thus, the so called Robust Designs are orthogonal arrays formally identified with
fractional factorial designs, constituting of a design matrix for the controlled variables
and another for the uncontrolled variables in such a way that the response is obtained
under the settings of the uncontrolled variables matrix, that will give the variances of
the system, and analyzed via the mathematical transform, the signal-to-noise ratio,
for optimization of the controlled variables and their levels.
It is indeed, quite a simple procedure and has the advantage of implementing at the
earlier stages of the process or product cycle the robustness of it.

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