Design of Experiments for Quality Parameters Assessment

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Abstract: - Recent quality assurance or quality planning is concerned with the application of off-line quality control techniques (pre-production experimentation and analysis) to product and process engineering. It is being increasingly recognized that pre-production experiments, assuming properly designed and analyzed, can contribute significantly towards quality improvements of a product. This paper deals with problems related to experimental design for quality planning and presents an example of central composite design application.

Key-Words: - process, quality, parameter, design, experiment, measurement

1 Preface

Experimental optimization and process characterization can be carried out in several ways. Most common is the one variable at a time (OFAT) approach. This approach is an experimental technique in which only one factor is varied in any experiment, the remaining factors being held constant. It fails to look for interactions among the factors and in locating the true optimum when interaction effects are present. The multivariable design of experiments (DOE) is a powerful approach for discovering a set of design or process variables, which are most important to the process and then determine at what levels these variables must be kept to optimize the response characteristic of interest.

DOE, in contrast to the one factor method (OFAT), advocates the changing of many factors simultaneously in a systematic way. Before an experiment can be conducted, the experimental design must be carefully planned to ensure that experimental objectives can be accomplished. The values of the independent variables define the experimental conditions or the design of the experiment. Experimental design refers to the formal plan in which the experiment will be set up and conducted and the plans for data collection and analysis. In many process development and manufacturing applications, the number of potential input variables is large. Screening designs are therefore used in the initial phases of a study when you wish to investigate the main effects of several factors simultaneously. Response surface methodology is then used to determine how a responses is affected by a set of statistically significant variables over some specified region or expected operating ranges. The central composite design can fit a full quadratic model and it is the most popular of the many classes of response surface designs.

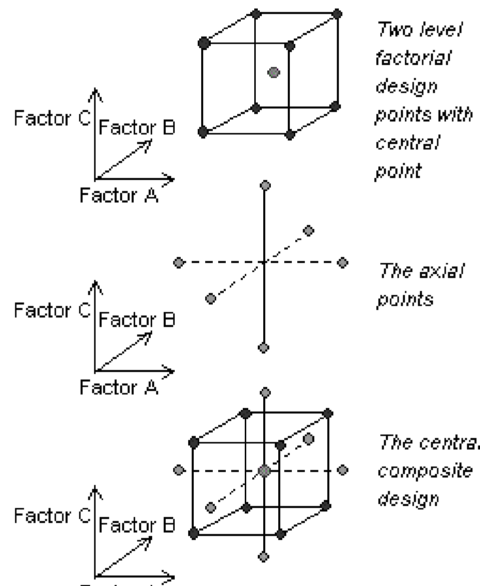

Fig. 1 - Generation of the central composite design for free factors situation

2 Central composite design

The central composite design consist of three parts: (*i*) a two-level full or fractional factorial design which typically place points at regular intervals in the design space; (*ii*) axial /star/ points in which all but one factor is set at zero (mid-range) and one factor is set at outer (axial) values; (*ii*) centre points - points with all levels set to the midpoint of each factor range. Figure 1 shows a generation of the central composite design for three factors. Generation of central composite design start with a factorial (or fractional factorial design) with centre points and add axial point to estimate curvature. The star points have all of the factors set to the midpoint, except one factor, which has the value ±α. The value of α determines the location of the star points in a central composite design. For special values of α, central-composite designs have special names, as follows: circumscribed, face-centred and inscribed.

Tab. 1 – Experimental design summarization

Run	Point type	Factor X_1 Temp. [°C]	X_2 Burn-in time [s]	X_3 Burn-in voltage [V]
1	Factorial	25	120	9
2	Factorial	25	420	15
3	Factorial	85	420	9
4	Factorial	25	420	9
5	Factorial	85	420	15
6	Factorial	85	120	15
7	Factorial	25	120	15
8	Factorial	85	120	9
9	Central	55	270	12
10	Central	55	270	12
11	Central	55	270	12
12	Central	55	270	12
13	Central	55	270	12
14	Central	55	270	12
15	Axial	105	270	12
16	Axial	5	270	12
17	Axial	55	270	7
18	Axial	55	270	17
19	Axial	55	522	12
20	Axial	55	18	12

3 The experiment solution according the central composite design

The response parameter in our case study of the burn-in process optimisation is yield. This response is affected by three parameters: temperature, burn-in time and burn-in voltage. For study the effects of three experimental factors in 20 runs we have created the central composite design. The experimental design is summarized in the table 1. This table also includes experimental results for partial runs. The order of the runs has been fully randomised. This will provide protection against the effects of lurking variables.

