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APPLICATION OF THE ROBUST DESIGN CONCEPT TO THE CATAPULT DESIGN

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BONG SIAK HONG

This project is submitted in partial fulfilment of
the requirements for the degree of Bachelor of Engineering with Honours
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APPROVAL SHEET

This project report attached here to, entitled "APPLICATION OF THE ROBUST DESIGN CONCEPT TO THE CATAPULT DESIGN" is prepared and submitted by BONG SIAK HONG in partial fulfillment of the requirement of Bachelor's Degree with Honours in Mechanical Engineering and Manufacturing System is hereby accepted.

Pn. Ervina Junaidi Project Supervisor	15/4/04 Date

This thesis is dedicated to my beloved father and mother.

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TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE: INTRODUCTION

1.1 History Of Robust Design

The General Headquarters of the Allied forces was established in Tokyo, Japan after World War II. At this time, the Japanese telephone system was far below the quality level than United States and Europe where connections routinely took a long time to establish or lost within a short period of time.

So, the Allied forces were given the responsibility to improve the quality of the communication systems by the Japanese government due to this problem.

In 1950, 26-year-old Dr. Genichi Taguchi who founded Taguchi Methods joined the Electrical Communication Laboratory (ECL) and he was in charge to improve Japan's telephone system which was poor and unsuitable for long term communication purposes.

The Electrical Communication Laboratory (ECL) successfully completed the development of new phone system components meeting all of the necessary requirements after six years experimentation and testing under Dr. Genichi Taguchi. The Japanese telephone companies awarded their business to the team at ECL due to Bell Labs fell behind and struggled to meet requirements. In fact, Bell Labs never completed the project. It is probably not fair to credit all the success to Dr. Taguchi, however, the ECL had applied certain strategies based on his ideas. Basically, his ideas concentrated on the following questions:

- What information is generated in order to accomplish superior product/process design and meet all requirements at once?

- What should be measured as data in order to generate the best information?

- How should the experimentation be designed?

- How should the data be analyzed?

- How is the validity of a result confirmed?

- How are these methods implemented?

This thinking evolved to become the latest form of Taguchi Methods for Robust Engineering.

ECL was very eager to develop a robust (high quality, reliable and durable) system because they did not manufacture products but designed the product and contracted the manufacturing to other firms from which they purchased the products for lease to the users. They do not have control over the quality or reliability of the manufacture of the products but ultimately became responsible for their repair / replacement if they failed to work. This greatly affected their bottom line since the expense for repair / replacement came in the form of warranty costs. Thus, the birth of Robust Engineering to use of the at least costly materials and manufacturing processes without compromising quality and performance.

One of the major unique considerations of Dr. Taguchi is that engineers can become more efficient in the evaluation of numerous problems associated with a design by concentrating not on the symptoms of poor function, but on the function itself. Problems are caused due to variability in the design's function. By implementing this philosophy, improving the function minimizes problems.

This type of "thinking" represents one of the most important factors of Robust Engineering. It is also one of the most difficult concepts to appreciate.

1.2 Project Objectives

Product Quality is very important in the product design, so the ability to meet customer requirements communicated through engineering specifications is the main key of the effectiveness of an engineering design. These specifications usually consist of a target value and an allowable range of variation in which the product output may vary to satisfy the expectations of the customer. Engineers are often responsible to determine the best or the necessary settings for their design input variables to meet an engineering specification in order to meet customer requirements.

In this project, I will conduct the project that integrates the learning and application of the Taguchi Method into hand-on experiments by which a self-manufactured elastic catapult to establish relationships between input variables and output variables based on the distance. This project will consist of process design, statistical data analysis and quality engineering where associated with meeting an engineering target to obtain the largest distance of an elastic catapult fires the parts.

