International Journal For Technological Research In Engineering
Volume 5, Issue 11, July-2018 *ISSN (Online): 2347 - 4718*

DESIGN AND ANALYSIS OF BORING BAR USING ANSYS

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Abstract: In this article,an analysis on deflection of the boring bar during internal boring operation has been carried out. Parameters such as back rake angle,side rake angle and nose radius have been fine-tuned in order to obtain minimum deflection at the tool tip. High Speed Steel (HSS) has been considered as tool material whereas Stainless steel (AISI 304) has been considered as work piece material. The three components of cutting forces have been computed using theoretical calculation [1]. Cutting forces are correlated to chip area and cutting edge contact length with mechanistic cutting force coefficients. The forces calculated have been used for analysis. Commercial FEM tool, ANSYS(ADPL) has been used for analysis and harmonic analysis has been carried out. The maximum displacement for the given tool geometry has been obtained from the analysis and corresponding parameters are chosen for manufacturing.
Keywords: Boring bar, harmonic analysis, Ansys.

I. INTRODUCTION

Boring is a process in which pre-drilled holes or holes in cast, forged or extruded components are enlarged or finished with acutting tool mounted on a boring bar. The process is mostly used in applications, where close dimensional tolerances and goodsurface finish are required. Because of the geometrical constraints,the boring bar should be long and slender, so it is easily subjectedto static and dynamic deflections.

Tool deflections or vibrationsnot only change the true process parameters (e.g., depth of cut)and thereby impose dimensional errors, but may also reduce thesurface quality and tool life. The study of tool deflection of boringprocess is therefore a prerequisite for selecting appropriate tool angles and also preserving process accuracy byavoiding excessive tool deflections or dynamic tool vibrations.

II. CHATTERING IN BORING BARS

Today in the manufacturing industry, the vibrations concerned with metal cutting, such as turning, milling and boring operations. Turning operations, and especially boring operations, are facing tough vibration related problems. To reduce the problem of vibration extra care must be taken in the production planning and preparation regarding the machining of a workpiece in order to obtain a desired shape and tolerance. Thus, the vibration problem in metal cutting has a considerable influence on important factors such as productivity, production costs, etc.The vibration in the boring bar are in the cutting speed and the cutting depth direction. The tool life is also likely to be influenced by the vibrations. Hence there is a need to minimize vibrations during boring operation.

III. CALCULATION OF CUTTING FORCES

Cutting force is represented by tangential F_t, thrust F_h andlateral $F_l$components. F_t is along the cutting speed direction whileF_h and F_l in XYplane. Since the chip thickness and approachangle change along the cutting edge, the magnitude andorientation of cutting force vary. If the tool rake face is smooth,the cutting edge can be represented by an assembly of elementalcutting edges [2]. In order to evaluate thecutting force, each element is considered as a single straightcutting edge. Experimental observations have shown that for asingle straight oblique cutting edge, cutting force components of F_t and F_h are nearly independent of inclination angle[3] . It is alsoknown that each component consists of cutting and edge subcomponents. Cutting subcomponent is proportional to the chip area and represents the chip removal force. Edge subcomponentis proportional to the cutting edge contact length and represents the forces due to the ploughing and rubbing of the cutting edge.

The localnormal rake angle (α_n) and oblique angle (i) can be evaluated theorotically [1] and are given as

$i = \tan^{-1}[\tan(\alpha_b)\cos(\psi) - \tan(\alpha_s)\sin(\psi)]$

$\alpha_0 = \tan^{-1}[\tan(\alpha_b)\sin(\psi) + \tan(\alpha_s)\cos(\psi)]$

$\alpha_n = \tan^{-1}[\tan(\alpha_0) \times \cos(i)]$

respectively. Where ψ is tool approach angle.

The elemental cutting force components of $\Delta F_t$and ΔF_fcan be modeled as functions of elemental chip area (ΔA) and cutting edge contact length (ΔL) and are given as[4]:

$\Delta F_t = \Delta F_{tc} + \Delta F_{te} = K_{tc}\,\Delta A + K_{te}\,\Delta L$

$\Delta F_h = \Delta F_{hc} + \Delta F_{he} = K_{hc}\,\Delta A + K_{he}\,\Delta L$

Where$\Delta F_t$is in Z direction while ΔF_t is in XY plane, perpendicular to the elemental cutting edge. ΔA and ΔL can be substituted with their values evaluated[2]. K_{tc} and K_{hc} are cutting force coefficients [4]

$$K_{tc} = \tau_s \frac{\cos(\beta_n - \alpha_n)}{\sin(\phi_n)\cos(\phi_n + \beta_n - \alpha_n)}$$

$$K_{hc} = \tau_s \frac{\sin(\beta_n - \alpha_n)}{\sin(\phi_n)\cos(\phi_n + \beta_n - \alpha_n)}$$

Whereβ_n andϕ_n are normal friction and shear angles, respectively,and are expressed by

$\beta_n = \tan^{-1}(\tan\beta \cos i)$

$$\phi_n = \tan^{-1}\left(\frac{r_t \cos(\alpha_n)}{1 - r_t \sin(\alpha_n)}\right)$$

Where$K_{te}$and$K_{he}$are edge coefficients and experimentally proven to be independent of oblique angle [5] and are given by[1]

