OPTIMIZATION OF MACHINING TECHNIQUES

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ABSTRACT: In this paper attempts to review the literature on the optimization of machining parameters in turning processes. Various conventional techniques used for machining optimization include geometric programming, more linear geometric programming, target programming, unconstrained sequential minimization technique, dynamic programming, etc. The latest optimization techniques include fuzzy logic, scatter search technique, genetic algorithm, Taguchi technique, and response. surface methodology.

Keywords: Machining optimization; goal programming; fuzzy logic; genetic algorithms; Taguchi technique; response surface methodology.

INTRODUCTION

It has long been recognized that conditions during cutting, such as feed rate, cutting speed, and depth of cut, must be selected to optimize the economics of machining operations, evaluated by productivity, total cost of manufacture by component or any other appropriate criteria. Taylor (1907) has shown that there is an optimal or economical cutting speed that could maximize the material removal rate. Manufacturing industries have long relied on the skills and experience of shop machine tool operators for the optimal selection of cutting conditions and cutting tools. Considerable efforts are still being made in the use of conservative manual-based cutting conditions and the selection of cutting tools at the process planning level. The most negative effect of such an unscientific practice is a decrease in productivity due to suboptimal use of machining capacity.

The need to select and implement optimal machining conditions and the most suitable cutting tool has emerged in recent decades. Despite Taylor's initial work to establish optimal cutting speeds in single-pass turning, progress has been slow as all process parameters need to be optimized. In addition, to obtain realistic solutions, the many limitations encountered in practice, such as low machine tool power, torque, force limits, and component surface roughness must be overcome.

The unavailability of the required technological performance equation represents a major obstacle to implementing optimized cutting conditions in practice. This is because extensive testing is required to establish empirical performance equations for each work material and tool coating combination for a given machining operation, which can be quite costly when considering a wide range of machining operations. machining. Additionally, performance equations need to be updated as new coatings, new work materials, and new cutting tools are introduced. While complete sets of equations can be found in some Chinese and Russian textbooks (Ai et al 1966; Ai & Xiao 1985; Kasilova & Mescheryakov 1985), as well as in the American textbook (ASME 1952) and Kroneberg's (1966). the authors have not included discussions of newer tools, new work materials, and tool coatings. Difficulties are found in locating empirical performance equations for modern tool designs because they are hidden under computerized databases in proprietary software (Sandvik 1981), as noted in recent surveys (Armarego and Ostafiev 1998); Ostafiev 1999).

REVIEW OF TRADITIONAL OPTIMIZATION TECHNIQUES

Traditionally, the choice of cutting conditions for cutting metal is left to the machine operator. In such cases, the experience of the operator plays an important role, but even for a qualified operator it is very difficult to achieve optimal values at all times. The machining parameters in metal turning are cutting speed, feed rate and depth of cut. Adjusting these parameters determines the quality characteristics of the turned parts. Following the pioneering work of Taylor (1907) and his famous tool life equation, different analytical and experimental approaches have been investigated to optimize machining parameters.

Gilbert (1950) studied the optimization of turning machining parameters based on the maximum production rate and the minimum production cost as criteria. Armarego and Brown (1969) studied the unlimited optimization of machine parameters by differential calculus. Brewer & Rueda (1963) performed a simplified optimal analysis for non-ferrous materials. For cast iron (CI) and steels, the criterion of minimizing the cost of machining has been adopted. Several nomograms have been developed to facilitate the practical determination of the most economical machining conditions. They pointed out that the most difficult materials to machine have a restricted range of parameters on which machining can be performed and that, therefore, any attempt to optimize their costs is artificial.

