

TAGUCHI EXPERIMENT

Assignment Test Submission Two –
Catapult Key Control Factors

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ABSTRACT

The Design of Experiments (DOE) provides a systematic approach to identify and analyse the possible effects of factors on an experiment. This report outlines an experiment to determine the key control factors of a lima six catapult using the Taguchi DOE Method. The experiment used the Taguchi L_8 orthogonal array to investigate five factors at two levels.

Front Position and Pull Back were identified as the key control factors.

The key control factors were used to predict the range of the catapult at given settings. In the verification firings the average range was measured to be 132cm which is less than the expected 150cm. The method of measuring the range was proposed as a reason for the difference in results, along with not considering the interactions between some of the control factors.

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1. INTRODUCTION

The systematic approach to identify and analyse all possible factors which can influence an experiment is known as the Design of Experiments (DOE) [1].

This report outlines an experiment to determine the key control factors of a catapult using the Taguchi Method of Design of Experiments. It explores how this can be used to predict the catapult's performance at a given setting.

2. BASIC THEORY

Design of Experiments (DOE) is used to understand the relationship between different input factors, also known as parameters, and their effect on the output response of an experiment [2]. Design of Experiments typically consists of [3]:

- Factors - independent variables to be investigated
- Levels – different values or settings of the factors
- Response – the dependant variable that is to be measured

Effective experimental design can improve an experiment by optimising the average response value and minimising the effects of variation [4].

The Taguchi Method of DOE aims to minimise the total number of experiments conducted while providing accuracy and consistency to the process [2]. In a Taguchi experiment only the main control factors and two factor interactions are considered [5]. There are specific orthogonal arrays (OA) used based on the scale of the experiment and the number of control factors and variation levels. The selection of OA is determined by the number of control factors and the number of levels to be investigated, Table 2-1 shows some potential array formations.

TABLE 2-1 - TAGUCHI ORTHOGONAL ARRAYS

		MAXIMUM NUMBER OF FACTORS														
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Number of Levels	2	L4	L4	L8	L8	L8	L8	L12	L12	L12	L12	L16	L16	L16	L16	L32
	3	L9	L9	L9	L18	L18	L18	L18	L27	L27	L27	L27	L27	L36	L36	L36
	4	L16	L16	L16	L16	L32	L32	L32	L32	L32	-	-	-	-	-	-
	5	L25	L25	L25	L25	L25	L50	L50	L50	L50	L50	L50	-	-	-	-

An example of an L_8 array is provided in Table 2-2. A L_8 array allows for up to seven factors to be considered at two levels each, with the potential for two interactions to be evaluated. The factors are selected in a random order to reduce the influence of the practice effect [1]. The practice effect refers to the improvements in performance from repeated exposure to processes or tests [6].

TABLE 2-2 - TAGUCHI L₈ MATRIX

FACTOR	1 A	2 B	3 AB	4 C	5 D	6 BC	7 E
EXPT 1	1	1	1	1	1	1	1
EXPT 2	1	1	1	2	2	2	2
EXPT 3	1	2	2	1	1	2	2
EXPT 4	1	2	2	2	2	1	1
EXPT 5	2	1	2	1	2	1	2
EXPT 6	2	1	2	2	1	2	1
EXPT 7	2	2	1	1	2	2	1
EXPT 8	2	2	1	2	1	1	2

Main Effect plots are used to show how each factor affects the response and highlight the interaction between relationships in the OA, often represented as linear graphs [5], where the steeper the gradient the greater the effect. Interactions are when control factors are influenced by each other and produce an outcome that is non-linear [1].

The Taguchi Method analyses the responses to achieve one or more of the following experimental aims [1]:

- To determine the best or optimum condition for a product or process
- To estimate the contribution of individual factors
- To estimate the response under the optimum conditions

3. METHOD AND APPARATUS

3.1 THE APPARATUS

The experiment was conducted using a lean 6sigma catapult, shown in Figure 3-1 with the control factor variables highlighted. The catapult was clamped at the end of a table using a G clamp and a three-meter measuring tape was used to measure the distance travelled by a ball fired from the catapult.

