Pacific International Journal, Vol. 1(1), 46-48; 2018
ISSN (Print) 2663-8991, ISSN (Online) 2616-4825
DOI: 10.55014/pij.v1i1.39
https://rclss.com/index.php/pij

Taguchi Philosophy of Engineering Quality

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Most technology development engineers use traditional reliability engineering methods to calibrate the objective functions of their new systems to meet various marketing requirements. Quality is related to products and services to customer satisfaction. Cost reduction and quality improvement is vital to business. Therefore it is no surprise that both consumers and management are so obsessed with the term quality that a separate branch of quality engineering has been developed. Quite a few glorified terminologies have cropped-up such as total quality management (TQM), Quality Function Development (QFD), ISO9000, Continuous quality improvement or KAIZEN, and more popularly six sigma design. These are management oriented and rather incomprehensible to an average engineer. In contrast Taguchi methods are easier to comprehend and adopt. They are also based on some common sense ideas. The managements interest was evoked owing to the claimed economic consequences of Taguchi methods of reduced cost with improved quality and consequent consumer satisfaction.
Keywords: TQM (Total Quality Management). QFD (Quality Function Development), LTB (Larger the better), STB (Smaller the Better), NTB (Nominal the Better), OA- Orthogonal Arrays

Introduction

Genichi Taguchi, a Japanese engineer developed an approach for improving quality at design stage compared to control strategies after manufacture. The thrust of Taguchi philosophy is twofold. One is that quality should be measured as a function of deviation from the nominal quality characteristic and minimizing this variation. Secondly quality should be infused into product design so that it is immune to successful in Japan during 1950's that it generated considerable interest and application in USA in 1980's. The management's interest was evoked owing to the claimed economic consequences of Taguchi methods of reduced cost with improved quality and consequent consumer satisfaction. It is misconception that quality increases costs. Actually it can result in reduced cost from fewer returns, repairs and warranty costs. It is better to improve quality by reducing faults rather than incorporate spectacular performance. Reducing wastage, mistakes, and sloppiness lead to better manufacturing quality as well as economy. Instead of trying to manage a problem (Posteriori control) it is better than cure. The facts of quality include design (function, aesthetic and customer requirements), Conformance (product and process specifications) and performance (reliability, maintenance, safety and economics) [1].

Quality can be improved by tightening tolerances on products but it adds to costs. Instead, Taguchi philosophy suggests tightening tolerances on process parameters by selecting them at nominal level and tolerance around that level. For example surface roughness can be controlled by suitable selection of cutting speed, feed rate and temperature (using coolant) and specifying tolerances for their variation. Taguchi methods recommend design of experiments and analysis for indentifying process parameters of relatively more importance, thus aiming to control vital few factors instead of trivial many.

Perspective of Taguchi methods:

Taguchi methods can be broadly categorized under four headings.

(i) Quality Engineering
(ii) Robust Design
(iii) Design of Experiments
(iv) S/N Ratio Analysis
(v)

Quality Engineering:

Taguchi defines quality as conformance to specification and its lack of deviation from the nominal quality characteristic. In a paradoxical fashion the Taguchi philosophy of quality is based on a premise that society incurs a loss any time the performance of a product is not on target. Thus quality is defined in terms of "loss function ". It can be conceptually understood that when a product deviates from its target performance, the manufacturer suffers a loss due to repairs and rectification of faults and market loss due to consumer

[Received 18 Feb 2018; Accepted 24 March 2018; Published (online) 31 March 2018]

dissatisfaction. Similarly the consumer suffers a loss which can be monetary as well as psychological due to inconvenience or hazardous result of a poor quality product. Thus the loss function represents the cost of problems in manufacture, maintenance and harmful side effects. For improving quality Taguchi advocates prevention over inspection. The poor quality is attributed to noise parameters which cause variation in product function. Such noise can originate in the manufacturing process, the consumers' misuse or environmental fluctuations. Taguchi methods suggest reduction of the variation from target performance by making products and processes immune to noise by a process typically termed as " Robust Design ". This is also claimed as "off line control "strategy[2].

Robust Design:

It includes three stages of design process

1. System design or functional design

   This involves development of basic functional prototype design in the selection of materials, shapes and sizes of parts and manufacturing processes.

2. Parametric design

   In this stage the nominal optimum settings of design parameters are determined. This can be done by developing a physical or mathematical model based on the design and subjection this to suitably designed experimental plan. This can lead to the optimum values of the process parameters for minimum deviation from the target performance (Robustness). This examines both the mean and variance of the performance parameter.

COLUMN	ASSIGNMENT OF FACTOR ORIENTATION
1	A
2	B
3	AXB
4	C
5	AXC
6	BXC
7	D

3. Tolerance design

   This deals with tightening tolerances of design parameters. It requires consideration fo loss function to determine manufacturing tolerances to minimize manufacturing cost and increasing products lifetime. This may involve a suitable compromise between quality loss and economic manufacture and based on analysis of experimental data [3].

