

OPTIMIZATION OF GEOMETRICAL PARAMETERS OF SINGLE POINT CUTTING TOOL TO REDUCE STRESS AND VIBRATION

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Abstract: A High Speed steel (UNST11302) single point turning tool of (20x20) cross-sectional area is used for turning operation. Tool experiences forces due rotation of spindle, feed rate and depth of cut, which produces chattering and high wear and tear. The objective of the study is to find the geometrical dimension and angle of the tool which has minimum vibration effect and minimum equivalent stresses. The natural frequency range was found to be 11384Hz to 45332 Hz. The horizontal and vertical cross sectional dimension are found to be 18.2 mm and 18.2mm and the optimal angle of tool should be Back Rack angle =10.88°, Side Rack angle =10.88°, End relief angle = 9.06°, End cutting angle =27.2°, Side cutting Edge angle =13.6° for minimum vibration frequency and minimum stresses

Keywords - Chattering, High speed steel, Natural frequency, Optimization, Single point tool

1. INTRODUCTION

Mechanical material removal processes are the backbone of industrial manufacturing practice. These processes provide a great deal of flexibility, since the shape and the kinematics of the tool and work piece define the geometry of the part. The material removal mechanism is a very important aspect of removing processes.

1.1 TURNING OPERATION

Among material removal processes, turning processes are the most widely used. In turning processes, a work piece rotates, providing the main cutting motion, while the tool is translated along the work piece, providing the feed motion. Based on the direction of feed motion, one can differentiate among longitudinal turning, facing, and form turning. In the first case there is an axial feed, in the second case a radial feed, and in the third case a simultaneous axial and radial feed motion. Modern machine tools, performing these processes, are usually automated to different degrees, including the implementation of computer numerical control of various kinds. The aspect of forces on single point cutting machine tool is taken into account to model the single point cutting tool.

1.2 VIBRATION DURING TURNING

During Machining, the removal of material from the work-piece by the tool is in the form of chips. The vibration is produced and is reflected in the form of noise. More friction will remove more material and produces more vibration and more noise. The measurement of vibration means measurement of relative vibration between work piece and tool. These vibrations occurs due to one or more of the following causes:

- a) In homogeneities in the work piece material
- b) Variation of chip cross section
- c) Disturbances in the work piece or tool drivers
- d) Dynamic load produced by acceleration of moving components
- e) Vibration which are transmitted from the environment
- f) Self-excited vibration often generated by the cutting process or by friction (machine-tool chatter) [1].

1.3 LITERATURE REVIEW

- Grabec (1988) [2] and Khraisheh et al (1995) [3] have performed the modeling of the dynamic cutting forces for chatter prediction with experimental data and compared with theoretical model.
- Lee et al (1989) [4] have attempted to correlate static and dynamic cutting forces to tool wear. The static forces showed that wear has been increased continuously at the initial stage then a consistent fluctuation, whereas the dynamic cutting forces exhibited a monotonic increase. Flank wear increased in the earlier phase of cutting before the tool failed.
- Marques and Mesquia (1991) [5] have investigated the relationship between wear of high-speed steel cutting tools and cutting forces. A wear force model has been proposed and experimentally verified.
- Kim and Lee (1991) [6] have performed the modeling of dynamic cutting forces with experimental data and compared with theoretical model predictions.
- Oraby and Hayhurst (1991) [7] have developed a model for tool wear analysis in a turning operation by force characteristics within different phases of tool wear.
- Elbestawi et al (1991) [8] have presented the on-line monitoring of flank wear in milling. This approach was based on the variations of magnitudes of cutting force harmonics with flank wear.
- Lee et al (1992) [9] have proposed TCMS using Fast Fourier Transform (FFT) software to track the dynamic cutting force signal.
- Ravindra et al (1993) [10] have proposed a mathematical model using cutting forces by regression analysis method for tool wear estimation.

I. PROBLEM FORMULATION

2.1 PROBLEM DEFINITION

A single point cutting tool (20x20) made of molybdenum High Speed steel (UNST11302) is used for turning operation. It experiences forces due rotation of spindle, feed rate and depth of cut (2000 N, 1100 N, 1000 N) which produces vibration in tool. This is responsible for high wear and tear of tool. The objective of the study is to find the geometrical dimension and angle of the tool which has minimum vibration effect and minimum equivalent stresses.