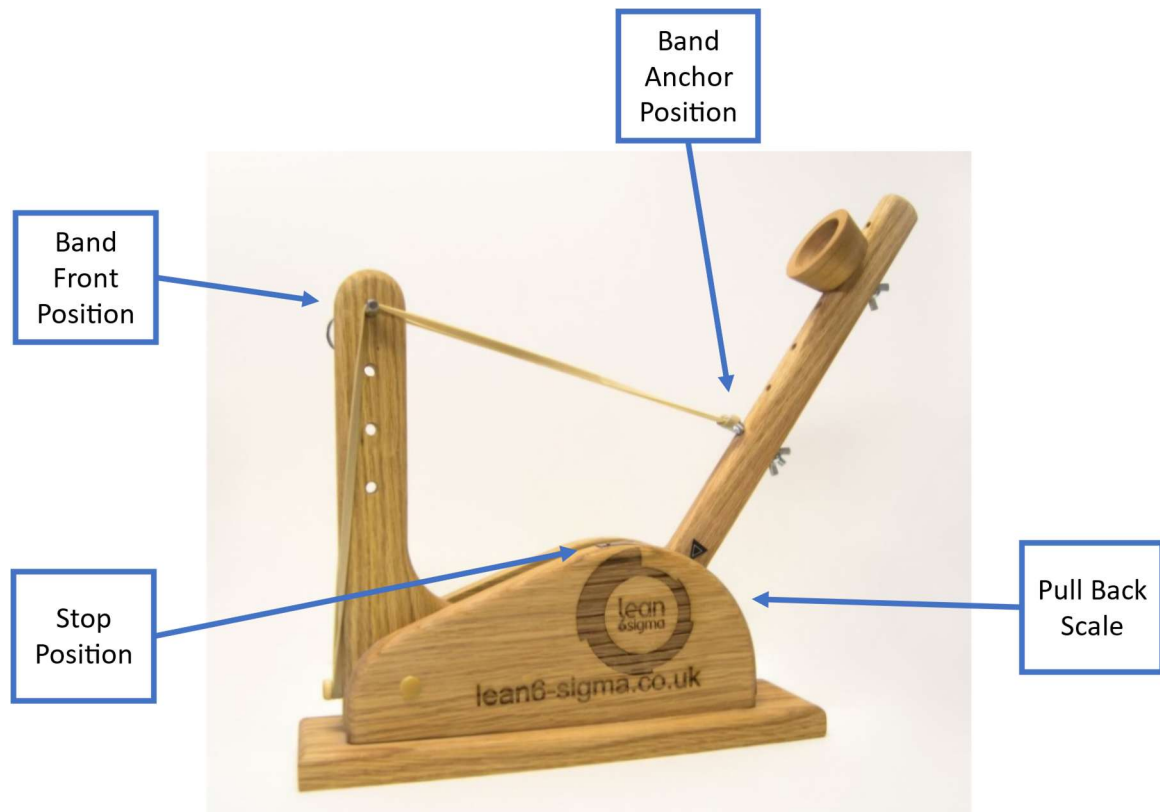


FIGURE 3-1 - EXPERIMENT APPARATUS - LEAN 6SIGMA CATAPULT [7]

Five factors were adjusted during the experiment, each with two levels recorded in Table 3-1.

TABLE 3-1 - EXPERIMENT CONTROL FACTORS

CONTROL FACTORS	LEVEL 1	LEVEL 2
BAND FRONT POSITION	Position 1	Position 3
BAND ANCHOR POSITION	Position 2	Position 4
STOP POSITION	Position 1	Position 3
PULL BACK	140°	170°
OPERATOR	Operator A	Operator B

3.2 THE METHOD

The Taguchi L_8 matrix in Table 2-2 has been used to determine the experiment order and the levels used. A total of eight initial firings were conducted, changing the variables in line with the order of experiments shown in Table 3-2. The interaction columns are included to aid with the analysis. Only the five factors in Table 3-1 were altered during the experiment. Each firing was repeated three times and the distance the ball travelled recorded before an average was found. The distance was measured with the 3m measuring tape and a recording taken of the ball landing to verify the landing position.

