# A critical review of machining parameters for hard steel turning

[1]Ujwal Gawai, [2]Irudayaraj S, [3]Joshi S.P

[1]Research Scholar, [2]Professors, Mechanical Engineering Department, Veltech University, Tamil Nadu, India

[3]Associate Professor, Mechanical Engineering Department JSPM Imperial College of Engineering and Research, Pune, India

**Abstract:** Hard Turning processes are widely used in the automotive industries, die and mould industries. Hard Turning refers to the process of single point cutting of hardened pieces within the two-micron range with hardness between 58 and 70 HRC. The present study deals with the critical review of optimizing the machining parameters of hard turning process that affects machined accuracy and surface finish. The input parameters as speed, depth of cut, and feed. The review will give a detailed insight of hard turning process which includes methodologies adapted by various researchers and the optimization technique implemented. The research gap is also included in the present study to carry the futuristic research work.

**Keywords**: Hard turning, Optimization, Speed, surface finish

## 1. Introduction

Turning processes are widely used in the aerospace, aircraft, and automotive industries. Although modern metal-cutting methods have improved in the manufacturing industry, including electron beam machining, ultrasonic machining, electrolytic machining, and abrasive jet machining, conventional turning still remains one of the most common machining processes. It presents a big challenge for achieving the high quality of turned surface by turning process by the manufacturing industry. Amongst traditional machining processes, Turning is one of the most important metal-cutting operations, comprising approximately 50% of all metal-cutting operations [1, 2]. Surface roughness is a critical quality indicator for a machined surface and has a bearing on many properties such as: wear resistance, fatigue strength, coefficient of friction, lubrication, wear rate and the corrosion resistance of the machined parts [3]. The Turning process is very expensive in terms of costs and productivity. Hence, any progress or improvement of the turning operation could significantly reduce the operation costs.

## 2. Literature Review

Given the ever-increasing demand for lower production costs, attention has been given to turning as an alternative to grinding of hardened steels for finishing purposes. Turning allows higher material removal rates than grinding, reducing cycle times and leading to increased productivity and costs reduction, which brings economic benefits. Conversely, the infinitesimal undeformed chip thickness achieved by grinding during the sparking out cycle leads to the production of components with superior dimensional and geometric quality. Finish turning of hardened steel is applied to materials which hardness ranges from 45 to 68 HRC [1-4] and has only become possible after the development of polycrystalline cubic boron nitride (PcBN) tools, since conventional tungsten carbide tools are subjected to accelerated wear rates due to high temperatures at tool-chip interface and strong adhesion of the chip on the rake face [2]. Polycrystalline cubic boron nitride and alumina based ceramics tools, such as titanium carbide reinforced aluminum oxide (Al2O3 + TiC), possess high hot hardness, wear resistance and chemical stability at high temperatures, features required to tackle hardened steels [5-8].

Metal cutting machine with desired stiffness and high spindle speed was the other hurdle for hard machining. With improved rigidity of the high performance CNC machine tools and cutting tools of appropriate material, hard machining is extensively and successfully being used to process complex work pieces in one step, and achieve size tolerances and finishes approaching grinding quality. Hard turned parts do not need always to be ground for finishing specifications [9-13]. With no grinding sludge to handle, the process is more environment-friendly. Hard turning can today consistently maintain a size tolerance of +/- 0.010mm or better over long production runs and achieve surface finish less than 0.3 micron. A rigid set up is a necessity for hard turning. May it be overhang of tool holder or work piece. A precision lathe or more so a turning centre is used for multi-surface machining of parts in one chucking keeping part features in proper relation to one another. If possible, a chucking CNC lathe may be dedicated to hard turning the parts instead of hard turning on all machines [1, 12-15].

