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"AN INVESTIGATION FOR IMPROVING THE QUALITY OF THERMO-PLASTIC EXTRUSION PRODUCTS BY USING NEW STATISTICAL METHOD"

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"تحسين ضبط جودة منتجات البثق الحراري باستخدام طريقة احصائية جديدة"

ملخص

تستخدم طرق ضبط الجودة التقليدية لتقليل التباين في عمليات الانتاج خلال مرحلة التصنيع . و قد تم الاستفادة من طرق ضبط الجودة الحديثة في ضبط الجودة الهندسية في مرحلة التصميم . و في هذا البحث تم تطوير طريقة حديثة مبنية علي ضبط الجودة الاحصائي اعتمادا علي طريقة تاجوشي . و ذلك بهدف تحديد الخصائص المتجمعة المثلي لعملية الانتاج لتقليل تباين الأداء مع الاحتفاظ بمتوسط يقرب من المستهدف . كما ناقش هذا البحث الخطوات المختلفة و العوامل المؤثرة علي دورة كاملة للمنتج و مرحلة التصميم له . والاسلوب المقترح مبني علي استخدام طرق احصائية لتحسين تصميم المنتج . و قد تم تطبيق هذا الاسلوب علي حالة عملية متواجدة في احد مصانع مدينة العاشر من رمضان . و استخلص هذا البحث الي تخفيض الانكماش بنسبة 63 % بالاضافة الي تخفيض تكلفة المنتج الي 37 % .

ABSTRACT

The traditional quality control procedures are adopted to reduce the variation in the process during the manufacturing stage. Modern quality control techniques are utilized as quality engineering in the design stage. In this paper a statistical quality control technique based on Taguchi method has been developed. The objective is to determine the optimum combination of the process characteristics that reduce performance variation while keeping the process average close to its target value. As well, various aspects of off-line quality control procedures are discussed in this paper. Off-line quality control refers to quality and cost control activities at the product and process design stage in the product development cycle. The proposed technique used statistical application methods for improving product design. It was applied on a practical case in one of the existing factories at the 10th of Ramadan City. It was found that the amount of improvement in shrinkage reduction was as much as 63%, as well, the cost of the product is also reduced by 37% .

INTRODUCTION

Approaches to the management of quality have evolved, tremendously, over the last decade. In the new paradigm, managers are replacing the conventional methods of inspection that catch defects before they reach customers. They are moving toward proactive improvement that reduce the product variations. This approach helps managers to provide superior products in the current globally competitive environment. In the new paradigm, all managers are involved in product improvement for the purpose of customer needs and satisfaction [9].

A products development cycle can be categorized into three stages viz. ; product design, process design and manufacturing. The traditional quality control procedures are utilized to reduce the variations in the process during the manufacturing stage. The other quality control techniques are utilized to quality control engineer in the design stage. Taguchi [11] developed a method to systematically analyze variables that affect product quality in order to determine the optimum combination of process characteristics that reduce the performance variation while keeping the process average close to its target value. The outcome of his work [11] is: inspection costs reduction, fewer rejects, fewer complaints, greater customer satisfaction, which may lead to increased market share, greater profits and a reliability improvement. The success of his techniques to quality control engineer into the product at the process design stages by the Japanese manufacturers has drawn considerable attention of Egyptian manufacturers. In this paper various aspects of these techniques are discussed. A modification of these techniques in order to satisfy the Egyptian industries environment is represented here. Such modified techniques are applied, hence, to one factories at the 10th of Ramadan City, an industrial state near Cairo, Egypt.

PRESENT TECHNIQUE

The present technique is based on Taguchi methodology [11, 12, 13] which is applied on off-line quality control in the design stage. If quality is concentrated on the quality of design, on-line quality control becomes much less important. Emphasis can be concentrated on off-line quality control. This technique breaks down off-line quality control into three stages viz. ; (i) system design (ii) parameter design (iii) tolerance design, as shown in Fig. (1).