TABLE 3-2 - EXPERIMENT TAGUCHI L_8 MATRIX

FACTOR	1 BAND FRONT POSITION	2 BAND ANCHOR POSITION	3 AB INTERA- CTION	4 STOP POSITION	5 PULL BACK	6 BC INTERA- CTION	7 OPERATOR
EXPT 1	1	2	1	1	140	1	A
EXPT 2	1	2	1	3	170	2	B
EXPT 3	1	4	2	1	140	2	B
EXPT 4	1	4	2	3	170	1	A
EXPT 5	3	2	2	1	170	1	B
EXPT 6	3	2	2	3	140	2	A
EXPT 7	3	4	1	1	170	2	A
EXPT 8	3	4	1	3	140	1	B

The two control factors which influenced the overall distance the most were selected as the key controls. The second round of firings were conducted while keeping the non-key factors constant and only changing the key factors. The results of these firings produced a refined data set which provided a mid-point measurement to be used in the final verification firing, to predict the expected distance travelled by the ball.

4. EXPERIMENTAL DATA

4.1 INITIAL FIRINGS RESULTS

The results from the initial firings are provided in Table 4-1. These enabled a series of graphs to be generated, which show the influence of the control factors. The graphs for each control factor are shown in Figure 4-1 - Figure 4-5. It can be shown from the steep gradient of the graph that the Front Position and the Pull Back had the greatest impact on the range, while the Operator had a negligible impact. The Front Position and Pull Back were considered to be the key factors, and taken forward to the second stage of firings.