Brewer (1966) suggested the use of Lagrange multipliers for optimization of the constrained unit cost problem, with power outage as the main constraint. Bhattacharya et al (1970) optimized the unit cost of turning, subject to the limitations of surface roughness and cutting power using the Lagrange method. Walvekar and Lambert (1970) discussed the use of geometric programming for the selection of machining variables. They have optimized cutting speed and feed rate to reduce production costs. Petropoulos (1973) studied the optimal selection of machining speed variables, viz. cutting and feed speed, through geometric programming. A limited unit cost problem in turning has been optimized by machining SAE 1045 steel with an ISO P-10 grade cemented carbide tool.

Sundaram (1978) applied an objective programming technique in metallurgy to select levels of machining parameters in a fine turning operation on AISI 4140 steel using cemented tungsten carbide tools. Ermer and Kromodiharajo (1981) developed a multi-step mathematical model to solve a constrained multi-pass machining problem. They concluded that in some cases, with some constant total depths of cut, multi-pass machining was more economical than single-pass machining, if the depth of cut for each pass was assigned correctly. They used high speed steel (HSS) cutting tools to machine carbon steel.

Hinduja et al (1985) described a procedure to calculate optimal cutting conditions for turning operations with minimum cost or maximum production rate as an objective function. For a given combination of tool and material to be machined, the search for the optimum was limited to a feedrate with respect to the depth of the cutting plane defined by the constraint of the chipbreaker. Some of the other limitations that are considered include available horsepower, workmanship, surface finish, and dimensional accuracy.

Tsai (1986) studied the relationship between multi-pass machining and single-pass machining. He introduced the concept of break-even point, that is, there is always a point, a certain depth of cut value, at which one or two pass machining is also effective. When the depth of cut falls below the balance point, the single pass is more economical than the double pass, and when the depth of cut exceeds this balance point, the double pass is better. Carbide tools are used to turn carbon steel work material.

Gopalakrishnan & Khayyal (1991) described the design and development of an analytical tool for the selection of turning machine parameters. Geometric programming was used as the basic methodology to determine feed and cutting speed values that minimize the total cost of machining SAE 1045 steel with ISO P-10 grade cemented carbide tools. Surface finish and machine power were taken as constraints while optimizing cutting speed and feed for a given depth of cut.

Agapiou (1992) formulated single and multi-pass machining operations. Production cost and total time were taken as goals and a weighting factor was assigned to prioritize the two goals in the goal function. He optimized the number of passes, depth of cut, speed of cut, and feedrate on his model through a multi-step solution process called dynamic programming. Various physical limitations were considered and applied in his model. In its solution methodology, each cutting pass is independent of the previous pass, so optimization of each pass is not achieved simultaneously.

Prasad et al (1997) reported the development of an optimization module to determine process parameters for turning operations as part of a PC-based generative CAPP system. Workpiece materials considered in their study include steels, cast iron, aluminum, copper, and brass. HSS and carbide tool materials are considered in this study. The minimization of the production time is taken as the basis for the formulation of the objective function. The stresses considered in this study include power, surface finish, tolerance, workpiece stiffness, cutting speed range, maximum and minimum depth of cut, and total depth of cut. Improved mathematical models are formulated by modifying part tolerance and stiffness constraints for multi-pass turning operations. The formulated models are solved by combining geometric and linear programming techniques.

LATEST TECHNIQUES

The latest techniques for optimization include fuzzy logic, scatter search technique, genetic algorithm, Taguchi technique and response surface methodology.

Fuzzy logic

Fuzzy logic has a great ability to capture common sense human reasoning, decision making, and other aspects of human cognition. Kosko (1997) shows that it overcomes the limitations of classical logical systems, which impose inherent restrictions on the representation of imprecise concepts. The imprecision of the coefficients and constraints can naturally be modeled by fuzzy logic. Fuzzy logic modeling opens up a new avenue for optimizing cutting conditions and tool selection.

a Methodology: According to Klir & Yuan (1998), fuzzy logic involves a fuzzy interference engine and a fuzzification-defuzzification module. Fuzzification expresses the input variables as fuzzy membership values based on various membership functions. The governing rules in linguistic form, such as if the cutting force is high and the machining time is high, then the tool wear is high, are formulated on the basis of experimental observations. Based on each rule, an inference can be made about the exit score and the value of the membership. The inferences drawn from various rules are combined to arrive at a final decision. The membership values thus obtained are blurred using various techniques to obtain the actual value, for example of flank wear.

