Effect of the Cutting Parameters on Chip Thickness in the Turning of Spring Steel (EN47)

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***Abstract*—The objective of present work is to measure the chip thickness of the spring steel work piece in turning on lathe. In this experimental work we have used single point cutting tool for machining of spring steel (EN47) work piece. The machining process is done in dry condition. In this experimental work the tests are performed with different cutting speeds, feed rates and depth of cut. Chip thickness values are measured from these experiments. The Coated carbide tool is used for experimental work. Total nine experiments are carried out and the results are graphically represented and analyzed. An orthogonal array, the signal to noise ratio and analysis of variance (ANOVA) are employed to investigate the cutting characteristics. On the basis of data obtained from the experiments performed, the variation of chip thickness is investigated and compared in order to predict the optimum cutting parameters.**

Index Terms*—Turning, spring steel (EN47), Taguchi method, chip thickness, dial gauge indicator, micrometer, S/N ratio, ANOVA, Minitab 17(keywords)*

I. INTRODUCTION

Machining is one of the most wide spread metal machining process in mechanical manufacturing industry. The goal of changing the geometry of raw material in order to form mechanical parts can be met by putting material together. Conventional machining is one most important material removal method. Machining is a part of the manufacture all most all metal products. In turning, higher values of cutting parameters offered opportunities for increasing productivity but it also involves greater risk of deterioration in surface quality and tool life. Turning operation is very important material removal process in modern industry. At least one fifth of all applications in metal cutting are turning operations.

Machining is a process of gradual removal of excess material from the preformed blanks in the form of chips. The form of chips is an important index of machining because it directly or indirectly indicates nature and behavior of the work material under machining condition, specific energy requirements (amount of energy required to remove unit volume of work material) in machining work and nature and degree of interaction at the chip-tool interface.

The form of machined chips depend mainly upon work material, material and geometry of the cutting tool, levels of cutting velocity and feed and also to some extent on depth of cut and machining environment or cutting fluid that affects temperature and friction at the chip-tool and work-tool interface [1].

A manufacturing process involves a number of process parameters (controllable and uncontrollable) which affect the output (response variable). Turning cutting parameters (input cutting parameters e.g.: cutting speed, feed rate, depth of cut, coolant, material and geometry of insert used for cutting) have a bearing on quality, time and cost of the resultant finished component. The basic idea of optimization is to increase quality and reduce cost and find the optimal set of input parameters.

II. METHODOLOGY

The methodology adopted in this work involves conducting experiments on conventional lathe machine based on design of experiments (DoE), measurement of chip thickness and investigation on influence of cutting parameters on the chip thickness values using ANOVA [2], Minitab and optimization of cutting parameters required for adaptive control of cutting parameter [3].

III. WORK PIECE MATERIALS

Spring steel (EN47) is used widely in the motor vehicle industry and many general engineering applications. It is suitable for applications that require high strength and toughness. Typical applications of EN47 include crankshafts, steering knuckles, gears, spindles and pumps. Thus it has been chosen as the work piece material in this study. Its nominal composition (wt%) and mechanical properties are shown in tables 1 and 2, respectively.

Figure 1 Work pieces (Spring Steel EN47)

Table 1 Chemical composition of EN47 spring steel (wt%)

Content	**C**	**Mn**	**Si**	**S**	**P**	**Cr**	**V**
Composition (wt%)	0.48	0.62	0.29	0.015	0.016	1.17	0.16

Table 2 Mechanical and Physical properties of EN47 spring steel

Hardness (HRC)	Density (kg/m^3)	Tensile strength (MPa)	Yield strength (MPa)	Thermal conductivity (W/mK)
	7700	750	450	25

IV. Design of experiments (DoE)

There are various ways in which design of experiments may be designed and it always depends on the number of factors and number of levels in each factors. As the number of experiments were too many in full factorial design which involves more machining time and cost, DoE was applied using Taguchi design to get an optimal number of experiments thereby reducing the machining time and cost involved. Taguchi method uses a special set of array called orthogonal array [4].
Moreover with increase in the number of process parameters, the number of experiments increases which have to be carried out.. The Taguchi is an experimental design technique which is used to reduce the number of experiments by using orthogonal arrays and also tries to control the factors which are going out of control. The basic philosophy of Taguchi is to provide quality in design phase. The greatest advantage of the Taguchi is that it reduces experiment time which reduces cost to find out significant factors in shortest possible time. The concepts of S/N ratio are useful in the improvement of quality through variability reduction and improvement of measurement. The S/N ratio can be classified into three categories given by equation when the characteristic is continuous:
According to orthogonal array properties best suitable/closest array chosen is L_9 array for three factors with 3 levels.

$$L_9 = 3 \times 3 = 9 \text{ experiments}$$

Table 3 shows the 9 experiments to be conducted for Taguchi DoE.

