© May 2019 | IJIRT | Volume 5 Issue 12 | ISSN: 2349-6002

Review of Parametric Optimization of the Production in Milling Operation by Principal Component Analysis (PCA)

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***Abstract-* Amid the considerable research has been studied on the parametric optimization of surface properties of the product in milling operation use of MQL. The most of the researches have been concentrated on geometric programming. However, the use of geometric programming in the previous studies was restricted for a specific cutting tool and work piece combination. Therefore, a separate solution procedure is required for different types of tool-work piece combinations. The grey–Taguchi method was adopted to optimize the milling parameters such as cutting speed, feed, depth of cut and MQL. In this paper, the cutting speed, feed rate, axial depth of cut and radial depth of cut and Zno MQL are given parameter to evaluate optimum output in terms of surface roughness and material removal rate restricted with some practical constraints of milling operations, are expressed in terms of variables which satisfy minimum production cost or maximum production rates of milling operations. Apart from optimizing a single response (process output), multi objective optimization problems have also been solved using Taguchi method followed by grey relation theory. However, this approach is based on the assumption that quality indices being uncorrelated or independent . But it is felt that, in practice, there may be some correlation among various quality indices (responses) under consideration. To overcome this limitation we apply grey based Taguchi approach L16 OA, the present paper proposes application of Principal Component Analysis (PCA) to convert correlated responses into uncorrelated quality indices called principal components. Finally based on grey relation theory Taguchi method has been applied to solve this optimization problem.**

Index Terms- MQL, surface roughness, nanofluid, feed, depth of cut and cutting speed.

1. INTRODUCTION

MILLING MACHINE

Milling machines were first invented and developed by Eli Whitney to mass produce interchangeable musket parts. Milling machine are metal forming and shaping equipment that use cutter with multiple teeth in contrast with single point tool used in the lathe and planner. Although crude, these machines assisted man in maintaining accuracy and uniformity while duplicating parts that could not be manufactured with the use of a file. Development and improvements of the milling machine and components continued, which resulted in the manufacturing of heavier arbors and high speed steel and carbide cutters. These components allowed the operator to remove metal faster, and with more accuracy, than previous machines. Variations of milling machines were also developed to perform special milling operations. During this era, computerized machines have been developed to alleviate errors and provide better quality in the finished product [1].

In manufacturing industries milling is fundamental metal cutting operation and End milling is the most frequent operation encountered, which was employed for making profiles, slots, engraves, contours, pockets in various components [2]. Milling machines are basically classified as being horizontal or vertical to indicate the axis of the milling machine spindle. These machines are also classified as knee-type, ram-type, manufacturing or bed type, and planer-type milling machines. During the last half of the nineteenth Century, milling machines gradually replaced shapers and planers which have lathe-type, single-point tool bits that move over the work in a straight line and scrape off metal one stroke at a time. Milling machines, with their continuous cutting action, not only remove metal faster than shapers and planers, they perform additional operations like cutting helices for gears and twist drills. Today, milling machines greatly outnumber shaping and planning machines. Americans in New England and later the Midwest continuously added features leading to the modern milling machine.

2. TYPES OF MILLING MACHINES

Milling machine are two types

1. Vertical Milling Machine
2. Horizontal Milling Machine

VERTICAL MILLING MACHINE

(a) Knee-Type Milling Machine

Knee-type milling machines are characterized by a vertically adjustable worktable resting on a saddle which is supported by a knee. The knee is a massive casting that rides erotically on the milling machine column and can be clamped rigidly to the column in a position where the milling head and milling machine spindle are properly adjusted vertically for operation [1]. The plain vertical machines are characterized by a spindle located vertically, parallel to the column face, and mounted in a sliding head that can be fed up and down by hand or power. Modern vertical milling machines are designed so the entire head can also swivel to permit working on angular surfaces. The turret and swivel head assembly is designed for making precision cuts and can be swung 360° on its base. Angular cuts to the horizontal plane may be made with precision by setting the head at any required angle within a 180” arc. The plain horizontal milling machine’s column contains the drive motor and gearing and a fixed position horizontal milling machine spindle. An adjustable overhead arm containing one or more arbor supports projects forward from the top of the column. The arm and arbor supports are used to stabilize long arbors. Supports can be moved along the overhead arm to support the arbor where support is desired depending on the position of the milling cutter or cutters. The milling machine’s knee rides up or down the column on a rigid track. The milling machine is excellent for forming flat surfaces, cutting dovetails and keyways, forming and fluting milling cutters and reamers, cutting gears, and so forth. Many special operations can be performed with the attachments available for milling machine use the knee is used for raising and lowering [4, 5].