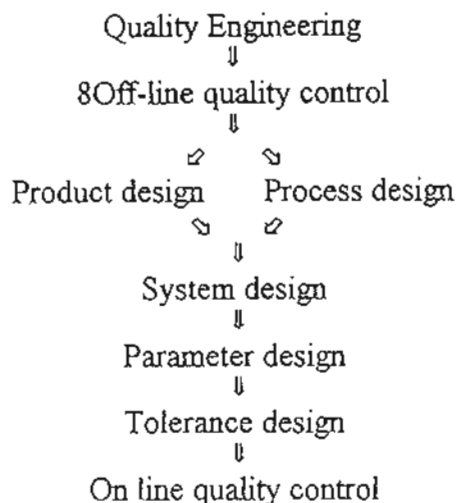


Fig. (1) - Stages of quality control

The system design stage is the process of applying scientific and engineering knowledge to produce a basic prototype model. The parameter design stage, is a process characteristic that minimizes performance variation. Usually, this parameter will have an importance over the initial settings of the system design. The tolerance design is a procedure to determine tolerances around the optimum parameter settings, identified at the parameter design stage, so that the overall cost will be minimized.

QUALITY AND THE LOSS FUNCTION

The quality of a product is defined as "the minimum loss imparted by the product to the society from the time a product is shipped" [14]. The loss is measured in monetary units and is proportional to the variations in the performance characteristic Y from its target T . The target values are to be stated in nominal levels rather than in terms of interval.

Let $E(Y) = \mu$ (process average) and the variance $\text{var.}(Y) = \sigma^2$,

Let T be the target value of the performance characteristic.

Ideally, $E(Y) = \mu = T$. The variance σ^2 represents the product's performance variation and is caused by variability in the measurements, fluctuations in the environmental variables such as temperature, humidity, dust ...etc., lead to product deterioration and manufacturing imperfections.

The smaller the performance variation around the target value, the better is the quality of the product. Countermeasures against performance variation caused by environmental variables and product deterioration can only be built into the product at the product design stage.

The loss function can be expressed as:

$$L(Y) = K(Y-T)^2 \quad (1)$$

where K is a constant. The expected loss can be computed as follows;

$$E[L(Y)] = E[K(Y-T)^2] = K \sigma^2, \quad \text{if } T = \mu \quad (2)$$

It can be seen from eq. (2) that a reduction in loss can be achieved by reducing the performance variation. The constant K can be determined if L(Y) is known for any value of Y. If the customer's tolerance interval is $(T \pm \Delta)$ and if cost to the customer of repairing or discarding the product is A, (£.E, Egyptian pound). Then equation (1) can be rewritten as follows;

$$A = K \Delta^2 \quad \text{or} \quad K = A / \Delta^2$$

The manufacturer's tolerance interval also can be obtained from the loss function (1). If the cost of repairing an item B, (£.E) exceeds the customer's tolerance limits then.

$$B = (A / \Delta^2) (Y - T)^2 \quad (3)$$

$$Y = T \pm (B / A)^{1/2} \Delta \quad (4)$$

Usually B is much smaller than A and, therefore, the manufacturer's tolerance interval will be narrower than the customer's tolerance interval. Then, for best performance it is necessary to adjust the process average (μ) to be as close as possible to the target value T, while simultaneously minimizing the product's performance variation.

PARAMETER DESIGN

Parameter design is the most important step of product design. It is based on classifying the variables that affect a product's performance into control factors (design parameters) [1,2]. These are factors whose nominal settings

are identified as impacting the response variable. Noise factors are all those variables that are uncontrollable or not intended to be controlled. The noise factors are classified into two groups; the inner and the outer noise. Examples of inner noises are manufacturing imperfection and product deterioration. Outer noises are variables external to a product that affect the product performance, such as temperature, humidity, dust,..., etc.

The purpose of parameter design is to investigate the overall variation caused by inner and outer noises when the levels of control factors are allowed to vary widely. Since the basic objective is to find a robust design that is unaffected by the inner and the outer noise, hence, potential noise factors are identified and their influence investigated.