FIGURE 4-1 - FRONT POSITION MAIN EFFECT GRAPH

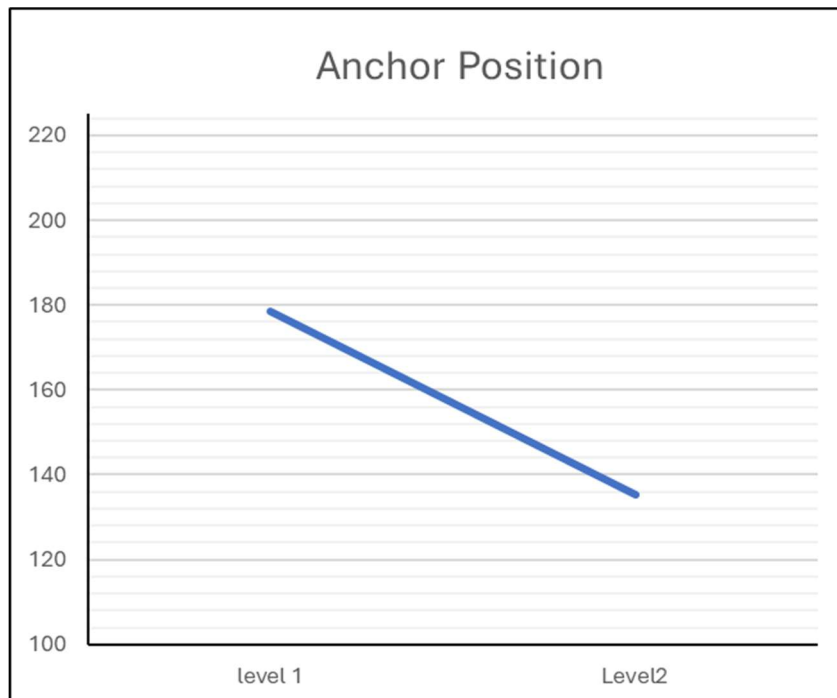


FIGURE 4-2 - ANCHOR POSITION MAIN EFFECT GRAPH



FIGURE 4-3 - STOP POSITION MAIN EFFECT GRAPH

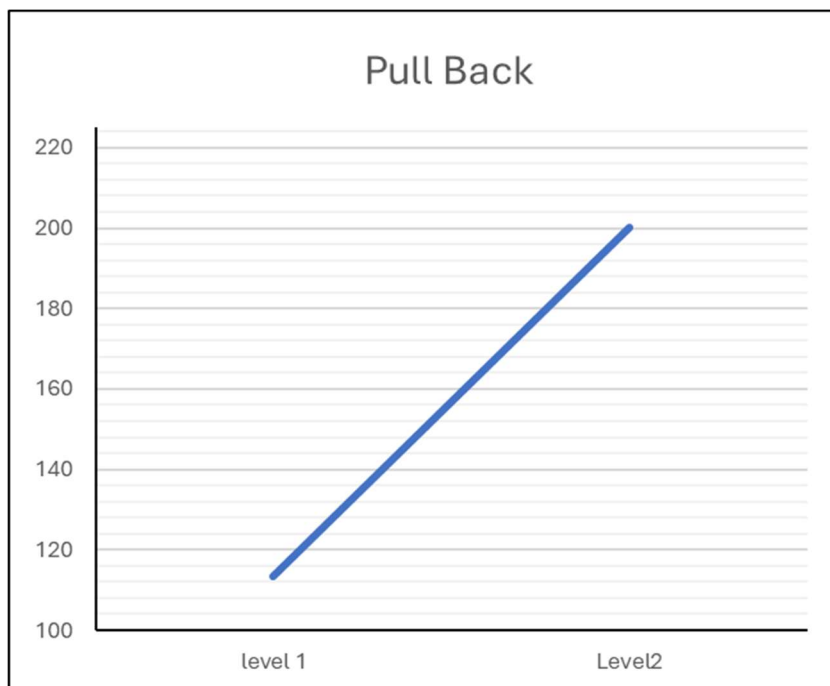


FIGURE 4-4 - PULL BACK MAIN EFFECT GRAPH

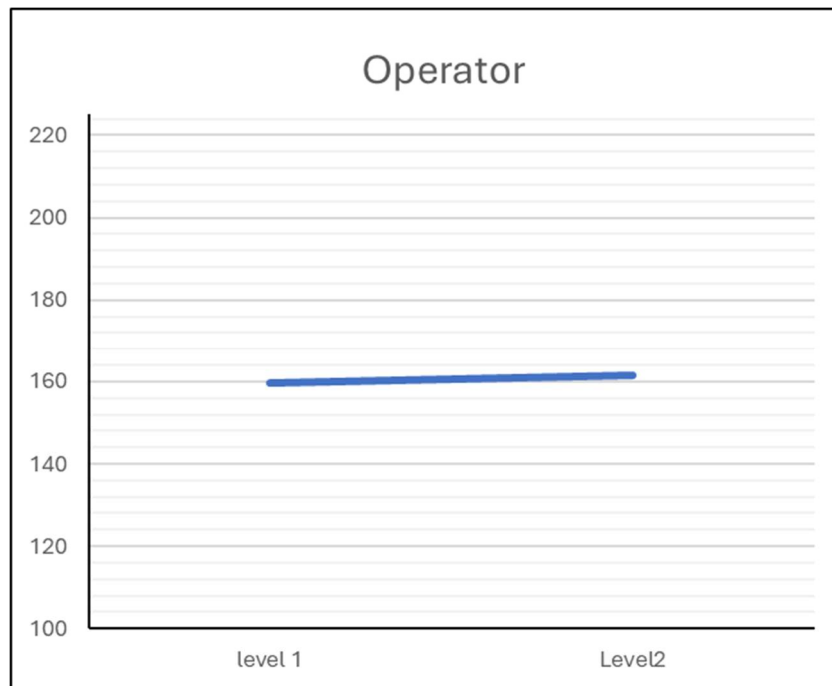


FIGURE 4-5 - OPERATOR MAIN EFFECT GRAPH

TABLE 4-1 - INITIAL FIRING RESULTS (130)

	EXPERIMENT ARRAY							RESULTS			
	Band front position	Band Anchor position	AB Interaction	Stop Position	Pull back	BC Interaction	Operator	Firing 1 Range (cm)	Firing 2 Range (cm)	Firing 3 Range (cm)	Average. Range (cm)
EXPT 1	1	2	1	1	140	1	A	145	132	235	171
EXPT 2	1	2	1	3	170	2	B	309	303	307	306
EXPT 3	1	4	2	1	140	2	B	112	115	107	111
EXPT 4	1	4	2	3	170	1	A	271	244	201	239
EXPT 5	3	2	2	1	170	1	B	132	132	131	132
EXPT 6	3	2	2	3	140	2	A	99	107	109	105
EXPT 7	3	4	1	1	170	2	A	127	132	112	124
EXPT 8	3	4	1	3	140	1	B	67	60	74	67

4.2 SECOND FIRINGS

The second firings constant control factors are provided in Table 4-2 and the key control levels in Table 4-3.

