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Philosophy of Taguchi Approach and Method in Design of Experiment

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ABSTRACT

In recent market and global requirements, the desires to provide higher level of quality in products and services for increasing market shares continues competitively among the manufacturers to ensure customer satisfaction will return with consistent orders. The important of product and process optimization has caused manufacturers focus greater attention to design optimization in order to stay competitive in the world market. The understanding on the fundamental of basic experimentation will be a starting point to improve process yield, product performance and productivity of company-wide operation. Thus, a more reliable and effective experimental approach subsequently will be the right choice to study the possible design factors that satisfy customers and process compatibility. This study presents the philosophy and method applied for Taguchi method design of experiment. The concept such as quality should be designed into the product, quality loss function, determining the optimization condition for the product or process, designing product and process that insensitive to the influence of uncontrollable factors or noise, signal-to-noise ratio and orthogonal arrays among the important terms in application of Taguchi method design of experiment.

Key words: Taguchi method, quality, signal-to-noise ratio, orthogonal arrays

INTRODUCTION

The massive competition in the world market is to satisfy customers' needs and expectation has triggered manufacturers to improve the product design and cost of manufacturing. In reality the application of statistical techniques and experimentation are not widely being used in the industrial organization. In such situation company that was unable to overcome the challenging demand has to close their operations and in worst scenario some organizations are engaged with millions of debts that hardly to be pay back. In general, many manufacturers are not being able to used design of experiment to make a quality product with lower manufacturing cost and faster in product development process. In replacement, trial and error still a popular approach to be employed. The conventional design of experiment is known as a very complicated and a costly process which required competent resources and accrue high experimental cost. It is a complex and not easy to use, especially when large number of experiments has to be carried out when the number of the process parameters increases (Nalbant *et al*., 2007).

The time required to complete an experiment is extremely long especially for investigating and evaluating large quantity of factors that are affecting the desired quality characteristics. The difficulties are further encountered when experiment has to be repeated for several modeling and verification purpose until accurate and validated result is obtained. Therefore the Taguchi method for design of experiment has become an alternative in solving these problems and also chosen as the right solution to industrial organization in improving their product and process design. The Taguchi method which was designed to reduce the engineering experimental time and cost stimulate the initiative and effort for product improvement and assisted the continuous improvement in processing capability. Its simplicity in data collection as well as practical in designing the product and process parameters make design of experiment is possible in any organization and business operation. One way to remain or stay in the market is to strengthen the new product development and the ability to overcome problem or challenge in production process in order to warrant the product are satisfying the customers and customers returned for new orders. To achieve desirable product quality by design, Dr. Taguchi (Roy, 1990) recommends three process stages; system design, parameter design and tolerance design.

Experimental guidance and templates or user friendly software will help to ensure the effective application of Taguchi method at workplace to solve problems related to product design, performance and improvement of the processes. The Taguchi methodology has taken the design of experiments from exclusive world of the statistician and brought it more fully into the world of manufacturing (Nalbant *et al*., 2007). It emphasizes the importance of designing quality control into manufacturing processes (Roy, 1990). Robust design is an engineering methodology for optimizing the product and process conditions which minimally sensitive to the various causes of variation and which produce high quality of product with low development and manufacturing costs (Phadke, 2008). Taguchi parameter and tolerance design are important tool for robust design. Robust design and indeed any statistical analysis need to be carried out with the engineering aims of study in mind (Dowey and Matthews, 1998). This study presented the philosophy and method applied for Taguchi method design of experiment.

THE THEORY AND PHILOSOPHY OF TAGUCHI APPROACH

The essence of Taguchi approach is its contribution to excellent quality control in the manufacturing industries. His concept has developed engineers to see quality as a yard stick in their design of product and process. The philosophy which based on three fundamental concepts has greatly caused the better application and development of technology and techniques in many industries. The three concepts are (Roy, 1990):

- Quality should be designed into the product and not in its inspection
- To achieve the quahty it is best to minimize the deviation from the target and product shall be designed to be insensitive to the uncontrollable environmental factors
- The cost of quality is measured as a function of deviation from the standard and the losses should measure the system-wide