The goal of the project is to determine the best setting for each potential input variable of control factors and noise factor that will allow a product manufacturer to launch parts (ping-pong balls) at maximum distance. An elastic catapult has numerous input variables, such as control factors and noise factor, which will affect performance of product design. Control factors consist of object placement, rubber band attachment, rubber band height and stop angle, while noise factor is release time. And each part of input variables consists of two levels that are categories as low and high.

CHAPTER TWO: LITERATURE REVIEW

2.1 Robust Design

Robust design is the systematic approach to find optimum values of design factors that lead to economical designs with low variability. Taguchi achieves this goal by first performing parameter design, and then, if the conditions are still not optimize, tolerance design are performed

The contribution of Taguchi to robust design is undeniable. However, his choices for robust design implementation are not unanimously accepted. For instance, [Nair (1992)][8] reports on a thorough panel discussion that criticized the use of S/N ratios and crossed arrays. Yet, there seems to be consensus about the fundaments of robust design: conducting experiments in order to study the effects of controllable factors on both the location and the dispersion of the response. Thus, [Pignatiello and Ramberg (1987)][8] propose to distinguish the strategic aspect (namely, Taguchi's philosophy of robustness) and the tactical issues (for instance, S/N ratios and DOE).

Many tactical alternatives can be found in the literature. Table 2 shows that researchers sometimes prefer using loss functions or studying the location and dispersion of the performance separately (instead of S/N ratios). Moreover, crossed designs, such as shown in Figure 2, may be replaced by combined designs, that is, a single array that does not distinguish noise factors from design factors.

Taguchi originally proposed his technique for product design. Later, researchers have also applied robust design to simulated systems. For instance, [Wild and Pignatiello (1991)][8], [Dooley and Mahmoodi (1992)][8], [Benjamin, Erraguntla, and Mayer (1995)][8], and [Sanchez et al. (1996)][8] propose simulation-based methodologies for the design of robust jobshop manufacturing systems. Simulation allows the use of larger samples than crossed and combined arrays.

According to Taguchi [Taguchi and Phadke (1984); Taguchi (1986)][8], Parameter design is the process of identifying the settings of the design parameters or process variables that reduce the sensitivity of the design to sources of variation. In parameter design an accurate modeling of the mean response is not as important as finding the factor levels that optimize robustness. Thus, once the variance has been reduced the mean response should be easily adjusted by using a suitable design parameter, known as the signal factor. An important tenet of robust design is that a design found optimum in laboratory experiments should also be optimum under manufacturing and service conditions. Also, since product designs are often broken down into subsystems for design purposes, it is vital that the robustness of a subsystem not be affected by changes in other subsystems. Therefore, interactions among control factors are highly undesirable.

Robust design can be achieved when the designer understands the potential sources of variation and takes the desired steps to desensitize the product to these potential sources of variation. Robust design can be achieved through brute force techniques of added design margins or tightening tolerances. The brute force methods such as try all possible levels of noise for each possible combination of design parameters and select the combination that has the least deviation. It can also be done through 'intelligent design' by understanding which product and process design parameters are critical to the achievement of a performance characteristic and what are the optimum values to both achieve the performance characteristic and minimize variation" (Robust Product Design through Design of Experiments). Sources of variation are sources of waste and inefficiency. By eliminated and identified sources of variation, the quality and productivity of products can be improves. Common sources of variation are variation in material properties: density, yield strength, modulus of elasticity, homogeneity, contamination etc, variation due to manufacturing process variability: dimensions, heat treatment, residual stresses etc, variation due to degradation with time: wear, corrosion, embrittlement etc and variation due to environment: temperature, humidity, dust, supply voltage, electromagnetic fields, vibration etc.

The purpose of robust product design is producing a product performance where insensitive to the effects of uncontrolled environmental variations. There are several objectives of design for robust product, such costs less to manufacture, since the cheapest materials and manufacturing tolerances may be used, costs less to repair and service, since allowances for the effects of wear and degradation have been designed in to the product, increases market share by minimizing time to market through less "surprises" in the product development process and higher quality to satisfy customer expectations of target performance under the intended operating conditions throughout the expected life of the product.