Recently cutting of hardened steels is a topic of immense importance for today's industrial production and scientific research. Hardened steels have numerous applications in the automotive, gear, bearing, tool and die industry. Traditionally hardened steels have been machined by the grinding process. On other hand grinding process is time consuming and it is applicable to limited range of geometries. Consequently, improved technologies are needed for the machining of hardened steels that will provide high material removal rates (MRR) and also to increase flexibility in terms of part geometry. Due to the recent developments of advanced cutting tool materials the interest in cutting hardened steels has increased significantly [5, 11, 16-19].

Hard turning is suitable for machining parts with hardness exceeding 45 HRc, which provides surface roughness, dimensional and shape tolerances similar to those achieved in grinding. Hard turning provide benefits like high flexibility and the ability to cut complex geometries with a single machine setup which are the main technological advantages of hard turning over the grinding process [2-4, 6]. According to Bartarya and Choudhury, if the right combination of insert nose radii, feed rate is used hard turning can produce better surface finish than grinding. Multiple hard turning operations may be performed in a single setup rather than multiple grinding setups.

Benefits of hard machining mostly include;

- Complex part contours can be easily machined by this process.
- Component types can be quickly changed over in this process.
- In one set – up, many operations can be completed.
- Metal removal rate is very high.
- The CNC Lathe which is used for soft turning process can be used for this process.
- Investment in machine tool is very low.
- Metal chips produced in the process are environmentally friendly.
- No coolant is required in many cases.
- Tool inventory required is small.

**2.1 Taguchi Method: Design and Analysis**

Taguchi methods are statistical methods developed by Genichi Taguchi to improve the quality of manufactured goods. Taguchi has envisaged a new method of conducting the design of experiments which are based on well-defined guidelines. This method uses a special set of arrays called orthogonal arrays. These standard arrays stipulate the way of conducting the minimal number of experiments which could give the complete and relevant information of all the factors that influence the performance parameter. The crux of the orthogonal arrays method lies in choosing the level combinations of the input design variables for each experiment [5, 6, 13]. Optimization of quality characteristics using parameter design of the Taguchi method is summarized in the following steps [6,-8].

- Identification and evaluation of quality characteristics and process parameters.
- Identification of number of levels for the process parameters and possible interactions between the process parameters.
- Assignment of process parameters to the selected appropriate orthogonal array.
- Conduction of experiments based on the arrangement of the orthogonal array.
- Calculation of signal-to-noise ratioS/N ratio.
- Analyze the experimental results using the S/N and ANOVA.
- Selection of the optimal levels of process parameters.
- Verification of the optimal process parameters through the confirmation experiment.

**2.2 Taguchi's Approach to Parameter Design**

Taguchi's approach to parameter design provides the design engineer with a systematic and efficient method for determining near optimum design parameters for performance and cost [9, 10]. The objective is to select the best combination of control parameters so that the product or process is most robust with respect to noise factors. The Taguchi method utilizes orthogonal arrays from design of experiments theory to study a large number of variables with a small number of experiments [2, 14]. Using orthogonal arrays significantly reduces the number of experimental configurations to be studied. Furthermore, the conclusions drawn from small scale experiments are valid over the entire experimental region spanned by the control factors and settings [6, 13].

Taguchi method provides tabulated sets of standard orthogonal arrays and corresponding linear graphs to fit specific projects [12-16]. After finalization of array, experiment is performed and analysis is made by graphs and S/N ratio. Linear graphs are simple tools for the allocation of effects (main effects and interactions) to the columns of an orthogonal array. A linear graph consists of dots, lines and numbers. Adot represents a main effect; a line between two dots represents the interaction between the two connected main effects (dots). Each of the dots and lines is numbered and the numbers represent the columns of the orthogonal array [1-4, 6-8]. A signal-to-noise (S/N) ratio is a performance measure, which estimates the effect of the noise factors on the quality characteristic. These S/N ratios are proposed to provide a product design that simultaneously places the response on a target and a minimum variance [1, 3, 6, 10, 13, 14]

**2.3 Signal-to-Noise (S/N) Ratio**

It is a performance measure, which estimates the effect of the noise factors on the quality characteristic. For each of the three optimization goals an S/N ratio has been developed. These S/N ratios are proposed to provide a product design that simultaneously places the response on a target and a minimum variance. The S/N ratios are defined as follows:

1) Nominal-the-best-situation: $S/N_t = 10 \log(y^2/s^2 - 1/n)$
2) Smaller-the-better-situation: $S/N_s = -10 \log(1/n \, \Sigma \, y_i^2)$
3) Larger-the-better-situation: $S/N_1 = -10 \log(1/n \, \Sigma \, (1/y_i^2)$

A S/N ratio is calculated for each value of the inner array over the complete outer array, so Σ refers to summing over the outer array values and s is the standard deviation calculated over the outer array values, expressing the variability induced by the noise factors. Each S/N ratio is constructed in such a way that it has to be maximized, this is done for convenience. A complete Taguchi analyses includes an analysis of the S/N ratio (dispersion) and an analysis of (location) and n is the number of measurements in a trial/row [13-16].

The performance of a product or process depends on a large number of factors. The problem is to find such settings of these factors that the product performs well under a number of conditions and during its intended life time. For this demand the product has to be robust against a number of factors/variables that disturb the function of it, these factors are called noise factors. Taguchi has classified the noise factors into three types: 1) Outer noise: environmental variables that affect the performance of a product, for example temperature, dust, humidity. 2)Inner noise: changes in material properties through usage, product deterioration, wear. 3)Vibrational noise: differences between the individual manufactured units, manufacturing variations. Products are said to have good quality if they are robust against these three types of noise [5, 6, 17, 18-22]. The following Fig. 1 demonstrates the steps applied in Taguchi's optimization method [6, 13, 14].

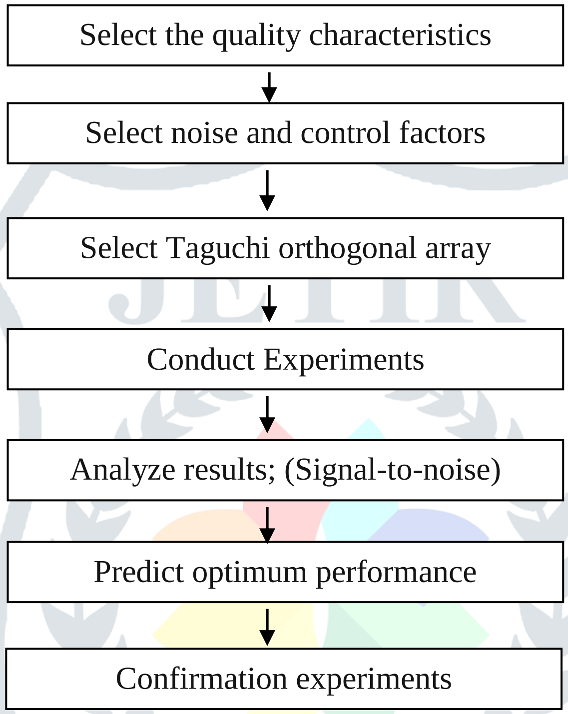


**Fig. 1** Taguchi's optimization method

**2.4 Research Findings from Literature:**

- Nowadays hard turning has usually been accepted as a potential alternative to grinding due to its flexibility, reduced machining cost, dry cutting and improved surface integrity.
- In most of the literature conventional CBN insert have been used for hard turning.
- The effect of cutting tool geometry has long been an issue in understanding mechanics of turning. Tool geometry has significant influence on chip formation, heat generation, tool wear, surface finish and surface integrity during turning. The variation in tool geometry i.e. tool nose radius, rake angle, groove on the rake face, variable edge geometry, wiper geometry and curvilinear edge tools has their effect on tool wear, surface roughness and surface integrity of the machined surface in the turning operation of components.
- In turning with a single-point tool, the surface finish is determined by the feed rate and nose radius, as these are in a direct relationship to the profile height of the surface (Rmax). This means that the higher the feed, the rougher the surface generated by the edge of a given nose radius. Wiper inserts have changed this through the effect of their specially developed edges that smooth the scalloped tops that would otherwise have been created.
- Thus wiper inserts are capable of giving better surface finish than conventional inserts at high feed rates.
- Two clear approaches are emerging. In one, hard turning followed with super-finishing is replacing grinding for the finishing. In second, a creep feed grinding process eliminates bulk material removal processes followed again by super-finishing as final machining operation.