It emphasizes the importance of designing quality control into manufacturing processes. The Taguchi approach stresses that quality variation is the main enemy of quality engineering and that every effort should be made to reduce the variation in quality characteristics. Robust design is an engineering methodology for optimizing the product and process conditions which minimally sensitive to the various causes of variation and which produce high quality of product with low development and manufacturing costs (Park, 1996). Taguchi parameter design is an important tool for robust design. In this method the tolerance design can be also classified as a robust design. Specifically robust design is identical to parameter design, but a wider sense parameter design is a subset of robust design. Two major tools used in robust design are (Park, 1996):

- Signaled-to-noise ratio which measures quality with emphasis on variation
- Orthogonal arrays which accommodate many design factors (parameters) simultaneously

Taguchi method is a powerful design of experiments which provide simple, efficient and systematic approach to optimize designs for performance, quality and cost (George *et al*., 2004). In enhancing the quality in the design stage, Taguchi has developed two-step process (Lofthouse, 1999):

- Optimizing the design of the product or process by manufacturing the product in the best manner most of the time with less deviation from the target
- To design product and process insensitive to the influence of uncontrollable factors in ensuring produced products are identical (less variation between the products)

The optimum level of a product when performed under available operating conditions has implied that the product performance has achieved the most and the least of the target value of quality measurement. Optimizing the design of the product means determining the right combination of ingredients or making the proper adjustment to the machine so that the best result is obtained (Roy, 1990). In Taguchi approach, the design of experiment process will considered all the main factors and their influencing factors to the dependent variable. The fundamental of this technique is to improve the quality of product by minimizing the effect of the causes of variation, since variability around the expected target is allowed; the effort is to reduce the variation without eliminating the causes of variation (Phadke, 2008). According to Phadke (2008) the variations that represent the noise factor are categorized into three sources:

- Unit to unit variation: It is caused by the variation in material, equipment performance and workmanship
- Environment (external factor): It is due to the environmental condition surrounding the processes
- Deterioration (internal factor): It is wear and tear of the components and consumables items used in the process

Often in an industrial setting, totally removing the cause of variation can be expensive (Roy, 1990). A low cost solution is achievable by adjusting the levels and controlling the variation of factors affecting the product or process performance. The parameter design focused by Taguchi is a reaction to this expectation and the cost of experiment could be saved further by avoiding additional experiment that need to reduce variation in product and process design. The basic approach about the design of experiment consists of four stages to such design (Lofthouse, 1999):

- Planning the experiment
- Designing the experiment
- Conducting the experiment and
- Analyzing the experimental results

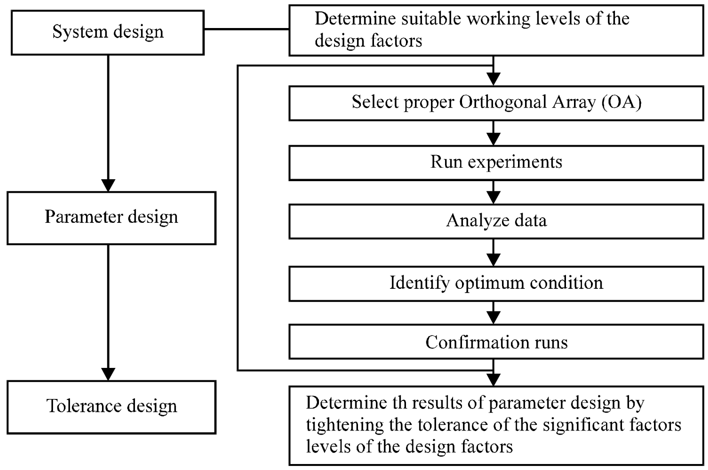

Fig. 1: Taguchi design procedure (Zhang *et al.*, 2007)

Figure 1 shows the Taguchi design procedure to represent the three stages; system design, parameter design and tolerance design (Zhang *et al.*, 2007).

This method is very much applicable and effective when applied to experiments with multiple factors, however the preliminary knowledge in engineering or science is a prerequisite for experimenters to determine the suitable levels and design factors. Knowledge of scientific phenomena and past engineering experience with similar product designs and manufacturing processes form the basis of engineering design activity (Phadke, 2008).