Table 3 The basic Taguchi L_9 orthogonal array

Run	**Control factors and level**		
	A	**B**	**C**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	2
9	3	3	1

Table 4 DoE factors and its levels

Variables or parameter	Code	Level 1 Low	Level 2 Medium	Level 3 High
Spindle speed (rpm)	**A**	357	550	853
Feed rate (mm/rev)	**B**	0.15	0.2	0.25
Depth of cut (mm)	**C**	0.2	0.4	0.6

V. EXPERIMENTATION

As per Taguchi DoE method, experiments were conducted on conventional lathe machine. Coated carbide tool (MTJNR/L1616H16) is used as cutting tool and material is EN47 spring steel. The tool should be selected according to the work piece because different tools give different reaction while cutting and some specific tools only can provide us the intended operation over the work piece. After each experiments chip thickness was measured using dial gauge indicator and micrometer. Prior to conducting experiments, good conditioned lathe machine was selected without any machine faults such as imbalance, misalignment, mechanical looseness, without bearing and gearbox faults.

Figure 2 Conventional Lathe Machine

Figure 3 Coated carbide single point cutting tool

Figure 4 Dial Gauge Indicator

VI. DESIGN AND ANALYSIS OF CUTTING PARAMETERS

The results of experiments are studied using signal to noise ratio (S/N) and ANOVA analysis. Based on the results, optimal cutting parameters for chip thickness are obtained. Taguchi uses the signal to noise ratio as quality characteristics. The concepts of S/N ratio are useful in the improvement of quality through variability reduction and improvement of measurement. Taguchi has find out that the two stage optimization procedure involving S/N ratio indeed gives the parameter level condition where the standard deviation is minimum keeping mean at the target value. The S/N ratio can be classified into three categories. In this

research the optimum parameter which gives minimum chip thickness can be obtained by using the "smaller the better" S/N ratio [5].
The S/N ratio with a smaller the better characteristics can be expressed as:

$$\eta_{ij} = -10\log\left(\frac{1}{n}\sum_{j=1}^{n} y_{ij}^2\right)$$

Where y_{ij} is the i_{th} response of j_{th} experiment and n is the total number of the tests.

VII. Result and Discussions

Figure 5 Chips obtained as per different combinations

Fig. 5 shows chip forms obtained at different cutting conditions. The chips obtained were basically continuous chips and possibly influenced by the stress, strain and temperature gradients. Continuous chips consist of elements bonded firmly together without being fractured. Under the best conditions the metal flows by means of plastic deformation, and gives a continuous ribbon of metal which, under the microscope shows no signs of tears or discontinuities. The upper side of a continuous chip has small notches while the lower side, which slides over the tool face, is smooth and shiny. The continuous form is considered most desirable for low friction at the tool-chip interface, lower power consumption, long tool life and good surface finish [6]. Factors favorable for continuous chip formation are: ductile material, fine feed, high cutting speed, large rake angle, keen cutting edge, smooth tool face and an efficient lubrication system.

Table 5shows the chip thickness measured with S/N ratios for various combinations.

Table 5 Experimental Results

Experimental Run	Spindle Speed (rpm)	Feed Rate (mm/rev)	Depth of cut (mm)	Chip Thickness (mm)	S/N Ratio
1	357	0.15	0.2	0.11	19.17215
2	357	0.2	0.4	0.15	16.47817
3	357	0.25	0.6	0.29	10.75204
4	550	0.15	0.4	0.02	33.9794
5	550	0.2	0.6	0.14	17.0774
6	550	0.25	0.2	0.3	10.4576
7	853	0.15	0.6	0.13	17.7211
8	853	0.2	0.2	0.11	19.1721
9	853	0.25	0.4	0.08	21.9382

From table 5, it was found that the chip thickness tends to increase as the feed rate increases at low and medium spindle speed. At high spindle speed chip thickness decreases as the feed rate increases. Hence, the feed rate influences the thickness of the chip as the spindle speed does. This is due to the increase in the undeformed chip thickness with increasing feed rate and the tangential force is proportional to the undeformed chip thickness as this increase will result in an increase in shear plane area.

When the cutting force decreases, the deformed chip thickness also decreases. This happened when the force Fc acts downward on the tool tip and tends to deflect the tool downward. This force/, is that which supplies the energy required for the cutting operation. It is assumed that as the chip thickness decreases so also does the power consumption of the machine, owing to low chip thickness during chip removal. At this time less vibration was observed and surface roughness improves.