Tab. 2 – Experimental results summary

Run	Point type	Yield [%]
1	Factorial	45
2	Factorial	63
3	Factorial	73
4	Factorial	57
5	Factorial	40
6	Factorial	91
7	Factorial	69
8	Factorial	88
9	Factorial	69
10	Central	64
11	Central	66
12	Central	61
13	Central	67
14	Central	71
15	Central	48
16	Axial	71
17	Axial	64
18	Axial	79
19	Axial	70
20	Axial	58

4 Experimental results and analysis

Experimental results are summarized in the table 2. The Pareto chart in the Fig. 2 shows each of estimated effects in decreasing order of magnitude. The length of each bar is proportional to the standardized effect, which is the estimated effect divided by its standard error. The yield is statistically significant affected by main effects of all factors and by interaction effects X_{13}, X_{12}.

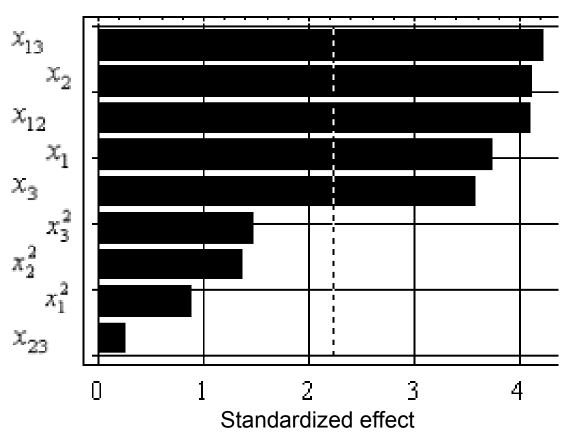

Fig. 2 – Main and interaction effects Pareto chart

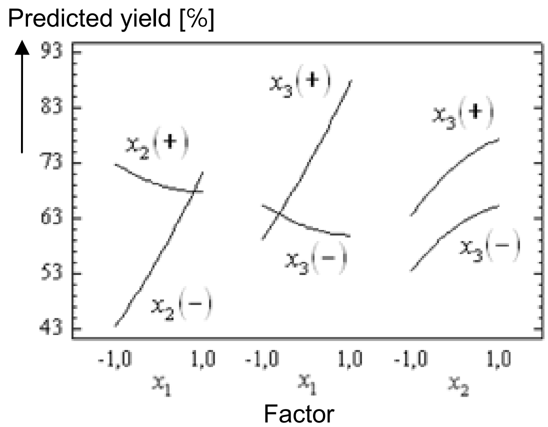

Fig. 3 – Interaction effects graph

The interaction plot depicted in the Fig. 3 shows the estimated yield as a function of pairs of factors. These plots are generated by using the fitted empirical model. In each plot, one factor is varied from its low level to its high level. On the one line, the second factor is held at its low level. On the other line, the second factor is held at its high level. All other factors besides the two involved in the interaction are held constant at their central values. The information obtained from this graph said that maximum yield can be expected for high factor settings.

4 Conclusion

This paper deals with problems related to experimental design for quality parameters assessment and presents an example of central composite design application. The used methodology consists of appropriate experimental plan that yields the most information from predetermined model with the least number of experiment runs. Empirical model coefficients and approximate models in the reference points obtained from the experimental data are created based on a multivariate regression analysis of each investigated response.

References:

[1] X1. Novotný,R., *Empirical Modelling for Optimisation Purposes*, Scientific Society of Mechanical Engineering, 2003

[2] X2. Montgomery, D., *Design and analysis of experiments*. Wiley, 1996, ISBN 0-471-52000-4

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