THEORY OF TAGUCHI IN DESIGN OF EXPERIMENT

Taguchi constructed a special set of general designs for factorial experiments that covers many applications. They are orthogonal arrays with number of experiment, factors and levels for each special design orthogonal arrays. The use of these arrays helps to determine numbers of experiments needed for a given set of factors. When fixed number of levels for all factors is involved and the interaction are unimportant, standard orthogonal arrays will satisfy most experimental design needs. Taguchi method successfully resolves the difficulties in compacting experimental design by having the orthogonal arrays that represents the possible experimental condition and a standard procedure to analyze the experimental result (Chen *et al.*, 2008). The Taguchi method is a concept developed base on the optimization through design of experiments, in which, experiment will be carried out and the value of quality is very much significant to discipline the way for developing a product and investigating complex problems (Roy, 1990). Undoubtedly, this method has provided cost effective ways to examine and find available alternatives in design and processing issues. The activities started with brainstorming the quality characteristics and design parameters that are important to product or processes, design and conducting the experiments, analyzing the results to determine the optimum conditions and finally run the verification test at the optimum condition. The team approach and brainstorming activity in design optimization is very much consistent with the success of the design experiments as the knowledge and information on variables are synergistically extracted in deriving the benefit from Taguchi method (Roy, 1990). The preliminary understanding of the whole process will help in planning the experiment and selecting the critical factors that are to be tested, hence the number of experiment could be determined and time could be estimated efficiently.

Taguchi method emphasizes on having the least number of experiment to be conducted. Why larger experimentation is needed since it can be conducted in more efficient and productive ways is the principles in the Taguchi method. Taguchi method is complimented with the use of statistical process control techniques, number of factors to be controlled and which factors were most significant and dominant are quantified by analyzing the variance contributed by each factors. The statistical techniques in visualizing variation and the mean are applied to successfully make the Taguchi methodology come into effects and reality. The Taguchi method will provide information on which factors are important to be controlled and which levels are suitable to put quality characteristic on target, this will comprehend the application of the statistical quality control in ensuring process capability are maintained to the expected variation and goals. Taguchi's robust design method will allow wider manufacturing tolerances, lower grades components or materials and wider operating environment (Phadke, 2008). It is a method of arriving at more reliable and durable products and process efficiently.

The benefit of improved design quality could be seen when product are produced in the production and reached to customer. The outcomes of minimal reduction in variation when product is produced with optimum combination of factors will yield consistent performance in desirable quality characteristic. Significantly, according to Phadke (2008) the benefits of the application of Taguchi method are: reduction in process variance, reduction in fatal defects, reduction in process time, transition of design from research to manufacturing and adaptation process to more precision technology. As a results customer satisfaction is increased and costs are controlled when less warranty issues and sales are booming as expected. This is described further in its loss function approach on how to quantify cost benefits. The loss function approach is used to estimate the potential saving based on the improvement achieved during the experimentation if the product were designed to the optimum condition prescribed by the Taguchi design of experimental results. The improvement could be made by calculating the changes on the Mean Square Deviation (MSD) for calculating the S/N ratio. A bigger S/N ratio compare to past performance indicates improvement is attained over the product or process and this is visualized by the variation of data against the mean and target. The amount of saving is calculated by using the loss function formula which considers the cost of failure and the value of MSD. The calculation of MSD is obtained by comparing the unit's performance against the targeted performance of the quality characteristic (Roy, 1990). Consequently the amount of expected saving could be estimated and process or product design could be adjusted according this goals and such decision are made to balance the profit and loss. On the another hand, Taguchi method is an efficient problem solving tools which can improve the performance of the product and process design and system with a significant achievement in experimental time and cost (Lakshminarayanan and Balasubramaniam, 2008).

Of all the three stages of the offline quality engineering system (system design, parameter design and tolerance design), Taguchi's parameter design has proved to be the most powerful stage for process optimization (Antony *et al*., 2001). The experiment with Taguchi method is using partial factorial experiments where number of test combination is reduced into special set for designated application. The special set consists of orthogonal arrays which will determine the least and feasible number of experiment needed for a given set of factors. The total number of experiment and possible number of factors at are depicted in Table 1.