Genetic algorithm (GA)

It is the algorithms based on the mechanics of natural selection and natural genetics that are the most robust and those that are most likely to locate the general optimum. It is because of this characteristic that GA crosses the solution space starting from a group of points and not from a single point. Cutting conditions are encoded as genes by binary encoding to apply GA in optimizing machining parameters. A set of genes combine to form chromosomes, which are used to carry out the basic mechanisms of GA, such as crossing over and mutation.

Crossing is the operation of exchanging part of two chromosomes to generate new offspring, which is important when quickly exploring the entire search space. The mutation is applied after the crossing to provide a bit of randomness to the new chromosomes. To evaluate each individual or chromosome, the coded cutting conditions are decoded from the chromosomes and used to predict machining performance metrics. The fitness or objective function is a necessary function in the optimization and selection process of the next generation in genetic algorithm. The optimal results of the cut-off conditions are obtained by comparing the values of the objective functions between all the individuals after a certain number of iterations. In addition to weighting factors and limitations, the right GA parameters are needed to function effectively. The GA optimization methodology is based on machining performance prediction models developed from a complete system of theoretical analysis, experimental databases and numerical methods. The GA parameters along with the relevant objective functions and the set of machining performance constraints are imposed on the GA optimization methodology to provide optimal cutting conditions.

an implementation of GA: First, variables are encoded as n-bit binary numbers assigned in a row as strings of chromosomes. To implement restrictions in GA, sanctions are imposed on individuals for restriction. If an individual has no restrictions, their physical form will be assigned to zero. Because people are selected to mate based on fitness value, people with zero fitness will not become parents. Therefore, most of the next generation are insured in feasible regions bounded by restrictions.

GA is initialized by randomly selecting individuals from the set of variables. Individuals are selected to be the parents of the next generation based on their physical fitness. The higher the fitness value, the greater your chance of being selected as parents. Wang and Jawahir (2004) used this technique to optimize the drilling parameters. Kuo & Yen (2002) used a parameter setting algorithm based on a genetic algorithm for multidimensional motion control of a CNC machine tool.

Scatter search technique (SS)

This technique is the result of strategies of combination of decision rules and substitution constraints. SS is completely generalized and independent of the problem because it has no restrictive assumptions about the objective function, the set of parameters, and the set of constraints. It is easily modifiable to optimize machining operations under different economic criteria and numerous practical limitations. You can achieve near-optimal solutions within a reasonable PC runtime. It can potentially be extended as an online quality control strategy to optimize machining parameters based on sensor signals. Chen and Chen (2003) have done extensive work on this technique.

A Methodology: First, machining models are needed to determine optimal machining parameters, including cutting speed, feed, and depth of cut, in order to minimize unit production cost. The unit cost of production can be divided into four basic cost elements:

- Cutting cost by actual cut in time
- Machine idle cost due to loading and unloading operation and idling tool motion cost
- Tool replacement cost
- Tool cost

For the optimization of the unit cost of production, it is necessary to take into account the practical limitations presented by the state of the machining processes. The limitations imposed during machining operations are:

Parameter constraint – Ranges of cutting speed, feed rate and depth of cut

Tool life constraint – Allowable values of flank wear width and crater wear depth Operating constraint – Maximum allowable cutting force, power available on machinetool and surface finish requirement.

An optimization model can be formulated for the multi-pass turning operation. The multi-pass turning model is a constrained nonlinear programming problem with multiple variables (machining variables). The initial solution for SS is chosen at random. User-specified parameters must be provided. The experiment can be performed on a PC with a Pentium800Mhz processor. The calculation results validate the SS advantage in terms of solution quality and calculation requirements.