By comparison with other types of optimization such traditional optimization, is usually directed at maximizing some performance parameter in a deterministic sense without consider the sources of variation might affect the performance of product. But, in pure robustification is directed at minimizing the variation of a performance parameter under the assumption that the designed nominal level of performance is satisfactory. In general product optimization, the cost of variation (conformance to specification) is just one of the cost components among others (performance, material, manufacturing etc) to be minimized.

Reference	# Design/ Noise Factors	Measure of robustness	Design of Experiments
Sanchez et al. (1996)	5/2	Quadratic loss function	Comparison : - combined: 2^{7-2} + two center points - crossed: (2^{5-1} + center points) x 2^2
Mayer and Benjamin (1992)	4/2	Close-to-target S/N	Crossed: 2^{4-1} x 2^2
Lim et al. (1996)	4/6	Smaller-the-better S/N for flowtime and larger the better for throughput	Crossed: L_{27}* x L_8* * : 3^{13-10} ** : 2^7
Dooley et Mamoodi (1992)	2/4	Signal-to-noise ratios of the performance mean and dispersion	2^2 x 2^{4-1}
Sanchez et al. (1993)	4/1	$\tilde{Y}$ (x), log (S (x))	2^{4-1} x 2^1, replicated four times
Moeeni, Sanchez and Vakharia (1997)	7/34	Quadratic loss function	2^{7-1} & noise factors oscillations***, replicated four times *** : frequency domain experiments

Table 1: Literature on Strategic Issues for Robustness Studies

2.1.1 Taguchi Design of Experiments

According to Taguchi [Taguchi and Phadke (1984); Taguchi (1986)][8], Design of experiments (DOE) is based on the objective of desensitizing a product to variation in the product and process design parameters. To consider quality implications during design, design process can be segmented into three stages, see figure 1.

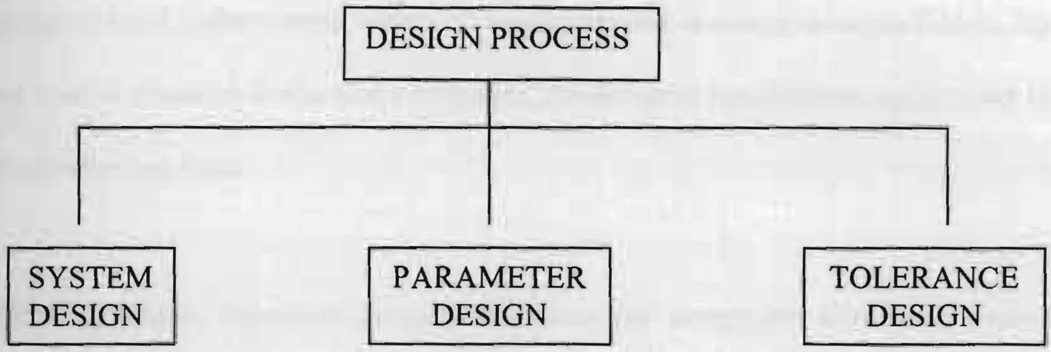

Figure 1: Taguchi's Design Process

The first stage is system design. This stage establishes what the product is going to be used for and general specifications. System design is the process of applying scientific and engineering knowledge to produce a basic functional prototype design. The initial design is sometimes functional, but it is also sometimes far from the optimum in terms of quality and cost.

The second stage is parameter design. It is an investigation conducted to identify the settings of design parameters that optimize the performance characteristic and reduce the sensitivity of engineering designs to the sources of variation. Parameter design requires some sort of experimentation for the evaluation of the effect of variation on the product's performance. A successful parameter design derives levels so that the design is robust to environmental variation without having to control the environment. These levels also assure that the design is robust to variation in its components (Robust Design Engineering). By knowing the effects of variation on the product, engineers are able to select the optimum levels for the controllable design parameters such that the system is functional. A functional system has a high performance level under a wide variety of conditions and is robust to noise factors. By paying special attention to the first two stages, the designer has the best opportunity to reduce production costs.

