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An Application of the Random Balance Method in Conjunction with the Plackett-Burman Screening Design in Metal Cutting Tests

ABSTRACT: This papers deals with an experimental study of metal cutting, particularly gundrilling. It argues that a proper experimental methodology based on the design of experiments (DOE) is an appropriate instrument to improve productivity and efficiency of machining. A screening DOE based on the random balance method and the Plackett-Burman screening design is considered. Such a DOE is referred to as a sieve design. The proposed method has proven to be very useful at the first stage of an experimental study of complex parameters as, for example, tool life testing, where the experimentalist wishes to include into consideration many design and process parameters. Conducting a relatively simple sieve DOE, the experimentalist easily can distinguish significant factors and their interactions of any order to be used in the subsequent full block DOE. A practical example of an application using the proposed DOE, a tool life test of gundrills, is considered in detail.

KEYWORDS: design of experiments, Plackett-Burman, random balance method, cutting tool life, gundrilling

Introduction

Although machining or material removal with cutting tools is one of the oldest methods of shaping parts, the most essential characteristics of this process such as tool life, cutting forces, integrity of the machined surface, and energy consumption can be determined only by experiment. As a result, any further improvements in the tool, machine and process design, and implementation of new cutting tool materials must be justified through a series of experimental studies that are very costly and time consuming. Therefore, the proper test strategy, methodology, data acquisition, and statistical model construction and verification are of prime concern in such studies [1].

The technique of the design of experiments (DOE) allows significant improvement in the methodology of machining tests [2]. It is true, however, only if DOE is implemented properly. Probably the weakest items of DOE implementation are the so-called preprocess decisions. Often, such decisions rely on experience, available information, and experts' opinions and thus are subjective. Even a small inaccuracy in the preprocess decisions may affect the output results dramatically. Therefore, the preprocess stage of DOE should be more formalized.

Normally any machining test includes a great number of independent variables. In the testing of gundrills, for example, there are a number of tool geometry variables (the number of cutting edges, rake angles, flank angles, cutting edge angles, inclination angles, side cutting edge back taper angle, etc.) and design variables (coolant hole shape, cross-sectional area and location, profile angle of the chip removal flute, shoulder dub-off shape and location, number and location of the supporting pads, radial relief, length of the cutting tip, the shank length and diameter, etc.) that affect drill performance. However, when many factors are used in DOE, the experiment becomes expensive and time consuming. Therefore, there is a dilemma. On one hand, it is desirable to include into consideration only a limited number of essential factors selected by the experts. On the other hand, if even one essential factor is missed, the final statistical model may not be adequate to the process under study.

Unfortunately, the decisions made at the preprocess stage about the number of essential variables cannot be verified independently before the tests. If a mistake is made at this stage, it may show up only at the final stage of DOE when the corresponding statistical criteria are examined. Obviously, it is too late now to correct the test results by adding the missed factor.

The theory of DOE offers a few ways to deal with such a problem [3,4]. The first relies on the collective experience of the experimentalist(s) and the research team in the determination of significant factors. One or more factors could be significant or not, depending on the particular test objectives and conditions. For example, the back taper angle in gundrills is not a significant factor in drilling soft materials or cast irons, but it becomes highly significant in machining hard titanium alloys and martensitic stainless steels. A second way is to use screening DOE. This method seems to be more promising in terms of its objectivity. Screening DOE is used when a great number of factors are to be investigated using a relatively small number of tests. These kinds of tests are conducted to identify the significant factors for further analysis using DOE.

Fractional factorial DOE commonly is used for screening DOE [3,4]. Using this method, the experimentalist should be aware that it cannot detect any interactions among the factors involved. Unfortunately, this simple fact is misunderstood in metal cutting where such DOE has been used to study interactions between variables [5]. Therefore, if any factor interactions could be significant, this test should not be used. Our experience, however, shows that there are a number of significant interactions between the process parameters in metal cutting so that this DOE can hardly be acceptable in metal cutting.

Plackett and Burman [6] developed a special class of fractional factorial experiments that includes interactions that can be used as a

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