The orthogonal array designed by Taguchi only work well when there is minimal interaction among factors on the measured quality objective are independent of each other and are linear. The optimum condition still could be attained even interaction occurs between factors. The degree of

Table 1: Common orthogonal array

Array	No. of factor	No. of levels
L4 (2)	3	2
L8 (2)	7	2
L12 (2)	11	2
L16 (2)	15	2
L32 (2)	31	2
L9 (2)	4	3
L18 (2)	1	2
L18 (3)	7	2
L27 (3)	13	3
L16 (4)	5	4
L32 (2)	1	2
L32 (4)	9	4
L64 (4)	21	4

Roy (1990)

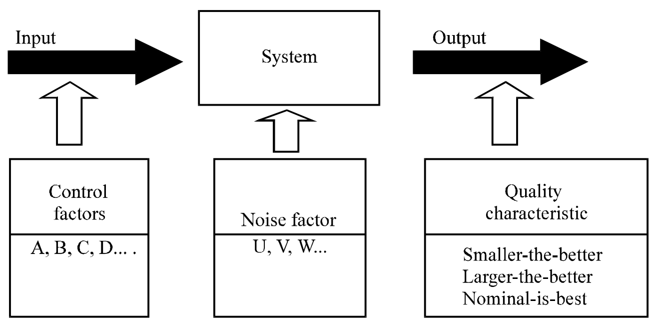

Fig. 2: Factor characteristic relation diagram (Park, 1996)

accuracy in performance estimate will depends on the degree of the complexity of interaction among all factors (Roy, 1990). Designing the experiment started with the identification of factors and effect of product and process under investigation. This could be done through cause and effect analysis in a team approach. This was explained in Fig. 2 that a system is referred to a process, manufacturing line, an R and D environment or a given experimental situation (Park, 1996).

The measurement of the quality characteristic shall be determined whether it is numerical or attribute data. The design of experiment will identify factors to be studied and the orthogonal arrays that suit the number and level of the factors. Order of running the experiments shall be in random to reduce error result in experimentation. To increase the accuracy replication or repetition in experiment is emphasized in Taguchi method. Replication requires a new run of the same experiment in random order. Repetition can be accomplished when noise factors are tested at certain levels and combination. Each trial is repeated as planned before proceeding to the next trial run (Roy, 1990). Sometimes it is not easy to set up an experimental conditions for noise factors, alternatively repeated observations can be taken by letting the noise conditions of the noise factors vary as they are naturally changed in practical situations (Park, 1996).

Analysis of data is conducted by evaluating the results of the measured quality characteristic. The result is tabulated to find the average performance at each level before the sum of square of each factor could be calculated. The average performance at each level for all factors will be calculated and these results will be plotted to identify the main effects to the quality characteristic. It is the factorial effect that represents the difference between levels of each factor. The strongest effect is accounted by the highest S/N ratio.

When required, study of interaction effect could be performed with special adoption of predicted interaction within factors in the orthogonal array of the experimentation. However, in Taguchi method consideration of factors interaction is very minimal as focus is more on the main effects. Taguchi methods do not specify any general guidelines for predicting interactions as the determination of possible interaction are known by some other means or from past experience or previous experiments (Roy, 1990). As the analysis in Taguchi is measuring the variance effects of each factor with mean to be on target. The calculation base on Analysis of Variance (ANOVA) is applied extensively to quantify the effect of factor to desired quality.

TAGUCHI APPROACH IN EXPERIMENTAL WORK

The use of Taguchi loss function is by converting all characteristic which having different units of measurement and magnitude of scale into a common measurement; a loss score. The loss function is a quadratic and non-linear relationship, the loss become increasingly large as the value deviates from the target value. The Taguchi loss function suggests prioritizing quality efforts are based on the largest deviation of actual process specifications from the target specifications. Taguchi propose that the greater the deviation from target, the higher the probability of failure and increased defect rates and quality cost (Hales *et al.*, 2006). Generally, three types of loss functions are used to calculate the amount of losses. First two sided loss function where nominal is the target and deviation from either side of the target is allowed as long as it remains within the specification limits. Any deviation from the target value will result in loss and zero loss occurs only when the characteristics measurement is equal to the target value (Phadke, 2008). The second and third types of loss function are one-sided function where deviations from target are allowed only in one direction (Ordoobadi, 2009). These loss functions are referred to as "bigger the better "and "smaller the better". The use of the Taguchi loss function is to quantify the impact or magnitude of selected performance characteristic. The loss function is calculated from amount MSD of the measured performance multiply with the value of the loss coefficient (K) for each of the quantity of measurement accordingly (Park, 1996):

- For smaller the better $L(y) = K (y^2)$
- For bigger the better $L(y) = K(1/y^2)$
- For nominal the best $L(y) = K(y-yo)^2$

Where, yo is the mean of the experimental data.