The third stage, tolerance design, establishes the acceptable tolerances around each parameter or target. This is when the designer sets acceptable tolerances around each parameter. Tolerance design is required if robust design cannot produce the required performance without costly special components or high process accuracy. It involves tightening of tolerances on parameters where their variability could have a large negative effect on the final system. This stage will most likely add costs to the product through efforts to ensure compliance with the tolerances.

An organization need to focus on minimizing variability in the product through product and process design and control of processes since an organization cannot cost-effectively inspect quality into the product. However, some variability is uncontrollable or very difficult to control such as noise. Noise is the result of variation in materials, processes, the environment or product's use. Products need to be designed so that they are robust because their performance is insensitive to this naturally occurring and difficult to control variation.

Design of Experiments techniques provide an approach to efficiently designing industrial experiments which will improve the understanding of the relationship between product and process parameters and the desired performance characteristic. This efficient design of experiments is based on a fractional factorial experiment, which allows an experiment to be conducted with only a fraction of all the possible experimental combinations of parameter values. Orthogonal arrays are used to aid in the design of an experiment. The orthogonal array will specify the test cases to conduct the experiment. Frequently, two orthogonal arrays are used: a design factor matrix and a noise factor matrix, the latter used to conduct the experiment is the presence of difficult to control variation so as to develop a robust design.

These experimental results can be summarized into a matrix called the signal to noise ratio that jointly considers how effectively the mean value (signal) of the parameter that has been achieved and the amount of variability that has been experienced. As a result, a designer can identify the parameters that will have the greatest effect on the achievement of a product's performance characteristic.

2.1.2 Six Steps For Robust Design

Robust design consists of searching for a product design that guarantees low variations in the performance level when the environment changes, instead of designing a product that is optimal for a single specific environment (noise configuration). This quality-improvement approach also known as parameter design, has been stated and popularized by Taguchi [Taguchi and Phadke (1984); Taguchi (1986)][8]. There are six steps for robust design:

a. Identify factors and specify targets

Distinguish between (a) design factors, which are independent variables of the model with values within the control of the designer, and (b) noise factors, which are not within the control of the designer. Define performance measures and possible target values. Taguchi proposes robustness measures called signal to noise (S/N) ratios that aggregate information on the average performance and its variability, see figure 2.

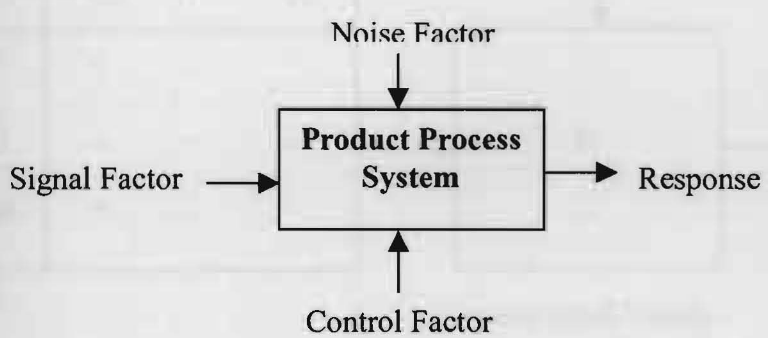

Figure 2: Parameter Diagram Of A Product/Process System

b. Formulate the design of experiment (DOE): crossed arrays

Design factors are varied according to an orthogonal array (OA) where combine OA for control factors and OA for noise factors into "product array". For each combination in this array, noise factors are systematically varied according to another orthogonal array called outer array. Thus, if there are 1 and 2 factor combinations in the design and noise arrays respectively, then m x n runs has to be examined (see figure 3). In the following, this DOE for robustness study is called a crossed array. This experimental set-up allows the identification of the design parameter values or factor levels that will produce the best performing, most reliable, or most satisfactory product over the expected range of noise factors or environmental conditions.