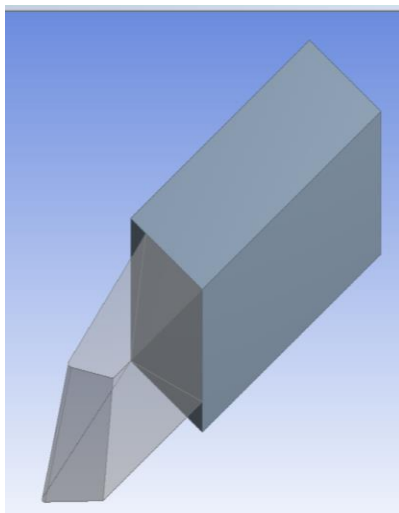


Figure 2.1 single point cutting tool

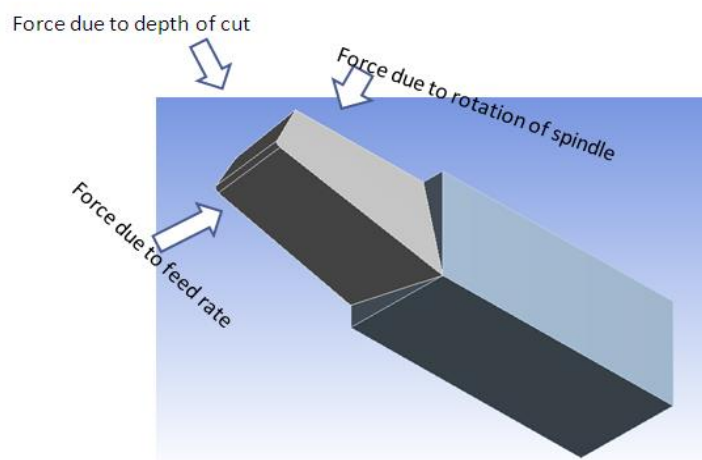


Figure 2.2 Forces on single point cutting tool

1.2 CUTTING TOOL SPECIFICATIONS

Table 2.1 Angle specification for turning tool

Back Rack angle	12°
Side Rack angle	12°
End relief angle	10°
End cutting angle	30°
Side cutting Edge angle	15°
Nose Radius	0.8mm

1.3 PROPERTIES OF HSS TOOL:

Table 2.2 Material specification for turning tool

Modulus of Elasticity	210 GPa
Density	8160 kg/m ³
Melting Point	460 °C
Poison's Ratio	0.3
Rockwell Hardness	62 to 65
Compressive Yield strength	3250 MPa

II. MODAL ANALYSIS AND HARMONIC ANALYSIS

3.1 MODAL ANALYSIS

A modal analysis determines the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component. It can also serve as a starting point for another analysis like harmonic analysis or a spectrum analysis. The natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions.

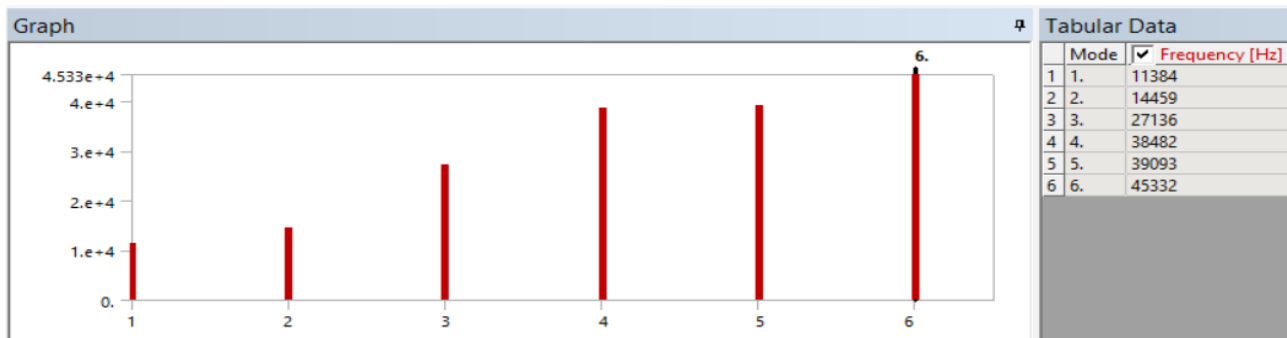


Figure 3.1 Range of natural frequency of single point cutting tool

3.2 HARMONIC ANALYSIS

harmonic analyses are used to determine the steady-state response of a linear structure to loads that vary sinusoidally (harmonically) with time, thus enabling you to verify whether or not your designs will successfully overcome resonance, fatigue, and other harmful effects of forced vibrations. In a structural system, any sustained cyclic load will produce a sustained cyclic or harmonic response. Harmonic analysis results are used to determine the steady-state response of a linear structure to loads that vary sinusoidally (harmonically) with time, thus enabling you to verify whether or not your designs will successfully overcome resonance, fatigue, and other harmful effects of forced vibrations.

