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*Make Harmony Between Technology and Nature, and Your Mind will Fly Free as a Bird*
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# THE TAGUCHI'S QUALITY LOSS FUNCTION IN DEVELOPMENT AND DESIGN FOR BULK GOODS IN THE AUTOMOTIVE FIELD

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***Abstract:*** *The present paper treats Taguchi's Quality Loss Function and gives indications of how to implement it in development, design and production of bulk goods. The authors have therefore analyzed a variety of product designs as well as their manufacturing processes and have evaluated them with regard to tolerance design. It was evident that, by using the Quality Loss Function, the product quality can be significantly improved by enlarging the manufacturing tolerances in the prints.*

***Key words:*** *Taguchi, quality, robustness, design, tolerance*

## 1. INTRODUCTION

The concept of the Quality Loss Function was developed by Genichi Taguchi, in the early 1950's. More and more major American manufacturers implemented Taguchi's methodology after 1980. The same trend could be observed in West Europe in the last decade, especially among automotive manufacturers and aircraft industry. Based on the Quality Loss concept, Taguchi, G. in (***, 2001) and (Taguchi et al, 2007), has further developed the complement methodologies Design of Experiments and Robust Design. (Creveling, 1996) introduces topics in traditional analytical and computer-aided tolerances development and Taguchi's quality loss function in conjunction with Motorola's six sigma quality methods. In (Chen et al., 1999), are solved robust design problems from a utility perspective by following upon the recent developments on relating utility function optimization to a Compromise Programming (CP) method. (Yu et al.'98) presents methods and tools to help decision making at the robust design of products.

## 2. THE QUALITY LOSS FUNCTION

Classical Quality Control, the so called Goal Post Method, uses upper and lower specification limits (LSL, USL) as boundaries between acceptable and unacceptable performance. Performance between the specifications is considered equally acceptable. Taguchi's idea is to replace the concept of "Quality" by its complement "Quality Loss". This means that parts of acceptable quality inherent the lowest quality loss, particularly zero. On the other hand, the engineering experience shows that quality degrades, with some exceptions, continuously. Taguchi proposed that performance degradation can be measured as a deviation from some target value as a quadratic quality loss function (fig. 1) and asserted that the degradation can be related to a loss in value to the consumer.

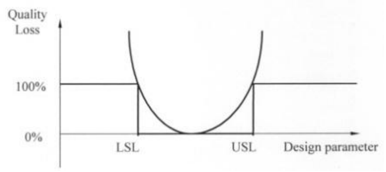


Fig. 1 Taguchi's Method for Quality Loss Evaluation

Even if a product is well within its specifications, it has a quality loss if its parameter value is not at the ideal performance target. This loss is defined in financial terms so that it can be compared to the product's manufacturing cost. For a manufactured batch, the quadratic loss function can be expressed as:

$$L = n \cdot k \cdot \left[\sigma^2 + \left(\bar{x} - \mu\right)^2\right] \tag{1}$$

Where: L = global financial loss; n=number of produced parts; μ = target value; k = a constant defining the loss for one non-conform part; $\bar{x}$ =actual mean value of a parameter.

The diagram shows that the lost value for lower product quality can be even higher than its own value. This comes from the fact that the costs for poor quality consist of a multitude of expenditures like: replacement of defective products, repair of defective products, additional logistic costs, image loss, costs for apologies, etc. Toyota Motor Company's principle in this matter is: "Whatever an executive thinks the losses of poor quality are, they are actually six times greater". Using the rel. (1) it is possible to determine the financial losses based on the process capability indices:

$$L = k \cdot n \cdot \left[1 + \frac{1}{9 \cdot Cp^2} + \left(\frac{Cpk}{Cp}\right)^2 - 2 \cdot \frac{Cpk}{Cp}\right] \tag{2}$$

With: *Cp* = process capability index; *Cpk* = critical process capability index. This type of evaluation applies only to those parameters which have a significant influence on the product quality, the so called Significant Characteristics. In order to identify the significant characteristics, Taguchi breaks down off-line quality control into three stages: system design, parameter design and tolerance design. System design is best achieved by a cross functional brain storming session. The goal is to optimize the product in a way that the system is less sensitive to accidental changes in noise factors. Such a system is called robust. The third stage is the tolerance design. 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. So, tolerance design is considered to be an economic issue and the loss function model promoted by Taguchi can be used as a basis. The first step in tolerance design is to determine the contribution of each noise factor to the variation; to know which noise factors were the causes of large variance. And then, the way of reducing the effect of the noise factor must be considered.

