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# Design of Experiment (DOE) approach to Optimize Accuracy of Surface Roughness

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**Keyword:** Average roughness (Ra), Design of experiment (DOE), Coordinate Measuring Machine (CMM)

**Abstract.** This paper presents an investigation on the accuracy of average roughness (Ra) in three surface areas of specimen. For this study, we used two different probes of Mahr Surf XR20 which was MFW 250 tracing arm 6851804 (4.5mm) and tracing arm 6851806 (9.0mm). Full factorial design was used in the experiment plan. The normal probability graph, main effect and interaction plot had been analyzed by using MINITAB (software). The experiment result showed that the tracing arm 6851804 (4.5mm) consisted of small errors compared to the tracing arm 6851806 (9.0mm) based on the main effect plot and interaction plot analysis.

## Introduction

The challenge of modern machining industries is mainly focused on the achievement of high quality, in terms of work piece-dimensional accuracy, surface finish, high production rate, less wear on the cutting tools, economy of machining in terms of cost saving and increase the performance of the product with reduced environmental impact [2,5]. Surface roughness plays an important role in many areas and a factor of great importance in the evaluation of machining accuracy [3]. Furthermore, a comparative study of surface roughness comes out which probes of Mahr Surf xr20 that will give more accurate result with using a different type of probe and this allow to instigation of Ra, roughness average.

It is well known that the different type of probe in surface roughness affects the measured surface geometry and surface roughness parameter. Typically an increase in the size of the stylus tip will result in a reduction in the measured roughness parameter due to the tips inability to contact the bottom of sharp valleys on the surface and this may lead to investigation of accuracy analysis(parameter) and finally we can get which probe give more accurate result in Ra [4].

This study will focus on two different probes of Mahr Surf XR20 that will be used on the one coin with three touch points to act as the independent variable during an experiment and the study focused on the Ra. The objectives of this paper are to study a comparison on the different types of probes, different operator and different cut of length on the accuracy average roughness (Ra) and to suggest the optimal parameter setting for each factor study using Design of Experiment.

This paper is organized as follows. Section 2 describes experimental procedure. In Section 3 the screening experiment and the analysis is explained in details. Finally, Section 4 presents the main conclusion of the paper.

**Experiment procedure.** The experiment was conducted to collect the results of surface roughness. There are three factors in this experiment which are different length of probes; operator and cut of length were chosen in the surface roughness experiment to achieve values approximate to the standard value by using Coordinate Measuring Machine (CMM) which is high end accuracy machine.

The DOE method was used to identify the best parameter setting for the surface roughness [1]. This is the major improvement for this study whereby the optimize parameter setting can be suggested for further improvement and become the standard procedure to setting at machine during the result collection. There are few steps to follow to ensure the result is validated and tovimprove the accuracy of the result.

**Design of screening experiment.** There are many controllable and uncontrollable factors that contribute to the accuracy of the result. A two-level full factorial design with resolution V, which is among the most widely used type of design in industry, was used for screening experiments [6,7]. The reason for the usage of resolution V was to analyze the main effect and two-factor interactions.

Surface roughness was measured as a characteristic value. Three factors were identified to be the main factors in affecting of accuracy of surface roughness result. The $2^3$ design of experiment had been conducted and $2^3$ factorials design that is, a design with three factors with two level which can be defined as low level and high level. In order to get high accuracy, 8 different settings of the machine had been applied to the machine with five replications to get the high accuracy of surface roughness result. The three factors were A= cut of types of probe, B= operator and C= cut of length. Each factor was run at two levels. The experimental conditions are given in Table 1.

Table 1: Experimental conditions for full factorial design

| Factors | Levels | |
|---|---|---|
| | Low (-1) | High (1) |
| Cut of types of probe (mm) | 4.5 | 9.0 |
| Operator | operator 1 (have experience) | operator 2 (no experience) |
| Cut of length (mm) | 0.25 | 2.50 |