Table 3.1 Variation of amplitude and phase with the given range of natural frequency.

	Frequency [Hz]	<input checked="" type="checkbox"/> Amplitude [MPa]	<input checked="" type="checkbox"/> Phase Angle [°]
1	4533.2	22.382	180.
2	9066.4	35.077	180.
3	13600	546.75	0.
4	18133	118.9	180.
5	22666	78.824	180.
6	27199	841.74	0.
7	31732	175.57	180.
8	36266	479.63	180.
9	40799	489.5	180.
10	45332	95.251	0.

3.3 EQUIVALENT STRESSES

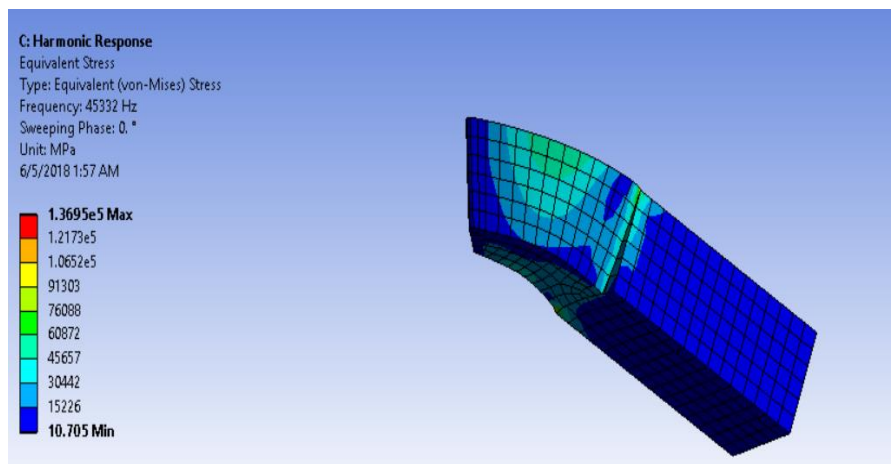


Figure 3.2 Showing Von Mises Stress (SEQV)

III. OPTIMIZATION

3.4 INTRODUCTION

Machining is very important process in which tools are used to remove metal from the work piece. In process of removing material from the work piece, it experiences several forces. The machine tool starts vibrating with different amplitudes and in different phases when it experiences different forces in different direction. This vibration is unwanted in the machining process which has to be minimised.

Here we are concerned with the dimension of tool for which it experiences minimum vibration and minimum stresses so that it may work for longer period of time or its life may be enhanced.

3.5 OBJECTIVE OF OPTIMIZATION

The above problem is mainly divided into two parts.

- To find the optimum cross-sectional parameters of the tool for the Minimum stresses and Minimum vibration
- To find the optimum value for different geometrical angles of the tool for the Minimum stresses and Minimum vibration.

3.6 OPTIMAL CROSSECTIONAL AREA FOR MINIMUM STRESSES AND MINIMUM VIBRATION

Table 4.1 Raw Optimization Data

Table of Schematic D2: Optimization					
	A	B	C	D	E
1	Name	P1 - XYPlane.H1 (mm)	P2 - XYPlane.V2 (mm)	P4 - Equivalent Stress Maximum (MPa)	P3 - Frequency Response Frequency (Hz)
2	1	18.2	18.2	72720	13600
3	2	18.6	20.2	95358	13600
4	3	19	19.2	90451	13600
5	4	19.4	21.2	1.3067E+05	13600
6	5	19.8	18.7	1.0431E+05	13600
7	6	20.2	20.7	1.7254E+05	27199
8	7	20.6	19.7	1.7819E+05	36266
9	8	21	21.7	1.0188E+06	27199
10	9	21.4	18.45	2.8086E+05	36266
11	10	21.8	20.45	5.7586E+05	36266