Taguchi technique

Genichi Taguchi is a Japanese engineer active in the improvement of Japanese industrial products and processes since the late 1940s. He has developed both the philosophy and the methodology to improve the quality of processes or products that rely heavily on statistical concepts and tools. , particularly statistically. designed experiments. Many Japanese companies have achieved great success in applying his methods. Wu (1982) reported that thousands of engineers performed tens of thousands of experiments based on his teachings. Sullivan (1987) reports that Taguchi has received some of Japan's most prestigious awards for quality achievement from him, including the Deming Prize. In 1986, Taguchi received the most prestigious award from the International Institute of Technology: the Willard F. Rockwell Medal for Excellence in Technology. Taguchi's main contribution has been to combine engineering and statistical methods to achieve rapid cost and quality improvements by optimizing product design and manufacturing processes.

Barker (1990) reported that since 1983, following Taguchi's association with the best companies and institutes in the United States (AT&T Bell Laboratories, Xerox, Lawrence Institute of Technology (LIT), Ford Motor Company, etc.), his methods have been called a radical approach to quality, experimental design and engineering. Sullivan (1987) reported that the term "Taguchi methods" (TM) refers to parameter design, tolerance design, quality loss function, on-line quality control, design of experiments using orthogonal networks, and the methodology applied to evaluate measurement systems.

Pignatiello (1988) identifies two distinct aspects of Taguchi's methods: Taguchi's strategy and Taguchi's tactics. Taguchi tactics refer to the collection of specific methods and techniques used by Genichi Taguchi, and Taguchi strategy is the conceptual framework or structure for planning a product or process design experience.

Ryan (1988) and Benton (1991) reported that Taguchi deals with design and engineering (offline) and build quality (online). This fundamentally differentiates TM from Statistical Process Control (SPC), which is purely an online quality control method. Taguchi's ideas can be summarized in two fundamental concepts:

- Quality losses must be defined as deviations from targets, not conformance to arbitrary specifications (Benton 1991).
- Achieving high system-quality levels economically requires quality to be designed intothe product. Quality is designed, not manufactured, into the product (Daetz 1987; Taguchi 1989).

Lin et al (1990) stated that the Taguchi methods represent a new philosophy. Quality is measured by the deviation of a functional characteristic from its target value. Noises (uncontrolled variables) can cause such deviations resulting in a loss of quality. Taguchi's methods seek to suppress the effect of noise.

Taguchi (1989) described that quality engineering encompasses all stages of product / process development: system design, parameter design, and tolerance design. Byrne and Taguchi (1987), however, have pointed out that the key to achieving high quality and low cost is the design of the parameters. Through the design of the parameters, the levels of product and process factors are determined, in such a way that the functional characteristics of the product are optimized and the effect of noise factors is minimized. Kackar and Shoemaker (1986) found that parameter design reduces variation in performance by reducing the influence of sources of variation rather than controlling them, making it a very cost-effective technique to improve engineering design.

a Applications: Chanin et al (1990) noted that Japanese companies such as Nippon Denso, NEC, and Fugitsu have become global economic competitors using the Taguchi approach, which has the potential to reduce experimentation time and costs in the development of products or processes, as well as quality improvement. Kacker & Shoemaker (1986), Phadke (1986) and Pao et al (1985) have pointed out that the methodology advocated by Taguchi has been applied within AT&T to a variety of problems ranging from the manufacture of integrated circuits to the optimization of time response of a UNIX system since Taguchi's first visit to AT&T Bell laboratories in 1980. Ghosh (1990) noted that Taguchi's ideas are also used in many other US companies such as Ford and Xerox. There are also many robust parameter design courses offered by organizations such as the American Supplier Institute, Rochester Institute of Technology, and the Center for Quality and Productivity Improvement at the University of Wisconsin at Madison. The American Institute of Providers also hosts an annual symposium where case studies on the application of Taguchi methods are presented.