Fig. Knee Type Milling Machine

(b) Vertical Milling Machine

The Milling Machine uses a rotating milling cutter to produce machined surfaces by progressively removing material from a work piece. The vertical milling machine also can function like a drill press because the spindle is perpendicular to the table and can be lowered into the work piece.

HORIZONTAL MILLING MACHINE

The Horizontal Milling Machine is a very robust and sturdy machine. A variety of cutters are available to removed/shape material that is normally held in a strong machine vice. This horizontal miller is used when a vertical miller is less suitable. For instance, if a lot of material has to be removed by the cutters or there is less of a need for accuracy - a horizontal milling machine is chosen. The cutter can be changed very easily [6].

The arbor bracket is removed by loosening nuts and bolts that hold the arbor firmly in position. The arbor can be slid off the over arm. The spacers are then removed as well as the original cutter. The new cutter is placed in position, spacers slid back onto the arbor and the arbor bracket tightened back in position [6].

3. TYPES OF MILLING CUTTER

HELICAL MILLING CUTTERS

The helical milling cutter is similar, to the plain milling cutter, but the teeth have a helix angle of 45° to 60°. The steep helix produces a shearing action that results in smooth, vibration-free cuts. They are available for arbor mounting, or with an integral shank with or without a pilot. This type of helical cutter is particularly useful for milling elongated lots and for light cuts on soft metal [5].

SIDE MILLING CUTTERS

Side milling cutters are essentially plain milling cutters with the addition of teeth on one or both sides. A plain side milling cutter has teeth on both sides and on the periphery. When teeth are added to one side only, the cutter is called a half-side milling cutter and is identified as being either a right-hand or left-hand cutter. Side milling cutters are generally used for slotting and straddle milling. Interlocking tooth side milling cutters and staggered tooth side milling cutters are used for cutting relatively wide slots with accuracy (Figure 1.8). Interlocking tooth side milling cutters can be repeatedly sharpened without changing the width of the slot they will machine. After sharpening, a washer is placed between the two cutters to compensate for the ground off metal. The staggered tooth cutter is the most washers are placed between the two cutters to compensate for efficient type for milling slots where the depth exceeds the width [5]

END MILLING CUTTERS

The end milling cutter, also called an end mill, has teeth on the end as well as the periphery. The smaller end milling cutters have shanks for chuck mounting or direct spindle mounting. End milling cutters may have straight or spiral flutes. Spiral flute end milling cutters are classified as left hand or right-hand cutters depending on the direction of rotation of the flutes. If they are small cutters, they may have either a straight or tapered shank. Large end milling cutters (normally over 2 inches in (diameter) are called shell end mills and are recessed on the face to receive a screw or nut for mounting on a separate shank or mounting on an arbor, like plain milling cutters. The teeth are usually helical and the cutter is used particularly for face milling operations requiring the facing of two surfaces at right angles to each other.

Fig. Milling Cutters

CONCAVE AND CONVEX MILLING CUTTERS

Concave and convex milling cutters are formed tooth cutters shaped to produce concave and convex contours of 1/2 circle or less. The size of the cutter is specified by the diameter of the circular form the cutter produces. 45° angular cuts may either be made with a 45° single angle milling cutter while the workpiece is held in a swivel vise, or with an end milling cutter while the workpiece is set at the required angle in a universal vise. The harder the material, the greater will be the heat that is generated in cutting. Cutters should be selected for their heat-resisting properties. Concave formed cutters produce a convex feature on the workpiece, most typically a male semicircle. Convex formed cutters produce a concave feature on the workpiece, most typically a female semicircle.

4. MILLING MACHINE OPERATION

The success of any milling operation depends before setting up a job, be sure that the to a great extent, upon judgment in setting up the job, work piece, the table, the taper in the spindle, selecting the proper milling cutter, and holding the cutter by the best means under the circumstances [5]. Some fundamental practices have been proved by experience to be necessary for and the arbor or cutter shank is all clean and good results on all jobs. Some of these practices are mentioned below.