The value of the loss coefficient is the cost of poor quality incurred when rework and scrap of sub and finish product is required. Other relevant cost of poor quality would be considered as an added cost in the value of the loss coefficient.

The experimental design in Taguchi method is asset of methodology by which inherent variability of materials and manufacturing processes has been taken into account at the design stage (Zhang *et al.*, 2007). The essence of Taguchi design is that multiple factors can be considered at once. Not only controlled factors are considered but also noise factors which exist within the production and user environment, all these are experimented to improve the yield in manufacturing and reliability in performance of the product. Taguchi design conducts balanced orthogonal experimental combinations which makes Taguchi design even more effective than fractional design.

THE EXPERTS' VIEW AND IMPLEMENTATION OF TAGUCHI DESIGN OF EXPERIMENT

There are three text books commonly available to be referred for studying, implementing and commenting on the Taguchi design of experiment. All of these books are discussing about the Genichi Taguchi ideas, since he was pioneered the concept of quality engineering using robust design (Phadke, 2008). According to Taguchi, it is important to make the product's function as close to the ideal function as possible. Therefore it is very important to measure correctly the distance of the product's performance from the ideal function. He said that in order to measure the distance, we have to consider the following problems:

- Identify the signal and noise
- Select several points from space
- Select an adequate design parameter to observe the performance
- Consider possible calibration or adjustment method
- Select an appropriate measurement related with the mean distance

Roy (1990) was a primer on the Taguchi Method. According to him, Taguchi's method is based upon an approach which is completely different from conventional practices of quality engineering. His methodology emphasizes designing the quality into the products and processes, whereas the more usual practice relies upon inspection. He said that Taguchi's approach has extremely improved Japanese products and western industries have found it's a simple and effective method in improving product and process quality. He added that the Taguchi techniques have been commonly applied to 'off line' quality control. The Taguchi method is for quality improvement and cost reduction rather than discovering the causal relationships of how things happen (Park, 1996). He said that Taguchi has classified factors into control, noise, signal adjustment, inductive and block factors. Each type of factor has an important meaning from an engineering point of view. The concept of robust design has many aspects, among them:

- Finding the smallest set of conditions from design variables which are robust to noise
- Achieving the smallest variation in product's function about a desired target value
- Minimizing the number of experiments using orthogonal arrays and testing for confirmation

He explained that Taguchi method is applied for both 'off line' and 'on-line quality' control.

According to Phadke (2008), designing high-quality product and processes at low cost is an economic and technological challenge to engineer. A systematic and efficient way to meet this challenge is a new method of design optimization for performance, quality and cost. The robust design method uses a mathematical tool called orthogonal arrays to study a large number of decision variables with small number of experiments. It also uses new measure of quality, called signal-to-noise (S/N) ratio, to predict the quality from customer perspective. Thus, the most economical product and process design from both manufacturing and customer points of view can be accomplished at the smallest, affordable development cost.

Khoei *et al.* (2002) used L4 and L9 orthogonal arrays to determine the optimum levels and relative magnitude effect of various factors. He had found that the parameter setting results could be confirmed by running a L18 orthogonal array. This indicates that the used of suitable orthogonal arrays will reveal the same experimental results as well as increasing the confidence about the optimum setting found from the earlier experiments. Ghani *et al.* (2004), Tasirin *et al.* (2007), Ibrahim *et al.* (2010), Jaharah *et al.* (2009) and Ghani *et al.* (2010) have proven that the Taguchi method in experiment is suitable to solve stated problem with minimum number of trials as compared with a full factorial design. In the study, they found that by using Taguchi method other significant effects such as the interaction among parameters could also be investigated. The experiment conducted on arriving at optimum parameter setting has provided significant evidence in feasibility of Taguchi method. Sharma *et al.* (2005) found that the experimental layout; procedure and steps had ensured greater validity of test result which finally attained the optimal setting of the process parameters.