The foundry division of Ford Motors has pioneered employee training in the Taguchi methods since 1983. Enright and Price (1987) cited some case studies from the foundry division of Ford Motors and illustrated the depth and impact on product quality and productivity that has occurred since the decision to implement the Taguchi approach was made. Moneymaker and Hubbard (1987) presented a case of application of the loss function concept to the quality improvement program at Rockwell International Steel Foundry in Atchison, Kansas. Lin and Kackar (1985) showed how a 36-pass orthogonal grating design was used to improve a wave soldering process by studying 17 variables simultaneously. Kamat & Rao (1994) presented a Taguchi optimization case study related to die casting component manufacturing processes. Using optimal combinations of parameters obtained from the analysis reduced rejection of die cast components by 90%. Tsui (1999) presented a robust design optimization for multiple feature problems. The rugged design improves the product design or manufacturing process by making the output response insensitive (resistant) to variations that are difficult to control. The multivariate quality loss function considered by Pignatiello (1993) has been expanded to include the smallest and largest type characteristics, the best. Under various assumptions, suitable two-step procedures have been developed to minimize mean multivariate loss. The proposed two-step procedure greatly reduces the size of the design optimization problem and allows future changes in the response target values without re-optimization. The proposed procedure was illustrated with an example of polysilicon deposition. Singh & Kumar (2003, 2004, 2005) applied the Taguchi technique to optimize surface finish, tool wear, cutting force and power consumed in turning operations for machining l 'En24 steel with inserts of Tungsten carbide coated with titanium carbide.

The success of many applications has demonstrated the power of Taguchi's holistic approach. It is also worth mentioning that many of the specific statistical techniques that he has prop

Response surface methodology (RSM*)*

Experimenting and making inferences are the two characteristics of general scientific methodology. Statistics as a scientific discipline is designed primarily to achieve these goals. Experiment planning is particularly useful for drawing clear and precise conclusions from experimental observations, on the basis of which inferences can be made in the best possible way. The methodology for making inferences has three main aspects. First, it establishes methods to draw inferences from observations when these are not exact but are subject to variation, because the inferences are not exact but are probabilistic in nature. Second, it specifies the data collection methods appropriately so that the assumptions for the application of appropriate statistical methods are satisfied. Finally, techniques are developed for the correct interpretation of the results.

The advantages of the design of experiments reported by Adler et al (1975) and Johnston (1964) are as follows.

- Numbers of trials are reduced.
- Optimum values of parameters can be determined.
- Assessment of experimental error can be made.
- Qualitative estimation of parameters can be made.
- Inference regarding the effect of parameters on the characteristics of the process can be made.

Cochran and Cox (1962) cited Box and Wilson for having proposed a response surface methodology to optimize experiments. In many experimental situations, it is possible to represent independent factors quantitatively. These factors can then be considered to have a functional relationship or response:

$$Y = \varphi(X_1, X_2, \dots , X_k) \pm e_r,$$

between the response Y and X1, X2,... Xk of k quantitative factors. The function φ is called response surface or response function. The residual er measures the experimental error. For a given set of independent variables, answer a characteristic surface. When the mathematical form of is not known, it can be satisfactorily addressed in the experimental region by a polynomial. The higher the degree of the polynomial, the better the correlation, although at the same time the costs of the experiment are higher.

The methodology can be applied to develop the mathematical models in the form of multiple regression equations that correlate dependent parameters such as cutting force, energy consumption, surface roughness, tool life, etc. with three independent parameters, to be cut. cutting speed, feed rate and depth of cut, in a turning process. Applying the response area methodology, you will consider that the dependent parameter is an area to which a mathematical model fits. For the development of regression equations related to various quality characteristics of turned parts, it can be assumed that the second-order response area is:

This assumption Y contains the linear, square and cross product terms of the variables Xi. To estimate regression coefficients, available from a number of experimental design techniques. Box & Hunter (1957) proposed that the scheme based on the central compound rotary design is very precisely adapted to second order response areas.