Milling operations may be classified under four general headings as follows:
1. Face milling: - Machining flat surfaces which are at right angles to the axis of the cutter,
2. Plain or slab milling: - Machining flat surfaces which are parallel to the axis of the cutter.
3. Angular milling: - Machining flat surfaces which are at an inclination to the axis of the cutter.
4. Form milling: -Machining surfaces having an irregular outline.

5. OBJECTIVE AND SCOPE OF THE PRESENT WORK

According to the previous literature the considerable research has been studied on the parametric optimization of surface properties of the product in milling operation. The most of the researches have been concentrated on geometric programming. However, the use of geometric programming in the previous studies was restricted for a specific cutting tool and workpiece combination. Therefore, a separate solution procedure is required for different types of tool-workpiece combinations. The grey–Taguchi method was adopted to optimize the milling parameters such as cutting speed, feed and depth of cut. In this study, the cutting speed, feed rate, axial depth of cut and radial depth of cut are given parameter to evaluate optimum output in terms of surface roughness and material removal rate restricted with some practical constraints of milling operations, are expressed in terms of variables which satisfy minimum production cost or maximum production rates of milling operations. Apart from optimizing a single response (process output), multi objective optimization problems have also been solved using Taguchi method followed by grey relation theory. However, this approach is based on the assumption that quality indices being uncorrelated or independent [Datta et al. (2009)]. But it is felt that, in practice, there may be some correlation among various quality indices (responses) under consideration. To overcome this limitation we apply grey based Taguchi approach L16 OA, the present study proposes application of Principal Component Analysis (PCA) to convert correlated responses into uncorrelated quality indices called principal components. Finally based on grey relation theory Taguchi method has been applied to solve this optimization problem.

6. DESIGN OF EXPERIMENT

Experiments have been carried out using Taguchi's L16 Orthogonal Array (OA) experimental design which consists of 16 combinations of spindle speed, longitudinal feed rate and depth of cut. According to the design prepared by Taguchi, L16 Orthogonal Array design of experiment has been found suitable in the present work. It considers four process parameters (without interaction) to be varied in four discrete levels. The experimental design has been shown in Table 4.2.

Spindle speed

$$A = \frac{N - N_o}{\Delta N} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (10)$$

Feed rate

$$B = \frac{f - f_0}{\Delta f} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (11)$$

Axial depth of cut

$$C = \frac{H - H_0}{\Delta H} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (12)$$

Radial depth of cut

$$D = \frac{h - h_o}{\Delta h} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (13)$$

Here A, B, C and D are the coded values of the variables N, f, W and D respectively N_0 , f_0, D_0 and d_0 are the values of spindle speed, feed rate and depth of cut at zero level; ΔN, Δf, ΔD, and Δd are the units or intervals of variation in N, f, D and d respectively.

7. CONCLUSION

In this study, the use of PCA based hybrid Taguchi method has been proposed and adopted for solution of multi objective optimization, along with a case study, in CNC end milling operation. PCA has been used to eliminate correlation among the responses and to convert the correlated responses into independent quality indexes; so as to meet the basic requirement of Taguchi method. Grey relation theory has been found efficient to convert multiple responses into an equivalent single objective function. Thus, a multi-objective optimization problem has been converted into a single objective function optimization problem which can be solved by Taguchi method. The following conclusions obtain from the results of the experiments and analysis of the experimental data in connection with correlated multi response optimization in turning.

1. Based on accountability proportion (AP) and cumulative accountability proportion (CAP), PCA analysis can reduce the number of response variables to be taken under consideration for optimization. This is really helpful in situations where large number of responses have to be optimized simultaneously.
2. Application of PCA can eliminate multi co-linearity (correlation) of the output responses and transform these correlated responses into uncorrelated quality indices called principal components. Absence of correlation between the responses is the basic assumption for applying Taguchi optimization technique.
3. Grey relation theory has been converting the multi objective problem into single objective problem. Thus the single objective problem can be solving by Taguchi's method.
4. Here I obtain the optimize result by Taguchi method which will give better output in all 16 combinations of variable. PCA and grey relation grade result is extremely closed to experimented results which indicate this optimization can be effectively used to minimize the number of operations.

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