Maghsoodloo *et al.* (2004) in his study confirmed that Taguchi loss function is a method to quantify the quality. He found that orthogonal arrays is simple and robust design on parameters. He confirmed that the tolerance design is able to identify optimum setting to reduce variability and to get mean on target. Mohamad Ibrahim *et al.* (2002) used L9 orthogonal array for experimental design to formulate the optimum electroless nickel bath. The experiment was conducted to analyze the effect of four factors; nickel salt, reducing agents, complexing agent and pH of the bath against the deposition rate. The optimum bath formulation was predicted based on the experimental results with pH of the bath known as the most significant control factor to be carefully considered. In micro injection molding process which produced micro lancet needle for biomedical application, (Chen *et al.*, 2008) had employed Taguchi method in injection parameters setting and successfully found the best parameter combination according to the preset quality features and finally concluded that the melting temperature and mold temperature have the most significant effects on the strength of the molded polylactic acid micro-needles. In micro injection molding process which was producing micro lancet needle for biomedical application, Wang *et al.* (2008) had employed Taguchi method in injection parameters setting and successfully found the best parameter combination according to the preset quality features and finally concluded that the melting temperature and mold temperature have the most significant effects on the strength of the molded polylactic acid micro-needles.

George *et al.* (2004) confirmed that the Taguchi method is an approach which able to formulate the optimum parameter setting for a shot peening process which identified the work height as the most critical parameter that affected the peening intensity. The optimum process was achieved with number of shot required is comparatively less to before experiments. Chen and Chen (2007) had successfully used Taguchi method to optimize the process parameters for rolling porous V-sectioned and T-sectioned beams with application of 3D finite element code to investigate the effect of the rolling condition on plastic deformation behavior of the porous beam at the roll gap. Shaji and Radhakrishnan (2003) had applied Taguchi method to determine the feasibility of using graphite as lubricant in the grinding process. Three quality characteristics were observed in grinding process for coolant and graphite, respectively. They were studied and compared for their average response and S/N results from the same parameters setting using L9 orthogonal array. This comparison lead to the finding that by applying graphite in grinding process as a lubricant, the tangential force and surface roughness are lower and normal force is higher compared to those in the conventional grinding.

CONCLUSIONS

The Taguchi approach to design of experiments is an effective strategy in product and process optimization. The approach of Taguchi method is able to improve the process performance when optimum parameters setting used in the process give better output performance in terms of quality and productivity. Taguchi method will identify the possible factors for the significant effect to response variable. This approach is applicable to attribute and variable data for which they are important to be analyzed. Once the factor of an unacceptable variation is identified, follow up corrective action or preventive action can be taken to improve and prevent the problem to occur and escalate. The Taguchi approach is in tandem with the approach required in effective way and scientifically implemented for solving problem. The improvement made through the Taguchi method can be quantified easily by applying the loss function concept and calculation of the loss. The amount saving can be calculated, estimated saving will assist to prevent unnecessary losses and this will increase the competitiveness of the manufacturer as well as increasing the customer confidence. It is strongly recommended to use Taguchi method in industry as one of the design experiment methodology in improving the product and process quality. The great importance of its approach will enhance the production performance in quality product with minimal operating cost. Taguchi approach will result in fast decision making and are very much useful to be used in a specific and simple process.

REFERENCES

Antony, J., S. Warwood, K. Fernandes and H. Rowlands, 2001. Process optimisation using Taguchi methods of experimental design. Work Study, 50: 51-58.

Chen, D.C. and C.F. Chen, 2007. Use of Taguchi method to study a robust design for the sectioned beams curvature during rolling. J. Mater. Process. Technol., 190: 130-137.

Chen, W.C., M.W. Wang, G.I. Fu and C.T. Chen, 2008. Optimization of plastic injection molding process via Tauchi's parameter design method, BPNN and DFP. Proceedings of the 7th International Conference on Machine Learning and Cybernatics, July 12-15, 2008, Kunming, China.

Dowey, S.J. and A. Matthews, 1998. Taguchi and TQM: Quality issues for surface engineered applications. Surf. Coat. Technol., 110: 86-93.

George, P.M., N. Pillai and N. Shah, 2004. Optimization of shot peening parameters using Taguchi technique. J. Mater. Process. Technol., 153-154: 925-930.