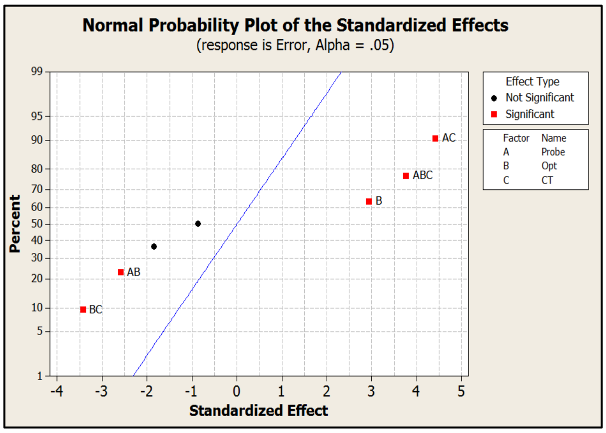
**Analyzing the screening experiment.** To analyze the effects of individual factors on the surface roughness, the data obtained from the experiment were statistically analyzed with MINITAB software [8]. The estimation effects were set to the main effect and two-factor interactions. The significance level was set to 95%.

Fig. 1 presents a normal probability plot of the effect estimates from this experiment. This plot confirms that the main effects of B.

Fig. 2 shows the main effect plot for surface roughness, and Fig. 3 is a two-factor interaction effect plot for surface roughness. Among the main effects, probe 4.5mm presented lower error than 9.0mm.Thus the probe 4.5mm gave an accurate results and the length of probes gave an effect since the error is small. For main effect operator, operator 1 showed less error, which means operator 1 performed good skill during the experiment. Finally, for main effect cut of length, longer distance which is 2.50mm gave more accurate results data of the average roughness (Ra).

Table 2: Surface Roughness Result Compare CMM Value

| No | Probe | Opt | CT | Actual (Ra) | Standard (CMM) | Error |
|---|---|---|---|---|---|---|
| 1 | -1 | 1 | 1 | 5.22 | 5.13 | 0.08 |
| 2 | 1 | -1 | 1 | 6.35 | 5.13 | 1.21 |
| 3 | 1 | 1 | 1 | 6.35 | 5.13 | 1.22 |
| 4 | 1 | 1 | -1 | 0.75 | 0.70 | 0.05 |
| 5 | -1 | 1 | 1 | 5.21 | 5.13 | 0.08 |
| 6 | -1 | 1 | 1 | 5.22 | 5.13 | 0.08 |
| 7 | -1 | -1 | -1 | 0.67 | 0.70 | 0.03 |
| 8 | 1 | 1 | 1 | 6.34 | 5.13 | 1.21 |
| 9 | -1 | 1 | -1 | 6.35 | 0.70 | 1.21 |
| 10 | -1 | -1 | -1 | 0.67 | 0.70 | 0.03 |
| 11 | 1 | 1 | -1 | 0.73 | 0.70 | 0.03 |
| 12 | 1 | -1 | -1 | 0.73 | 0.70 | 0.03 |
| 13 | -1 | -1 | 1 | 5.21 | 5.13 | 0.08 |
| 14 | 1 | 1 | 1 | 6.35 | 5.13 | 1.21 |
| 15 | 1 | -1 | -1 | 0.73 | 0.70 | 0.03 |
| 16 | 1 | 1 | -1 | 0.72 | 0.70 | 0.03 |
| 17 | -1 | 1 | -1 | 6.35 | 0.70 | 1.21 |
| 18 | 1 | -1 | -1 | 0.73 | 0.70 | 0.03 |
| 19 | -1 | 1 | -1 | 6.35 | 0.70 | 5.65 |
| 20 | 1 | -1 | 1 | 6.35 | 5.13 | 1.21 |
| 21 | 1 | 1 | -1 | 0.73 | 0.70 | 0.03 |
| 22 | 1 | 1 | 1 | 6.35 | 5.13 | 1.21 |
| 23 | -1 | -1 | -1 | 0.67 | 0.70 | 0.02 |
| 24 | -1 | 1 | 1 | 5.21 | 5.13 | 0.08 |
| 25 | 1 | -1 | -1 | 0.73 | 0.70 | 0.03 |
| 26 | -1 | 1 | 1 | 5.21 | 5.13 | 0.08 |
| 27 | 1 | -1 | 1 | 6.35 | 5.13 | 0.21 |
| 28 | -1 | 1 | -1 | 6.33 | 0.70 | 5.64 |
| 29 | -1 | -1 | 1 | 5.21 | 5.13 | 0.08 |
| 30 | 1 | -1 | 1 | 6.35 | 5.13 | 1.21 |
| 31 | -1 | -1 | 1 | 5.21 | 5.13 | 0.08 |
| 32 | -1 | -1 | -1 | 0.67 | 0.70 | 0.03 |
| 33 | -1 | -1 | -1 | 0.67 | 0.70 | 0.03 |
| 34 | -1 | 1 | -1 | 6.35 | 0.70 | 5.65 |
| 35 | -1 | -1 | 1 | 2.51 | 5.13 | 2.62 |
| 36 | 1 | -1 | 1 | 6.33 | 5.13 | 1.20 |
| 37 | 1 | 1 | 1 | 6.34 | 5.13 | 1.21 |
| 38 | -1 | -1 | 1 | 5.21 | 5.13 | 0.07 |
| 39 | 1 | -1 | -1 | 0.73 | 0.70 | 0.03 |
| 40 | 1 | 1 | -1 | 0.73 | 0.70 | 0.03 |