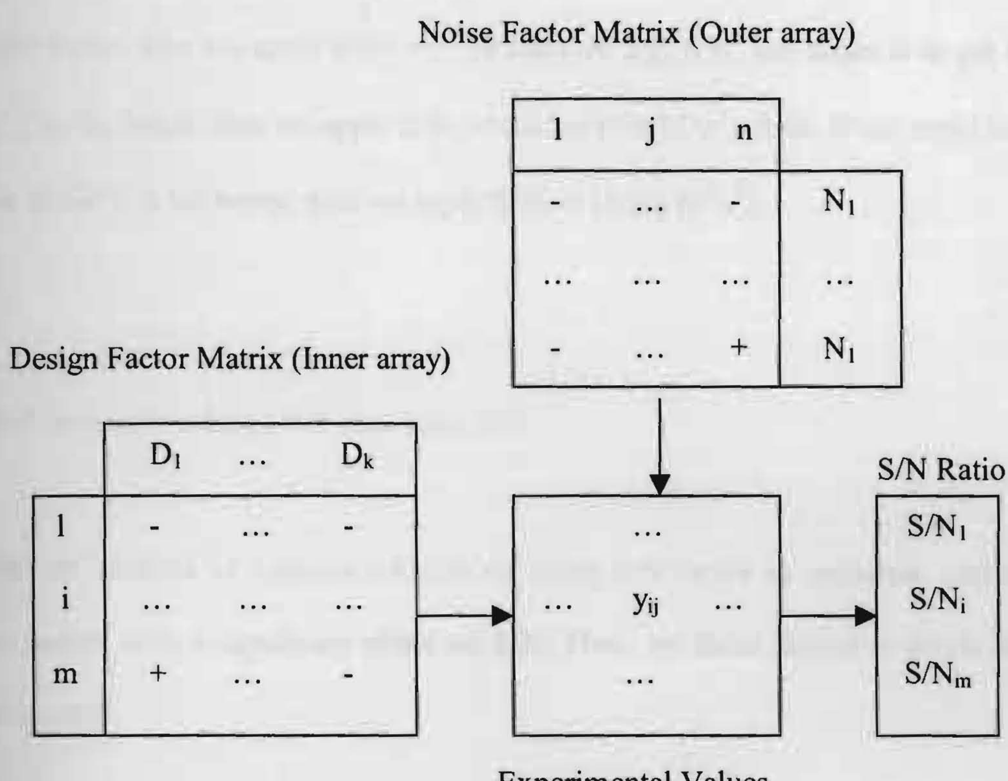

Figure 3: Experimental Strategy for Robust Design: Crossed Arrays

c. Execute the runs and compute the performance statistics

After the experiments are conducted and the signal to noise ratio determined for each design factor test case, a mean signal to noise ratio value is calculated for each design factor level or value. This data is statistically analyzed using analysis of variation (ANOVA) techniques. Very simply, a design factor with a large difference in the signal noise ratio from one factor setting to another indicates that the factor or design parameter is a significant contributor to the achievement of the performance characteristic. When there is little difference in the signal to noise ratio from one factor setting to another, this indicates that the factor is insignificant with respect to the performance characteristic. The formula to calculate the signal to noise ratio are different where based on the situation. For example, if our target is to get the smaller Y is the better, then we apply $S/N_S = -10 \log (1/n \ \Sigma y_{ij}^2)$. If our target is to get the larger Y is the better, then we apply $S/N_L = -10 \log (1/n \ \Sigma 1/y_i^2)$. And, if our target is to get the closer Y is the better, then we apply $S/N_T = 10 \log (\tilde{y}^2/s^2)$.

d. Find parameter settings that maximize S/N

Perform an analysis of variance (ANOVA) using S/N ratios as response. Identify design factors with a significant effect on S/N. Then, set these factors at levels that maximize S/N.