4. Design of Experiments:

   The regression models can be very complex if interaction effects are also considered. Taguchi methods consider only direct effects. Thus the additive cause-effect model has the form $Y = U + P_I + Q_J + R_K + \overset{o}{\alpha}$ (1)

Where U is the mean value of 'Y' in the region of the experiment and P_I, Q_J ,…Etc. are the main effects of factors P,Q etc. at I and J levels and $\overset{o}{\alpha}$ is an error term. Thus restricted to main effects only, one can select partial factorial or latin square plan which leads to considerable reduction of data. Taguchi constructed special sets of orthogonal arrays (OAs) for experiment design by combining Latin square designs in a unique fashion. For example four factors at three levels require a tool of 3^4=81 cells in a factorial design. But Taguchi's O.A manages by 9 cells (Table 1) with a nomenclature as $L_N(P^k)$ O.A. where L_N represents the number of experiments. P is the number of levels and k number of factors.OAs are one of the most significant contribution of Taguchi to the researchers for planning the experiments [4]. Though basically designed for direct effects, Taguchi has incorporated some tow factor interactions using certain special unassigned OA columns and to identify the columns and to identify them he has devised a method known as "Linear graph technique". In linear graph one represents the columns of the array by dots (representing main factor effects) and lines connecting the dots (interactions effect) (Fig.I).The L8-OA with 7 columns having four factors A,B,C and D with interaction between A,B and C only is illustrated in Table 2.

Table I : $L_9(3^4)$ orthogonal array

Expt.No	Factors and their levels			
	P	Q	R	S
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 2: L8 OA With three 2-factor Interactions

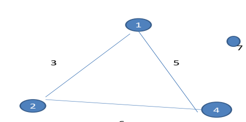

Fig 1.A linear graph for L8 array with 7 columns

Classification factors:

Control factors – Design factors that are to be set at optimal levels to improve quality and reduce sensitivity to noise.

Noise factors- Factors that represent the noise that is expected in production or in use.

Adjustment factor – Affects the mean but not the variance of are response Signal factors – Set by the user to communicate desires of the user.

Experiment procedure

1. Identify design factors and noise factors.
2. Design an experiment to study the effect of design factors (inner array).
3. Goal of the experiment is to identify design factors, which affect significantly the average and those affecting variance.
4. Analyze the result by signal to noise ratio for studying the variability as well as identifying optimum settings.

Analysis:

The analytic approaches include the loss function and signal to noise ratio.

Loss Function:Variation is unavoidable in all manufacturing processes and rejections occur when the variation occurs beyond the specified tolerances since inspection in not 100 percent, defective parts can reach consumers and result in warranty cost and loss of market by consumer dissatisfaction. Thus loss function has a quadratic relationship

$L(Y) = k\,(Y-\hat{0})^2$ (2)

Quality loss leads to financial loss to both consumer and manufacturer and Taguchi described it as "Societal loss ". Therefore the objective should be minimization of the quality loss. This can have two sources. First one is the average performance 'I' being different than target $\hat{0}$ and causes a loss of $k(Y-\hat{0})^2$. The second results from the performance 'Y' being different than its own average 'I' and equals to 'k$\hat{0}^2$.

For ideal performance 'I' should approach $\hat{0}$ and $\hat{0}^2$ approach zero. The former implies accuracy and the latter precision. The approach leads to the other analytical approach of S/N ratio which specially is suitable of combining both mean and variance to identify superior setting which otherwise would be difficult.

S/N Ratio:

The conventional specification of tolerance as $+\ddot{a}$ variation from the target is sometimes not adequate. It is better to minimize this deviation rather than specify it. Therefore the proper approach to quality assurance is the achievement of target with minimum variation [l4 l5]. For a standard approach for optimization Taguchi suggests minimization of loss function involving target as well as variance or in other words minimization of the loss function $L(Y) = k\,(\hat{0}^2/i^2)$ where I is the target signal and $\hat{0}$ is the deviation or noise. This is basis of the measure signal to noise ratio and its maximization. The optimization statistic thus becomes maximization of $(i^2/\hat{0}^2)$ denoted as S/N ratio and there can be three possible quality characteristics.

1. Larger the better (LTB) e.g. Machining rate(3)
2. Smaller the better (STB) e.g. tool wear(4)
3. Nominal the better (NTB) e.g. dimension(5)

The MSD takes a different form in each case

1. LTB: MSD $=\frac{1}{N}\sum_{I=1}^{N}(\frac{1}{Y_i})^2$
2. STB: MSD= $\frac{1}{N}\sum_{I=1}^{N}(Y_i)^2$
3. NTB: MSD=$\frac{1}{N}\sum_{I=1}^{N}(Y_i-\tau)^2$

Concluding Remarks:

Whether it is TQM, six sigma, Taguchi methods or any other approach on quality engineering they are all based on statistical principles but finally emerge as management functions with thrust o reducing cost and amalgamation with reduced faults and rejections rather than incorporating higher qualities. Of them Taguchi methods are more appealing and comprehensible. Managements are attracted by the claim of low cost quality control and academic researchers for adopting novel techniques of experimentation and data analysis. In a nutshell the contribution of Taguchi can be categorized as Robust Design for reduced variation from target performance, experiment design with orthogonal arrays, analysis by quality loss function for tolerance design and optimization with S/N ratio. The most common argument opposing Taguchi methods is its lower efficiency than statistical methods, limited levels and choices of design factors. The concept of loss function though interesting, its calculation may not be tangible. Added cost of manufacture and loss of reputation are complex which cannot be correctly predicted. Perhaps it is best to blend the Taguchi's economic engineering ideas with the efficiency of statistical techniques. However for analysis and optimization of non-deterministic or stochastic process,the Taguchi method of S/N is best suited.

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