EXPERIMENTAL ANALYSES

Several companies are now aware of the opportunities to reduce inspection and reworking costs, by designing quality into new products, or existing processes using different quality control methods. During parameter design stages, experiments are conducted to identify process design factors that minimize the expected loss [3, 4]. Taguchi suggests orthogonal arrays to be used as inner and outer arrays and signal to noise ratio for the performance statistic, while Kackar [7] refers to these as design matrix and the noise matrix. A collection of orthogonal array designs involving factors at two and three levels are provided by Taguchi and Wu [14]. These designs are balanced pair-wise, such that each level of a factor occurs with each level of any other factor the same number of times. The objective of the present work is to study the factors, K , affecting the product quality and cost (x_1, x_2, \dots, x_k) upon the expected response μ . An experimental design D is used to explore this relationship. Each experimental run represents separate settings of these factors. A typical parameter design experiment consists of two parts: an inner array and outer array. The columns of the inner array represent selection product design factors, entries in the columns representing test settings of these factors. Each row of the inner array represents a product design. The columns of an outer array represent noise factors with each row representing different combinations of noise factors. Let the number of rows of the inner and the outer arrays be (m) and (n) respectively. The total number of runs in the combined parameter design experiment is $m \times n$. The levels of noise factors are selected such that these repeated observations are representative of the effects of all possible levels of the noise factors. The repeated observation on the response variable from each test run in the inner array is employed to compute a criterion called a performance statistic. These

performance statistics are then employed to determine the optimum combination of the design parameters that minimize the expected loss. In order to obtain the data necessary for the statistical analysis, five separate sets of experimental results were run.

SIGNAL TO NOISE (S/N) RATIO

Taguchi recommends signal to noise ratio, s/n , to be used as the performance statistic [14]. The s/n ratio is a function of μ/σ which is inverse of the coefficient of variation. The s/n ratios are defined in such a way that maximizing s/n will be equivalent to minimizing the performance variation. When the response variable is continuous, the loss defined by $L(Y)$ takes a one of the three forms depending on whether smaller is better, larger is better or a nominal value is the best. Taguchi recommends the following s/n Ratios for the three situations.

For case 1 : Nominal is best type

$$S/N = -10 \text{ Log } 10 \mu^2 / \sigma^2 \quad (5)$$

For case 2 : Smaller is better type

$$S/N = -10 \text{ Log } 10 \frac{1}{n} \sum_{i=1}^n Y_i^2$$

$$S/N = -10 \text{ Log } 10 \text{ [mean square quality characteristic]} \quad (6)$$

For case 3 : Bigger is better type

$$S/N = -10 \text{ Log } 10 \frac{1}{n} \sum_{i=1}^n (1/Y_i^2)$$

$$-10 \text{ Log } 10 \text{ [mean square of quality characteristic reciprocal]} \quad (7)$$

Where Y_i : represent the i^{th} observation, corresponding to a specific row in the inner array

n : is the number of repeat measurements in that row.

The maximization of s/n ratios given above for case 2 and 3 is equivalent to minimizing the expected mean square error $MSE = E(Y-T)$ or, equivalently, maximizing $\{-10 \log_{10} MSE\}$ [5, 6, 7]. The s/n ratios which Taguchi recommend are sample estimates of $\{-10 \log_{10} MSE\}$ for case 2 and 3. For case 1, in which nominal value is the best criterion when the variance σ^2 and

the expected response are linked. Kackar [7] shows that an efficient performance measure that would minimize MSE when it is equal to $\log(\mu^2/\sigma^2)$.

In all three cases, s/n ratios are to be maximized in order to reduce mean square error and hence loss. When the response variable is not continuous another procedure referred to as "accumulation analysis" is suggested [8, 9, 14].

The present technique suggests a two-stage procedure to arrive at the optimum combination of factors that maximizes the s/n ratio while maintaining the mean response on the target. The factors may be identified into four groups viz ;

- (a) - Factors that influence μ only (x_1)
- (b) - Factors that influence s/n ratio only (x_2)
- (c) - Factors that influence σ^2 only (x_3)
- (d) - Factors with no detectable influence (x_4)

First, the combinations of x_2 factors that maximize the s/n ratio are selected. These factors are the control factors. The next stage is to identify other factors X that influence μ but not s/n ratios. Such factors are called the signal factors. By analysis of the data in the original form, factors that affect μ can be identified. These are then compared to the significant factors based on analysis of s/n ratio. Once x_1 factors are identified, they are used to set the mean response on target. If an x_3 factor is found it can be used to further decrease σ^2 and hence lower the expected loss.