Lambert and Taraman (1973) developed a suitable mathematical model for the cutting force acting on a carbide tool when machining SAE 1018 cold rolled steel in a turning operation, then they used the model in the selection of cutting speeds. . , feed speed and depth of cut, so that the metal removal speed can reach the highest possible value without violating a certain force restriction. Using the response surface methodology, the three independent variables (cutting speed, feed speed and depth of cut) could be studied simultaneously to study their effects on the cutting force, resulting in significant savings, time and money in comparison. with traditional analytical methods.

Taraman (1974) studied research on multi-independent variable turning with multiple machining output using the response surface methodology. The objective of this research was to develop a methodology that would allow determining the cutting conditions (cutting speed, feed rate and depth of cut) in such a way that the criteria specified for each of several parameters depending on the machining (surface finish, tool strength and tool life) could be achieved simultaneously. For this, the first mathematical models were developed that represent the relationship between the dependent and independent variables of the process. A central composite design was used to develop the models to minimize the amount of experimentation. The models were represented by response surfaces and the contours of these surfaces were obtained at different levels of each of the independent variables in the planes of the other independent variables. By overlaying the contours, an appropriate combination of cutting speed, feed rate and depth of cut can be selected to meet specific criteria. Disposable tungsten carbide inserts were used to turn SAE1018 cold rolled steel.

Hassan & Suliman (1990) presented mathematical models for the prediction of surface roughness, tool vibration, energy consumption and cutting time, when turning medium carbon steel using tungsten carbide tools under dry conditions. The functional relationships between these variables and the independent variables of the machining (cutting speed, feed and depth of cut) were established by means of a second order multiregression polynomial analysis. The developed surface roughness model was used as an objective function to establish the optimal cutting conditions, while the level of vibration of the tool, energy consumption and cutting time were considered functional limitations.

El Baradie (1993) presented a study of the development of a surface roughness model for turning gray cast iron (154 BHN) using pointed carbide tools under dry conditions and for a constant depth of cut (d 1.00 mm). The mathematical model using the response surface methodology was developed in terms of cutting speed, feed rate and tip radius of the cutting tool. These variables were investigated through a design of experiments and the use of the response surface methodology. The turning operation was carried out at 10 h.p. tower. The pieces were cast in the form of cylindrical bars 200 mm in diameter and approximately 500 mm in length. The cutting tests were carried out with a tungsten carbide insert (K10 grade). Surface roughness measurements were made using a Taylor-Hobson Surtronic surface roughness measuring instrument. This study presents a first order model that covers the cutting speed range of 110 to 350 m / min and a second order model that covers the cutting speed range of 80 to 495 m / min. The contours of the surface roughness outputs were obtained in planes containing two of the independent variables. These contours have been further developed to select the proper combination of cutting speed and feedrate to increase the speed of metal removal without sacrificing the quality of the surface roughness produced.

CONCLUSIONS

A literature review shows that various traditional machining optimization techniques such as Lagrange's method, geometric programming, objective programming, dynamic programming, etc. they have been successfully applied in the past to optimize the various variables of the turning process. Fuzzy logic, genetic algorithm, dispersion search, Taguchi technique and response surface methodology are the latest optimization techniques that are successfully applied in industrial applications for the optimal selection of process variables in the field of machining. . A review of the literature on optimization techniques revealed that there are, in particular, successful industrial applications of designing experimental approaches for optimal configurations of process variables. Taguchi's response surface methods and methodology are robust design techniques widely used in industries to render the product / process insensitive to uncontrollable factors such as environmental variables. Japanese companies such as Nippon Denso, NEC and Fugitsu have become global economic competitors using the Taguchi approach that offers the potential to save time and costs of experimentation in the development and improvement of products or processes. It is generally accepted that offline experiences during the product or process design phase are of great value. Reducing quality loss by designing products and processes that are insensitive to variations in noise variables is a new concept for statisticians and quality engineers.

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