Ghani, J.A., I.A. Choudhury and H.H. Hassan, 2004. Application of Taguchi method in the optimization of end milling parameters. J. Mater. Process. Technol., 145: 84-92.

Ghani, J.A., M.N.A.M. Rodzi, M.Z. Nuawi, K. Othman and M.N.A. Rahman *et al.*, 2010. Application of Taguchi method for analyzing factors affecting the performance of coated carbide tool when turning FCD700 in dry cutting condition. Proceedings of the International Conference on Advances in Materials and Processing Technologies, October 24-27, 2010, Paris, France, pp: 993-998.

Hales, D.N., S.M. Siha, V. Sridharan and J.I. McKnew, 2006. Prioritizing tactical quality improvement: An action research study. Int. J. Oper. Prod. Manage., 26: 866-881.

Ibrahim, G.A., C.H. Che Haron, J.A. Ghani and H. Arshad, 2010. Taguchi optimization method for surface roughness and material removal rate in turning of Ti-6Al-4V ELI. Int. Rev. Mech. Eng., 4: 216-221.

Jaharah, A.G., C.H.C. Hassan, M.J. Ghazali, A.B. Sulong, M.Z. Omar, M.Z. Nuawi and A.R. Ismail, 2009. Performance of uncoated carbide cutting tool when machining cast iron in dry cutting condition. Int. J. Modern Phy. B, 23: 1796-1802.

Khoei, A.R., I. Masters and D.T. Gethin, 2002. Design optimisation of aluminium recycling processes using Taguchi technique. J. Mater. Process. Technol., 127: 96-106.

Lakshminarayanan, A.K. and V. Balasubramanian, 2008. Process parameters optimization for friction stir welding of RDE-40 aluminium alloy using Taguchi technique. Trans. Nonferrous Met. Soc. China, 18: 548-554.

Lofthouse, T., 1999. The taguchi loss function. Work Stud., 48: 218-223.

Maghsoodloo, S., G. Ozdemir, V. Jordan and C.H. Huang, 2004. Strengths and limitations of taguchi's contributions to quality, manufacturing and process engineering. J. Manuf. Syst., 23: 73-126.

Mohamad Ibrahim, M.N., C.W. Sia and Z.A. Ahmad, 2002. Preliminary step in formulating the optimum electroless nickel bath using Taguchi method. J. Teknologi, 37: 67-74.

Nalbant, M., H. Gokkaya and G. Sur, 2007. Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning. Mater. Design, 28: 1379-1385.

Ordoobadi, S., 2009. Evaluation of advanced manufacturing technologies using Taguchi's loss functions. J. Manuf. Manage., 20: 367-384.

Park, S.A., 1996. Robust Design and Analysis for Quality Engineering. 1st Edn., Chapman and Hall, London.

Phadke, M.S., 2008. Quality Engineering Using Robust Design. Dorling Kindersley Publishing, Inc., India, Pages: 250.

Roy, R.K., 1990. A Primer on The Taguchi Method. Van Nostrand Reinhold, New York, USA., ISBN: 13-9780442237295, Pages: 247.

Shaji, S. and V. Radhakrishnan, 2003. Analysis of process parameters in surface grinding with graphite as lubricant based on the Taguchi method. J. Mater. Process. Technol., 141: 51-59.

Sharma, P., A. Verma, R.K. Sidhu and O.P. Pandey, 2005. Process parameter selection for strontium ferrite sintered magnets using Taguchi L9 orthogonal design. J. Mater. Process. Technol., 168: 147-151.

Tasirin, S.M., S.K. Kamarudin, J.A. Ghani and K.F. Lee, 2007. Optimization of drying parameters of bird's eye chilli in a fluidized bed dryer. J. Food Eng., 80: 695-700.

Wang, M.W., G.L. Fu and J.H. Jeng, 2008. Optimal molding parameter design of PLA micro lancet needles using Taguchi method. Proceedings of the IEEE International Conference on Service Operations and Logistics and Informatics, October 12-15, 2008, Beijing, China, pp: 2731-2735.

Zhang, J.Z., J.C. Chen and E.D. Kirby, 2007. Surface roughness optimization in an end-milling operation using the Taguchi design method. J. Mater. Process. Technol., 184: 233-239.