CASE STUDY

The present case is taken by applying these quality techniques in one of the factories at the 10th of Ramadan City. The quality characteristic is the post extrusion shrinkage of extruded thermo-plastic speedometer casing. Excessive shrinkage causes noise in the assembly. The post extrusion shrinkage is obtained based on a two hour heat soak test. In this case study, an extensive cause and effect diagram shows that twelve 2-level factors are more suitable to consider. They are classified according to the three separate operations of the production process as in Table (1).

Since no interactions were to be studied, data is collected using an L_{12} orthogonal array experiment. Five separate shrinkage results are obtained for each experimental run. The results are summarized as in Table (2). The signal to noise ratios s/n is calculated using the formula

$$s/n = -10 \log_{10} \frac{1}{n} \sum_{i=1}^n (Y_i^2)$$

$$\text{For the first run } s/n = -10 \log_{10} \frac{1}{5} (0.58^2 + 0.62^2 + 0.59^2 + 0.54^2 + 0.55^2) \\ = 4.78$$

The optimum value will correspond to reduction in mean shrinkage as well as in the variability. A higher value of s/n ratio will imply an improvement in either a reduction in the average or a reduction in the variability or both. Based on analysis of variance of the s/n ratios, significant factors are selected first and an optimum condition is reached using average response of these significant factors. The total of s/n ratios for each factor level is given below;

S/N Totals For Each Factor Level.

$A_1=73.82$	$B_1=65.30$	$C_1=53.77$	$D_1=62.20$	$E_1=69.31$	$F_1=70.68$
$A_2=67.47$	$B_2=75.99$	$C_2=87.52$	$D_2=79.09$	$E_2=71.98$	$F_2=70.61$
$G_1=69.57$	$H_1=54.06$	$I_1=69.05$	$J_1=75.77$	$K_1=71.60$	
$G_2=71.72$	$H_2=87.23$	$I_2=72.27$	$J_2=65.52$	$K_2=69.65$	

Analysis of Variance computations

$$\text{Correlation Factor CF (average square sum of total } s/n \text{ ratio)} = (141.29)^2 / 12 \\ = 1663.57$$

$$\text{SST (Sum Squares of total } s/n \text{ ratio)} = (4.78^2 + 9.16^2 + 12.17^2 + \dots + 5.13^2) - \text{CF} \\ = 1897.724 - 1663.57 = 234.15$$

$$\begin{aligned} \text{SSA} &= (A_1 - A_2)^2 / 12 = 3.36 & \text{SSB} &= (B_1 - B_2)^2 / 12 = 9.52 & \text{SSC} &= 94.92 \\ \text{SSD} &= & & = 23.77 & \text{SSE} &= & = 0.59 & \text{SSF} &= 0.0004 \\ \text{SSG} &= & & = 0.385 & \text{SSH} &= & = 91.68 & \text{SSI} &= 0.86 \\ \text{SSJ} &= & & = 8.76 & \text{SSK} &= & = 0.320 \end{aligned}$$

The total sum is 234.17

Since there are twelve s/n ratios, and the total number of factors is 11, there is no degree of freedom available for error. Factors **E**, **F**, **G**, **I** and **K** which have relatively small value for sum of squares is pooled to get an error of squares 2.155 with 5 degrees of freedom. Based on the F-tests the factors **C**, **D** and **H** were the most important factors that affect shrinkage and they accounted for a total of 89% of the variability. The other significant factors were **A**, **B**, and **J**. Based on the averages of the two levels of these factors, the optimum condition is found to be **A₁**, **B₂**, **C₂**, **D₂**, **J₁** and **H₂**.