TABLE 4-2 - SECOND FIRING CONSTANT FACTORS

FACTOR	LEVEL
ANCHOR POSITION	Position 2
STOP POSITION	Position 3
OPERATOR	Operator B

TABLE 4-3 - SECOND FIRING KEY FACTORS LEVELS

FACTOR	LEVEL 1	LEVEL 2
FRONT POSITION	Position 1	Position 3
PULL BACK	140°	170°

The firings were conducted in the order shown in Table 4-4 which also shows the results of the experiments.

TABLE 4-4 - SECOND FIRING RESULTS

	EXPERIMENT ARRAY		RESULTS			
	Band front position	Pull back	Firing 1 Range (cm)	Firing 2 Range (cm)	Firing 3 Range (cm)	Average. Range (cm)
EXPT 1	1	140	138	114	98	117
EXPT 2	3	140	60	53	71	61
EXPT 3	1	170	272	273	240	262
EXPT 4	3	170	140	189	152	160

4.3 VERIFICATION RESULTS

The mid-point range for the key factors has been determined utilising the average range from the two levels of the control factor. Table 4-5 provides the midpoint of each key control factor to give an overall midpoint range of 150cm.

TABLE 4-5 - SECOND FIRING MIDPOINT VALUES

	LEVEL 1 AVERAGE RANGE (CM)	LEVEL 2 AVERAGE RANGE (CM)	MIDPOINT RANGE (CM)
FRONT POSITION	189	111	150
PULL BACK	89	211	150

A verification firing was conducted with the control factors set to the levels outlined in Table 4-6. The key control factors levels were the midpoint of the levels used in the previous firings, meaning that predicted range would be approximately 150cm.

TABLE 4-6 - VERIFICATION FIRING CONTROL FACTOR LEVELS

FACTOR	LEVEL
ANCHOR POSITION	Position 2
STOP POSITION	Position 3
OPERATOR	Operator B
FRONT POSITION	Position 2
PULL BACK	155°

The verification test was repeated three times to provide an average range, the results of which are provided in Table 4-7. This shows an average range of 132cm, which has an error rate of 12%.

TABLE 4-7 - VERIFICATION TEST RESULTS

	RESULTS			
	Firing 1 Range (cm)	Firing 2 Range (cm)	Firing 3 Range (cm)	Average. Range (cm)
EXPT 1	120	142	135	132

5. EVALUATION

The Taguchi experimental array provided a method to conduct the catapult experiments. It was effective in randomising the order, minimising the practice effect and allowing the key control factors to be identified.

The expected range in the verification test was lower than expected, this could have been due to the accuracy of the method used to measure the distance the ball travelled. Using a series of pre-

determined distance markers or by introducing a way for the ball itself to create a mark on the surface when it lands, may improve the accuracy of the distance readings.

The interactions between different control factors were not considered when determining the key control factors. Figure 5-1 and Figure 5-2 highlight that there is some interaction between the Front Position and the Anchor Position (AB interaction) and the Anchor Position and the Stop Position (BC Interaction) by the intersection of the two lines. Further analysis is needed to determine the overall effect of this interaction and the impact it has on the range of the catapult.

