Experimental Design and Analysis of the Cobra Laser

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INTRODUCTION

This study examined the factors influencing the performance of the Cobra laser. The Cobra laser is used for engraving and cutting a variety of materials. When evaluating Applied Light's service, customers are most interested in the depth of a cut and the cost of production. In this case, cost is a factor of the amount of time it takes to complete a job. The goal of this study was to minimize time by identifying the laser settings that will maximize the efficiency of the laser. For the purposes of this experiment, we examined the number of rotations it took to cut out a circle in an aluminum coupon.

METHODS

EXPERIMENTAL FACTORS

There are four parameters that can be adjusted on the Cobra laser: speed, frequency, zoom beam, and aperture. Speed is measured in inches per second (ips) and indicates how fast the laser beam moves across the surface. Frequency is measured in kilohertz (kHz) and is the number of repeated pulses per period of time. Zoom beam affects up collimation and aperture (measured in millimeters) affects the power and the divergence of the laser beam. These two factors work in conjunction with each other, through a process of up collimation and divergence, to change the F - number settings of the laser, which ultimately determines the focal length and diameter of the laser beam.

Table 1: Settings for Experimental Factors at Various Levels

Level	Speed	Frequency	Zoom Beam	Aperture
Low	1 ips	2.2 kHz	4.0 x	1.5 mm
Center	2 ips	4.0 kHz	5.0 x	2.8 mm
High	3 ips	8.0 kHz	6.0 x	4.5 mm

RESPONSE VARIABLE

Applied Light is interested in minimizing their costs by minimizing time spent on deep engraving and cutting. In order to measure time, this study selected the number of rotations it takes to cut a circle through an aluminum coupon as the response variable. We determined the circle was cut when either the circle fell through without any influence from an external source or when the circle fell through with a light tap from a pencil. To ensure consistency, the same researcher was responsible for lightly tapping the circle using the same pencil.

EXPERIMENTAL DESIGN, PROCESS AND MODEL ANALYSIS

The main purpose of this experiment was to help Applied Light minimize their time spent on the laser by finding some range of optimal parameter settings for the Cobra. For efficiency, we used a factorial design which allowed for analysis of the individual and interaction effects of all four experimental factors simultaneously.

The Full factorial design contained two levels and a center point for each of the four factors. This factorial design investigates the effects of the four experimental factors on the response variable, assuming the relationship is linear. Testing at the center point helped in determining the presence of curvature and in estimating the error in the experiment.

The run order of the 20 observations was randomized in order to control bias. In order to control for possible confounding variables, we used aluminum coupons of the same thickness and size, and used the same machine during the same time period for all of the runs. As mentioned previously, we standardized the way we measured the response variable by assigning the same person to test if the coupon was cut and by using the same pencil to tap the circles. This standardization also helped control variability in the response.

RESULTS

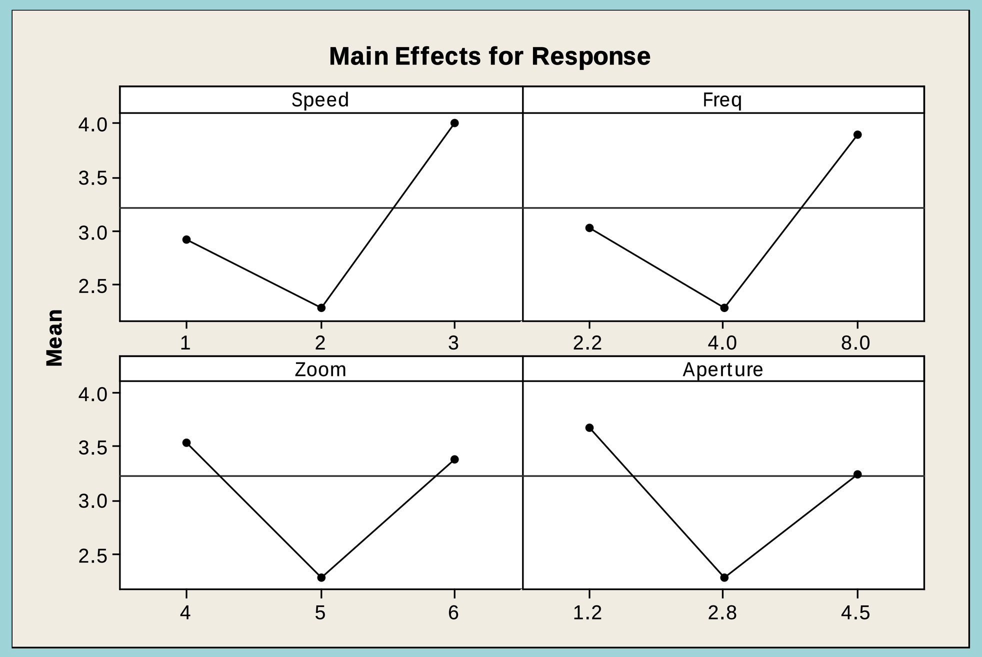
During the experiment, the number of rotations we observed ranged from the minimum of 9 to the maximum over 150. Table 2 displays the corresponding settings.