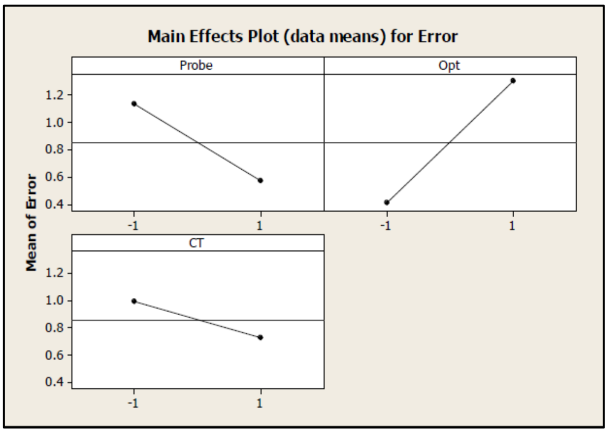




Fig. 1: Normal probability plot

Fig. 2: Main effect plot

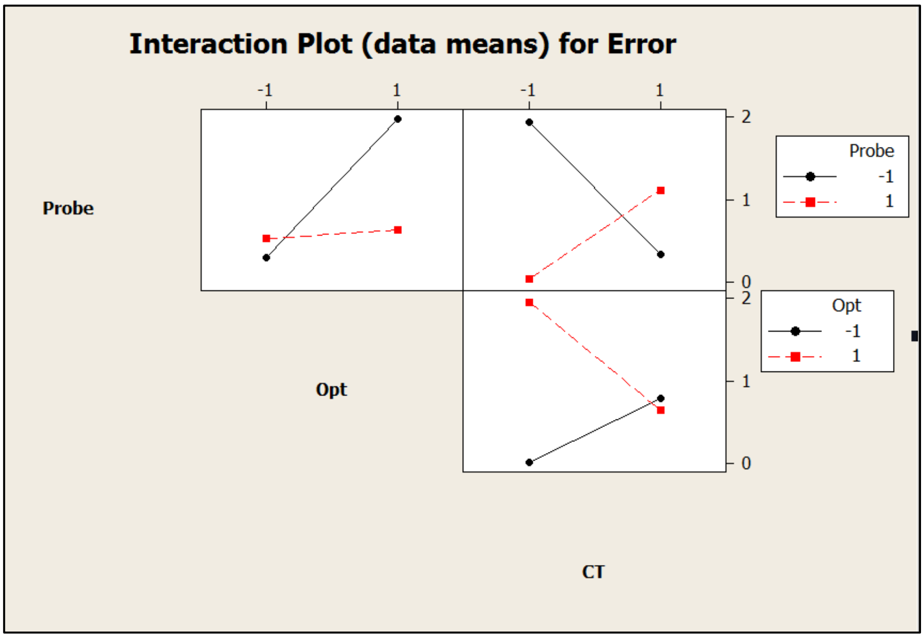



Fig. 3: Two-factor interaction plot

From the Fig. 3, it is shown that the interaction effects that gave lower error were, probe 4.5mm and operator 1, probe 9.0mm and cut of length 0.25mm and lastly, interaction plot between operator 1 and cut of length 0.25mm.

## Conclusion

In this paper, in order to study comparison of different types of probes, different operator and different cut of length on the accuracy average roughness (Ra) and to suggest the optimal parameter setting for each factor study using Design of Experiment were suggested. The general conclusions can be summarized using full factorial design, probe 4.5mm, operator's experience and length of cutting 0.25mm were found the minimum error for variation with the value obtained by CMM non-contact machine. Other than that, according to experiment results, application of DOE by full factorial design will be able to optimize the accuracy of surface roughness.

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