Table of Schematic D2: Optimization , Candidate Points								
	A	B	C	D	E	F	G	H
1	Reference	Name	P1 - XYPlane .H1 (mm)	P2 - XYPlane.V2 (mm)	P4 - Equivalent Stress Maximum (MPa)	P3 - Frequency Response Frequency (Hz)		
2					Parameter Value	Variation from Reference	Parameter Value	Variation from Reference
3	<input checked="" type="radio"/>	Candidate Point 1	18.2	18.2	★★★ 72720	0.00 %	★★★ 13600	0.00 %
4	<input type="radio"/>	Candidate Point 2	19	19.2	★★★ 90451	24.38 %	★★★ 13600	0.00 %
5	<input type="radio"/>	Candidate Point 3	18.6	20.2	★★★ 95358	31.13 %	★★★ 13600	0.00 %

Figure 4.1 Results of optimization of frequency and Equivalent Stresses

3.7 OPTIMAL ANGLES FOR MINIMUM STRESSES AND MINIMUM VIBRATION

Table 4.2 Raw Optimization Data for lot size of 15 for different angles

Sno.	Back Rack angle	Side Rack angle	End cutting angle	End relief Angle	side cutting edge angle	Equivalent stresses	Frequency
1	10.88	10.88	27.20	9.07	13.60	5.64E+04	13650
2	11.04	12.08	29.20	9.47	14.03	1.01E+05	13650
3	11.2	11.48	31.20	9.87	14.46	5.12E+06	45500
4	11.36	12.68	27.87	10.27	14.89	1.11E+05	13650
5	11.52	11.18	29.87	10.67	15.31	1.16E+06	27300
6	11.68	12.38	31.87	9.15	15.74	1.19E+05	13650
7	11.84	11.78	28.53	9.55	16.17	3.38E+05	27300
8	12	12.98	30.53	9.95	13.66	1.78E+05	13650
9	12.16	11.03	32.53	10.35	14.09	1.40E+05	27300
10	12.32	12.23	27.42	10.75	14.52	9.52E+04	13650
11	12.48	11.63	29.42	9.23	14.95	1.96E+05	13650
12	12.64	12.83	31.42	9.63	15.38	1.68E+05	27300
13	12.8	11.33	28.09	10.03	15.80	2.22E+05	13650
14	12.96	12.53	30.09	10.43	16.23	1.47E+05	13650
15	13.12	11.93	32.09	10.83	13.72	2.48E+05	27300

	A	B	C	D	E	F	G	H	I	J	K
1	Reference	Name	P9 - XYPlane .A3 (degree)	P10 - XYPlane .A6 (degree)	P11 - ZXPlane .A5 (degree)	P12 - Plane4 .A3 (degree)	P13 - Plane9.A2 (degree)	P6 - Equivalent Stress Maximum (MPa)		P8 - Frequency Response Frequency (Hz)	
2								Parameter Value	Variation from Reference	Parameter Value	Variation from Reference
3	Candidate Point 1	DP 23	10.88	10.88	27.2	9.0667	13.6	56416	0.00 %	13650	0.00 %
4	Candidate Point 2	DP 32	12.32	12.23	27.422	10.747	14.518	95171	68.70 %	13650	0.00 %
5	Candidate Point 3	DP 28	11.68	12.38	31.867	9.1467	15.743	1.1888E+05	110.69 %	13650	0.00 %

Figure 4.2 Results of Angle optimization for Minimum frequency and Minimum Equivalent Stresses

IV. CONCLUSION

The following conclusions are drawn from the modelling, modal analysis, harmonic response analysis and optimization of single point cutting tool used for turning operation

1.The modal analysis of single point cutting tool which is modelled in ANSYS and is made of molybdenum High speed steel (UNST11302) is done to determine the natural frequency of the tool. The frequency range was found to be 11384Hz to 45332Hz. Figure 3.1 shows this frequency range.

2.The Harmonic analysis of above mentioned single point cutting tool is done to determine the variation of vibration when this tool is subjected to different forces which acts on it while machining operation is done. Table 3.1 shows the variation of amplitude and phase within the above mentioned natural frequency range. The Equivalent stresses are also determined and are shown by Figure 3.2

3.To minimize the vibrational effect optimization is done with various raw optimization data. The horizontal and vertical cross sectional dimension with minimum vibration frequency and minimum stresses are found to be 18.2 and 18.2 while for maximum stresses and maximum vibration frequency is found to be 21 and 21.7 respectively.

4.It is concluded that to minimize the vibration and Equivalent stresses the optimal angle of tool should be Back Rack angle =10.88°, Side Rack angle =10.88°, End relief angle = 9.06°, End cutting angle =27.2°,Side cutting Edge angle =13.6°

5.It is also concluded that the tool with either of the optimised dimension will have least Equivalent stresses and vibrational effects. This will enhanced the tool life.

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