## REFERENCES


1. Nouari M, List G, Girot F, Coupard D (2003) Experimental analysis and optimisation of tool wear in dry machining of aluminium alloys. Wear255(7):1359-1368
2. Kurt M, Bagci E, Kaynak Y (2009) Application of Taguchi methods in the optimization of cutting parameters for surface finish and hole diameter accuracy in dry Turning processes. The International Journal of Advanced Manufacturing Technology40(5-6):458-469
3. Wang X, Feng, CX (2002) Development of empirical models for surface roughness prediction in finish turning. The International Journal of Advanced Manufacturing Technology20(5):348-356
4. Bagci E, Aykut Ş (2006) A study of Taguchi optimization method for identifying optimum surface roughness in CNC face milling of cobalt-based alloy (stellite 6). The International Journal of Advanced Manufacturing Technology29(9-10):940-947
5. Phadke MS (1989) Quality engineering using design of experiments. In:Quality Control, Robust Design, and the Taguchi Method. Springer, US, pp 31-50.
6. Montgomery DC (2008)Design and analysis of experiments. John Wiley and Sons, NJ
7. Nian CY, Yang WH, Tarng YS (1999) Optimization of turning operations with multiple performance characteristics. Journal of Materials Processing Technology95(1):90-96
8. Siddiquee AN, Khan ZA, Goel P, Kumar M, Agarwal G, Khan NZ (2014) Optimization of Deep Turning Process Parameters of AISI 321 Steel Using Taguchi Method. Procedia Materials Science6(1):1217-1225
9. Chen WC, Tsao CC (1999)Cutting performance of different coated twist drills. Journal of Materials Processing Technology88(1):203-207
10. Kilickap E (2010) Optimization of cutting parameters on delamination based on Taguchi method during Turning of GFRP composite. Expert Systems with Applications37(8):6116-6122
11. Dasch JM, Ang CC, Wong CA, Cheng YT, Weiner AM, Lev LC, Konca E (2006) A comparison of five categories of carbon-based tool coatings for dry Turning of aluminum. Surface and Coatings Technology200(9):2970-2977
12. Kıvak T, Samtaş G, Çiçek A (2012) Taguchi method based optimisation of Turning parameters in Turning of AISI 316 steel with PVD monolayer and multilayer coated HSS drills. Measurement45(6):1547-1557
13. Kackar RN(1989) Taguchi's quality philosophy: analysis and commentary. In:Quality control, robust design, and the Taguchi method. Springer, US, pp 3-21
14. Taguchi G (1986)Introduction to quality engineering: designing quality into products and processes.ARRB, US
15. Taguchi G, Chowdhury S, Taguchi S (2000)Robust engineering. McGraw-Hill, New York
16. Taguchi G, Chowdhury S, Wu Y (2005)Taguchi's quality engineering handbook. Wiley, Hoboken, NJ
17. Prasanna J, Karunamoorthy L, Raman MV, Prashanth S, Chordia DR (2014) Optimization of process parameters of small hole dry Turning in Ti–6Al–4V using Taguchi and grey relational analysis. Measurement48(1):346-354
18. Meral G, Sarıkaya M, Dilipak H, Şeker U (2015) Multi-response Optimization of Cutting Parameters for Hole Quality in Turning of AISI 1050 Steel. Arabian Journal for Science and Engineering 40(12):3709-3722
19. Levin RI (2008)Statistics for management. Pearson Education India
20. Srivastava TN (2008)Statistics for management. Tata McGraw-Hill Education, India
21. Chen CL (1988) Analysis of variance.
22. Lindman HR (1992) Analysis of variance inea: perimcntal design Springer-Vcrlag,New York