The setting that required the least number of rotations had all factors at the center level. The other three replicates generated at the center point required 10 rotations. The settings that required the most rotations were at the high levels of frequency and speed, and at the low level of aperture. Zoom beam did not seem to affect the result in that case. The results were transformed with natural logarithm to meet the requirement of our model analysis. In order to visualize the results at different production settings, we used the main effect plots to show trends between levels of each factor and their corresponding results.

Table 2: Extreme Observations from the Experiment

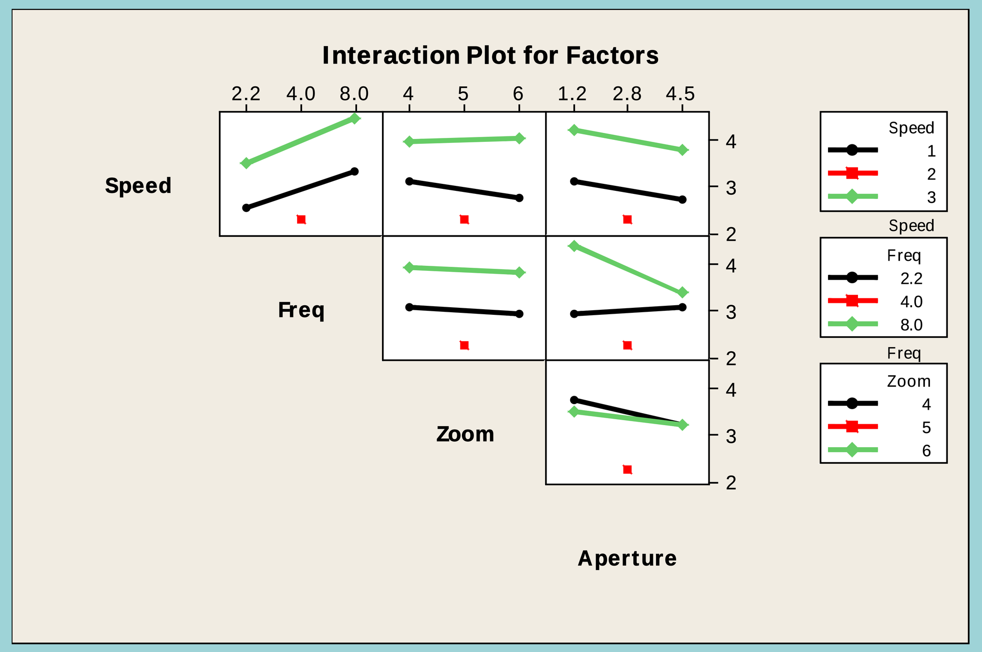
# of Rotations	Speed	Frequency	Zoom Beam	Aperture
9	2 ips	4 kHz	5.0 x	2.8 mm
150	3 ips	8 kHz	4.0 x	1.2 mm
150	3 ips	8 kHz	6.0 x	1.2 mm

Figure 1: Main Effects Plots between Factors and Results (in log)



The vertical axis on the left displays the natural log of the number of rotations; lower number of rotations is more desirable than higher number of rotations. The four plots collectively appear in V-shape curve, suggesting that the optimal results are the center level for each factor. It also suggests that the relationship between factors and results may not be linear. In addition, we used interaction plots to check for interactions between pairs of factors and observed obvious interaction between frequency and aperture. Figure 4 illustrates these results.