The average response at this optimum condition is (\hat{U}):

$$\hat{U} = \bar{A}_1 + \bar{B}_1 + \bar{C}_2 + \bar{D}_2 + \bar{J}_1 + \bar{H}_1 - 5T$$

$$= 12.3 + 10.88 + 14.58 + 13.18 + 12.63 + 9.01 - (5 \times 141.29) / 12$$

$$= 72.57 - 58.87 = 13.70$$

Where : T is the sum of total s/n ratio.

The value of average response at optimum condition (\hat{U}) is compared with the estimated average for existing set up values (**A₁**, **B₁**, **C₁**, **D₁**, **J₁**) which is equal to 10.69 as given in Table (1). The presented quality technique will improve the amount in shrinkage reduction from 34% with the existing set up before the study, to 9% with the optimum suggested set up. The reduction in variability which is 0.08 with the existing set up will be 0.042 with the optimum suggested set up. Based on the loss function, the cost per unit may be suggested as 8.5 £.E under the existing set up conditions, while the estimated cost per unit can be reduced to 5.1 £ E when the suggested optimum conditions are applied.

CONCLUSIONS

In this paper, statistical quality techniques based on Taguchi method is presented and discussed in details. The presented techniques are applied to an existing practical case in a factory at the of 10th of Ramadan City. These methods has already produced substantial improvement in quality at a reduced cost in manufacturing industries. It is found that the amount of improvement in shrinkage reduction was as much as 63%, while, it is also reduced the cost of the product, due to optimum conditions, by as much as 37%. Such techniques will continue to be extremely important in quality improvement efforts.

It may be concluded that the most important contribution of the present work is the recognition that the greatest improvement in quality and cost starts at the design stage rather than at the manufacturing stage. The success of this technique as presented in this case study should encourage its application on other Egyptian factories.

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Table 1. Production Process Factors

Liner Process		Wire Braiding		Coating Process		
No	Process	No	Process	No	Process	
					Case	
1	Liner O.D.	4	Haire Braid Type	8	Coating Material	H ₁ = Existing H ₂ = Change
2	Liner Die	5	Braiding Tension	9	Coating Die Type	I ₁ = Existing I ₂ = Change
3	Liner Material	6	Wire Diameter	10	Melting Temp.	J ₁ = Existing J ₂ = Cooler
		7	Liner Temp.	11	Cooling Method	K ₁ = Existing K ₂ = Change

Table 2. Shrinkage Results of Experimental Work

Control Factor Experiment Run	A	B	C	D	E	F	G	H	I	J	K	R ₁	R ₂	R ₃	R ₄	R ₅	S/N Ratio
1	1	1	1	1	1	1	1	1	1	1	1	0.58	0.62	0.59	0.54	0.55	4.78
2	1	1	1	1	1	2	2	2	2	2	2	0.41	0.32	0.30	0.34	0.36	9.16
3	1	1	2	2	2	1	1	1	2	2	2	0.13	0.26	0.27	0.28	0.26	12.17
4	1	2	1	2	2	1	2	2	1	1	2	0.17	0.21	0.16	0.17	0.13	15.39
5	1	2	2	1	2	2	1	2	1	2	1	0.14	0.13	0.15	0.18	0.17	16.44
6	1	2	2	2	1	2	2	1	2	1	1	0.18	0.19	0.14	0.11	0.17	15.88
7	2	1	2	2	1	1	2	2	1	2	1	0.07	0.05	0.20	0.19	0.18	16.34
8	2	1	2	2	1	2	2	1	1	2	2	0.35	0.30	0.25	0.34	0.36	9.82
9	2	1	1	2	2	2	1	2	2	1	1	0.24	0.22	0.19	0.25	0.21	13.03
10	2	2	2	1	1	1	1	2	2	1	2	0.16	0.17	0.13	0.12	0.13	16.87
11	2	2	1	2	1	2	1	1	1	2	2	0.49	0.54	0.46	0.47	0.46	6.28
12	2	2	1	1	2	1	2	1	2	2	1	0.55	0.57	0.55	0.56	0.54	5.13
Total (Σ S/N ratio)																	141.29