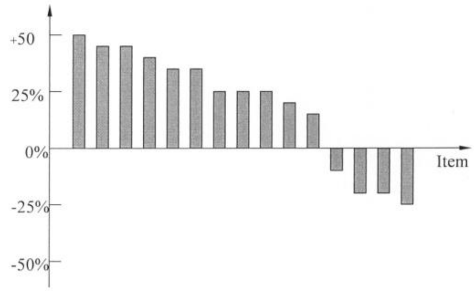


Fig. 2 Pareto analysis of modified manufacturing tolerances

Through the tolerance design the designer makes tradeoffs between the increased cost of the product and the improved quality. Over the years, many distinct approaches have been developed to implement the Taguchi's parameter and tolerance concepts; they can generally be classified into the following three categories: pure analytical approach, structural simulation approach, physical experimentation approach. The involved costs for these categories as well as the results validity and precision enhances from the first to the last. Due to the lack of precise theoretical models that explain product process performance characteristics in terms of different variables, the most predominant approach to implementing parameter and tolerance design involves physical experimentation.

## 3. CONTRIBUTIONS TO IMPROVING PARAMETER AND TOLERANCE DESIGN

The analysis of different products designs of precision components have shown that the most of the manufacturing parameters defined in prints are not directly related to the product function. There is only a fraction of about 7 to 8% which go back to the quality loss as defined by Taguchi. The majority of the parameters in this fraction were provided with unnecessarily tight tolerances. Experiments carried out with components with enlarged tolerances (up to 50%) showed no significant quality losses. Fig. 2 shows the Pareto analysis of tolerance changes made to different parameters without affecting the customer demanded quality level (positive values stand for tolerance enlargement, negative ones for constriction). In order to design a robust product in accordance to Taguchi's concept, the following design recommendations should be considered: determine the parameters with major influence on function and manufacturability (significant characteristics); reduce the number of significant parameter and determine which factor is causing most variations; define the parameter tolerances to reduce variation in product quality; use the independent principle for geometric dimensioning and tolerance (ISO8015); display the significant characteristics and their target value; use statistical tolerance analysis, wherever is appropriate. The presented recommendations are successfully applied to several case studies at some automotive companies.

## 4. INDUSTRIAL CASE STUDY

We consider the hydraulic cylinder from the production of an automotive elements' construction company. Taking into consideration the dimensional parameter:

| Standard deviation, σ [mm] | $C_p$ | Rejected parts [ppm] | Classical financial loss [€/an] | Taguchi financial loss [€/an] |
|---|---|---|---|---|
| 0.00250 | 2 | 0.002 | 0 | 27000 |
| 0.00300 | 1.67 | 0.6 | 0.6 | 40000 |
| 0.00375 | 1.33 | 65 | 65 | 62000 |
| 0.00500 | 1.00 | 2740 | 2740 | 111000 |
| 0.00750 | 0.66 | 46000 | 46000 | 250000 |

Tab.1. Production "on goal": XM=goal (30 mm)

| XM-Goal [mm] | $C_{pk}$ | Rejected parts [ppm] | Classical financial loss, [€/an] | Taguchi financial loss, [€/an] |
|---|---|---|---|---|
| 0.000 | 1.67 | 0.6 | 0 | 40000 |
| 0.001 | 1.55 | 4 | 4 | 44000 |
| 0.002 | 1.44 | 17 | 17 | 58000 |
| 0.003 | 1.33 | 65 | 65 | 80000 |
| 0.004 | 1.22 | 255 | 255 | 111000 |

Tab. 2 Production accepting XM-goal>0; σ=0.0003mm ($C_p$=1.67)

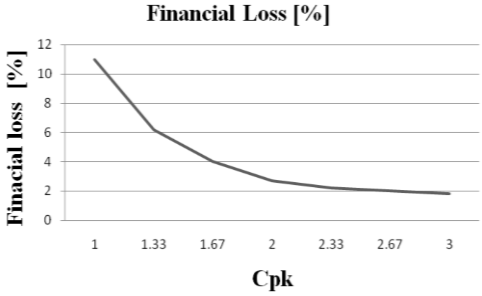


Fig. 3 Financial loss reported to Cpk

Cylinder's nominal diameter: AD=20±0,015 mm; final fabrication cost for this parameter is 1 € for production volume of 1 million cylinders /year. K= $1€/0,015^2=4444€/mm^2$ . If this parameter is produced "on goal", the financial loss / year is in table 1, if not, in table 2. As a result at $C_{pk}$=1.33 and the same number of rejected parts comparing yearly financial losses, they are smaller for production "on goal". Fig 3 shows that the diminishing of the financial loss is accelerated for $C_{pk}$ values between 1 and 1.67; for $C_{pk}$>1.67, the diminishing is irrelevant. In conclusion, the company may consider acceptable Cpk=1.67, for part's robust design.

## 5. CONCLUSIONS

The quality loss function, as well as the additional Taguchi methods, solves in a way the conflict between "high quality" and "low manufacturing costs", offering an engineering tool to exactly define the product quality during the development phase of a product. In robust design, it is important not only to achieve the robust objective performance but also to maintain the robustness of design feasibility. So, tolerance design becomes crucial in order to reduce manufacturing costs at acceptable quality level. The aime of this paper is to motivate the research to make a bridge, the gap between the robust conceptual design and the robust parameter design.

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