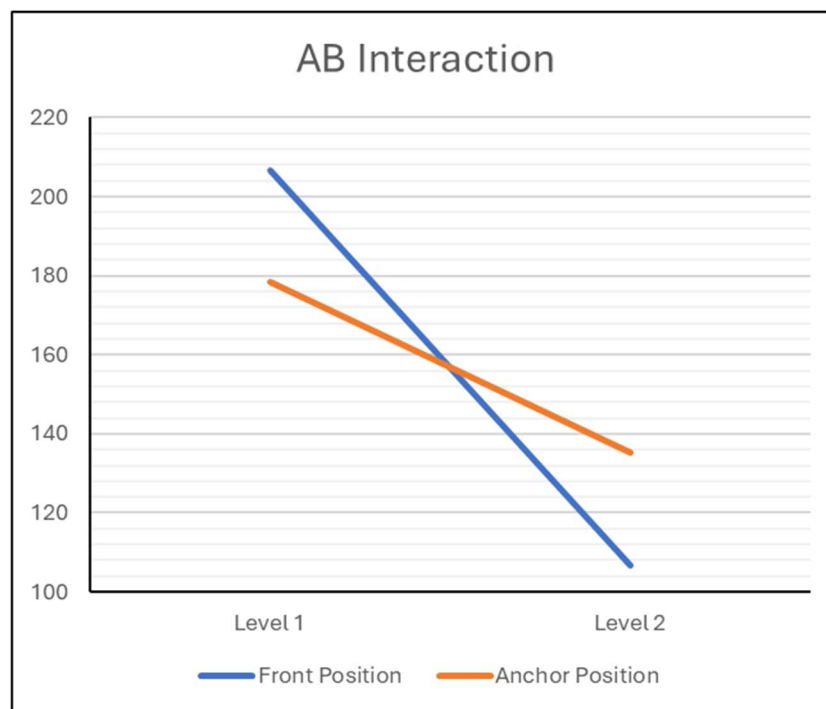


FIGURE 5-1 - AB INTERACTION GRAPH

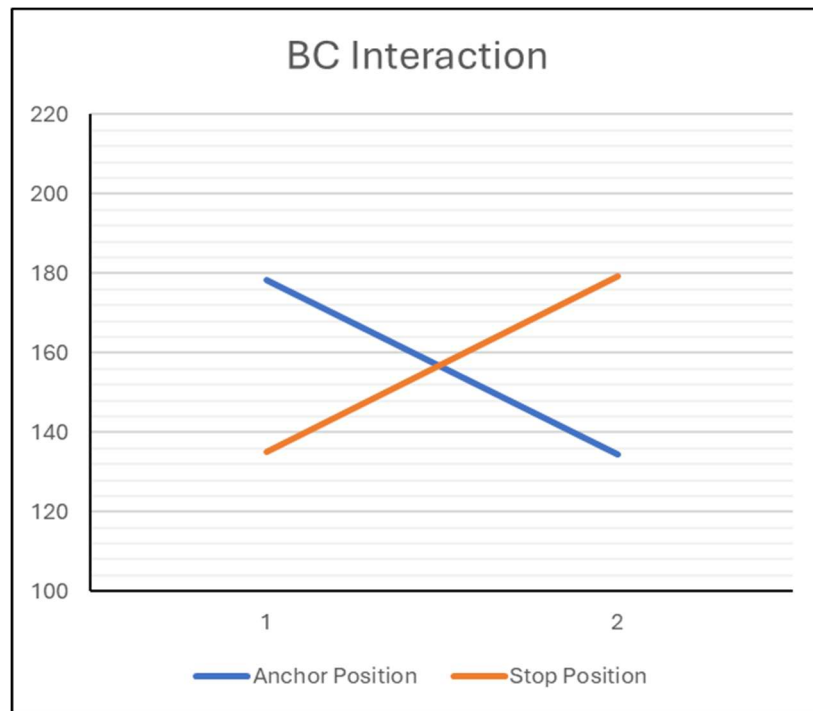


FIGURE 5-2 - BC INTERACTION GRAPH

6. CONCLUSION

Overall, the Taguchi Method of Design of Experiments provided an effective means of conducting an experiment to determine the key control factors of a catapult. These were identified to be the Front Position and the Pull Back.

Although the predicted distance for the verification testing of 150cm was not reached, further analysis of the AB and BC interactions may highlight additional considerations on the impact on the catapults range.

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