Figure 2: Main Effects Plots between Factors and Results (in log)



The vertical axis on the right shows the natural log of the number of rotations and the lower number is more desirable for production. The red dots that give the optimal results are the settings at the central level. Lines are approximately parallel in most plots except the one between frequency and aperture (the highlighted block). The crossed lines indicates that the effect of the aperture on cutting aluminum differed at different level of frequency in the experiment. When frequency is at the high level (green line), increasing aperture reduces the number of rotations required to cut. When frequency is at the low level (black line), increasing aperture increases the number of rotations required to cut. As a result, the interactions between two factors were included in the model analysis.

The model determines that speed, frequency, zoom beam and aperture are significant factors for cutting aluminum on Cobra machine. We also found that interactions between frequency and aperture, and between speed and zoom are significant. Due to the presence of significant interactions, each factor's effect on the laser efficiency depends on the settings of the other factors. The analysis of variance confirms the fit of the model and the presence of curvature in the relationship between number of rotations required to cut and levels of factors. Table 3 summarizes the results of model analysis.

RESULTS, CONTINUED

Table 3: Model Analysis Results

Full 2-Way Interaction Factorial Fit

Factor	Effect	Significant*
Speed	+	Yes
Frequency	+	Yes
Zoom	-	Yes
Aperture	-	Yes
Speed x Frequency	+	No
Speed x Zoom	+	Yes
Speed x Aperture	-	No
Frequency x Aperture	+	Yes
Frequency x Zoom	-	No
Zoom x Aperture	+	No

R^2 (adj) = 98.4%

***Significance level 5%**

Analysis of Variance

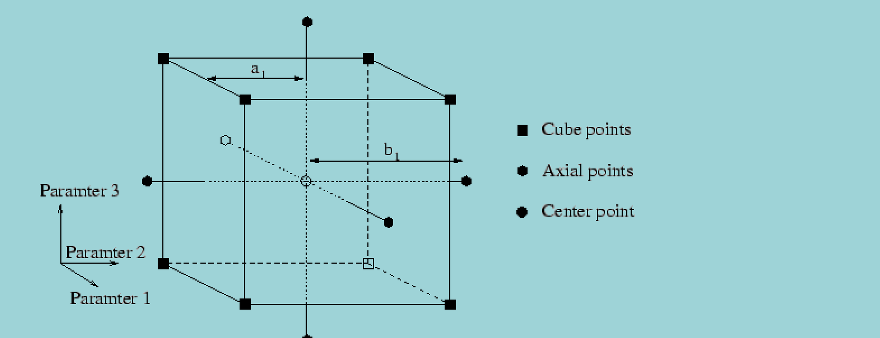
Source	Significant*
Main Effects	Yes
2-Way Interactions	Yes
Curvature	Yes
Lack of Fit	No

***Significance level 5%**

DISCUSSION

From experimental observation, an increase in speed or frequency will increase the number of rotations, while an increase in zoom beam or aperture will decrease the number of rotations needed to cut an aluminum coupon. From our model analysis, we found the main effects for all factors to be significant. We also found that the two-way interactions between speed and zoom, and frequency and aperture were significant. Due to the interaction effects, we cannot state a definitive rule for the effect each factor has on the Cobra's performance. By observation alone, we consistently found the center point to have the fewest rotations, which suggests that it may be the optimal setting: speed at 2 ips, frequency at 4.0 kHz, zoom beam at 5.0 X and aperture at 2.8 mm. This is consistent with the model results, which indicated that curvature is significant. Now that we have determined that curvature is present, we recommend conducting another experiment using a central composite design in order to fit a full quadratic model. This experimental design allows for response surface analysis, which will enable us to find the optimal settings for each factor. In addition to the corner points and center point used in the full factorial design, the central composite design also includes axial points, located on a hyper-cube. Figure 3 illustrates a three-way central composite design.

Figure 3: Central Composite Design (with three input parameters)



Source: http://www.iue.tuwien.ac.at/phd/plasun/node32.html

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