Table 6 S/N response table for chip thickness factor

Level	A	B	C
1	-23.54	-27.08	-23.90
2	-25.22	-24.88	-27.26
3	-25.82	-22.61	-23.42
Delta	2.28	4.47	3.85
Rank	3	1	2

The delta values (difference between maximum and minimum S/N values) are shown in table. Feed rate and depth of cut are the two factors which are having highest difference between values 4.47 and 3.85 respectively. Based on the Taguchi prediction larger is the difference of S/N ratio value corresponding value will have more effect on the chip thickness. Thus it can be concluded that with increase in the value of feed rate and depth of cut, the value of chip thickness will also increase.

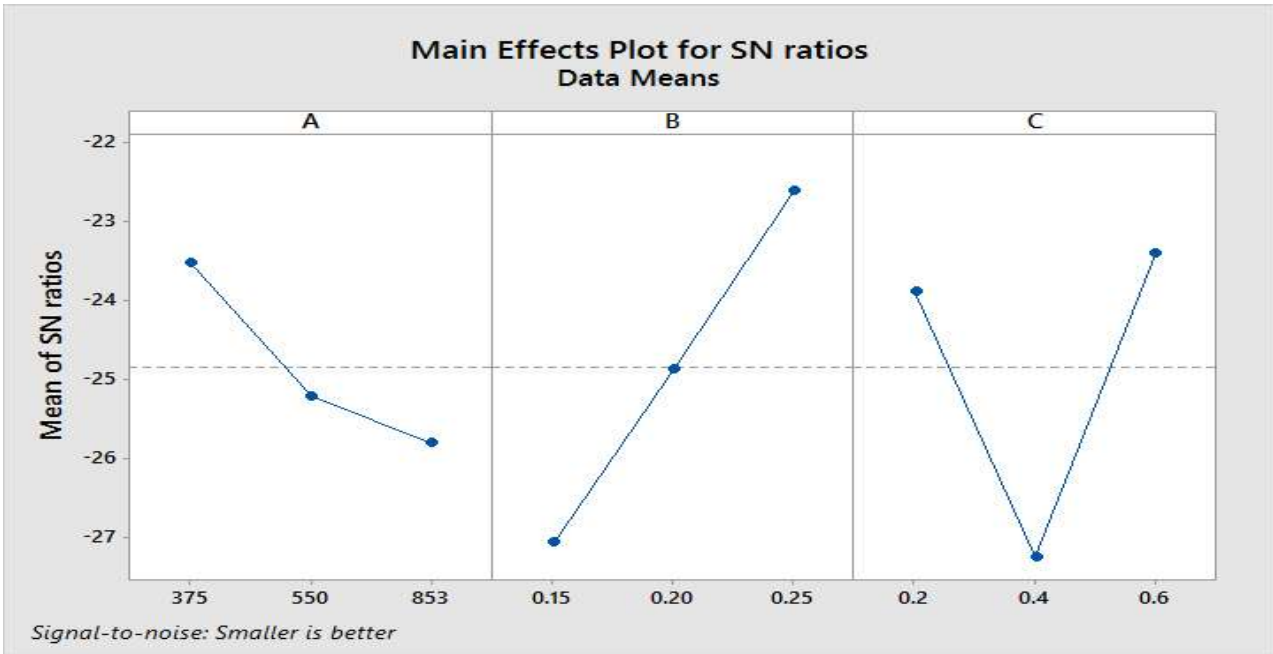

Figure 6 Main effect plot for S/N ratio (chip thickness)

Fig. 6 shows the main effect on chip thickness is primarily due to feed rate and depth of cut. The spindle speed found to be least significant from the main effect plot. From table 6 and fig. 6, all levels total are compared and combination yielding the highest combined S/N ratio is selected for minimum chip thickness. In this experiment, A1-B3-C3 combination yields the minimum chip thickness. This is the optimal levels combination of factors for turning operation in lathe for EN47.

VIII. CONCLUSION

The influence of spindle speed, feed rate and depth of cut on the chip thickness is analyzed for orthogonal cutting of spring steel (EN47) using coated carbide cutting tool. Continuous chips were obtained for all the cutting condition investigated. The experimental results based on S/N ratio and ANOVA analysis provides a systematic and efficient methodology for the optimization of cutting parameters for chip thickness. The chip thickness is mainly affected by cutting speed, feed rate and depth of cut, by increasing any one the chip thickness is increased. The best parameters for chip thickness have been found from table 4 as spindle speed 357 rpm in level 1, feed rate 0.25 mm/rev in level 3 and depth of cut 0.6 mm in level 3.

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