K_{te}(N/mm)= 70.0696–3.2188DOC- 0.1736V

K_{he}(N/mm)= 130.279-7.06169DOC-0.5678V

Chip thickness ratio (r_t), shear angle (ϕ), shear stress (τ_s) and edge coefficients (K_{te} and K_{he})are evaluated from

orthogonal database and are given as[1]:
r_t= (0.07455+0.00029α_0) $e^{4.06182\,f}$
β(deg)=41.8658+0.2627α_0-17.2996f
τ_s(MPa)=194.562+163.951f-0.669069V
+1.29077α_0
Where f is feed in mm/rev,V is cutting speed in m/min,α_0 is rake angle in (^{0}),DOC is depth of cut in mm.
For each element, theelemental values of F_t and F_h are computed and summed up along the cutting edge to obtain the resultant thrust and tangential components [1]:
$F_t = F_{tc} + F_{te} = \sum \Delta F_{tc} + \sum \Delta F_{te}$
$F_h = F_{tc} + F_{he} = \sum \Delta F_{tc} + \sum \Delta F_{he}$
Once the directions and magnitudes of the resultant tangentialand thrust components are known, the third component F_l can befound with respect to the fact that the resultant cutting force mustlie in the plane normal to the tool cutting face in the chip flowdirection. It is shown by vector analysis that the third componentwhich satisfies this condition can be obtained by [5]

$$F_l = \frac{F_{tc}[\sin(i) - \cos(i)\sin(\alpha_n)\tan(\eta_c)] - F_{hc}\cos(\alpha_n)\tan(\eta_c)}{\sin(i)\sin(\alpha_n)\tan(\eta_c) + \cos(i)}$$

Note that the chip flow angle is determined theoretically [3] and is given by

$$\eta_c = 54{,}8276\text{x} \left(\frac{f^{(0.2247)}.r^{(0.2715)}}{Doc^{(0.4488)}}\right)$$

Finally, cutting force components are projected to x, yand z directions:$F_z = F_t$
$F_x = F_h \cos(\psi) + F_l \sin(\psi)$
$F_y = F_h \sin(\psi) - F_l \cos(\psi)$

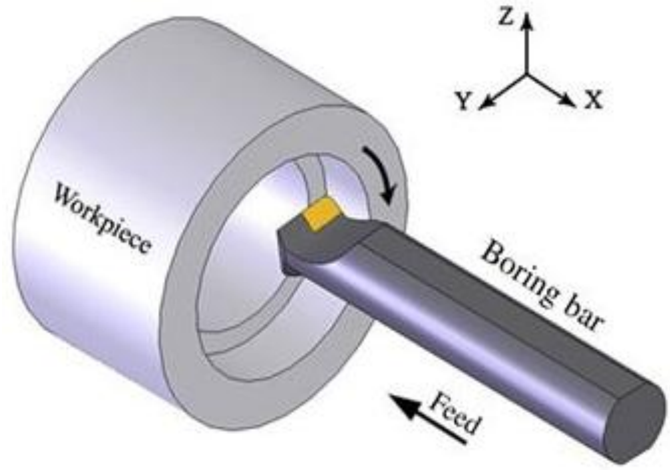
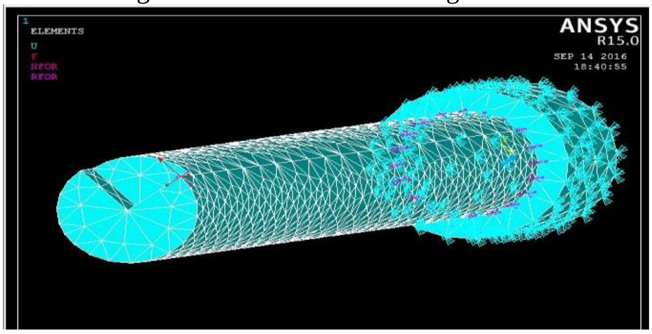


Figure 1.Directions of boring operation

IV. DESIGN AND ANALYSIS IN ANSYS

The forces which are derived using the above formulae are applied to the end of the tool using ansys and harmonic analysis is performed. The back rake and side rake angles are varied from -10^0 to 20^0 and corresponding forces (30x30=900 set of forces) are calculated.The combination of forces which give minimum deflection are noted.The rake angles corresponding to these forces are used for manufacturing of tool as they give minimum delection and less chatter.

Figure 2. FEA Model of Cutting Tool :



A boring bar of following material and following dimensions is considered.
The greater the nose radius,the greater the radial and tangential cutting forces and the emergence of vibration[6].Hence the insert with nose radius 0.4mm is taken instead of 0.8mm.So 0.4mm is taken as default.
Material : High speed steel (M-46%,C-1.26%,Si-0.53,Cr-3.95,V-3.15,W2.05,Mo-8.25,Co-8.3)
*Properties:*Young's modulus=2.1E11N/m^2, Poisson's ratio=0.2, Density=7830kg/m^3
Dimensions: Length =310mm,Overhang=270mm,
Tool diameter=35mm,Workpiece diameter= 50mm.Back rake and side rake angles varied from -10^0 to 20^0, nose radius=0.4mm.The cutting edge contact length ΔL is equal to feed i.e 0.2mm.
ΔL=0.2mm, Chip area ΔA=ΔLxDoc=0.06mm
Where Doc is depth of cut.

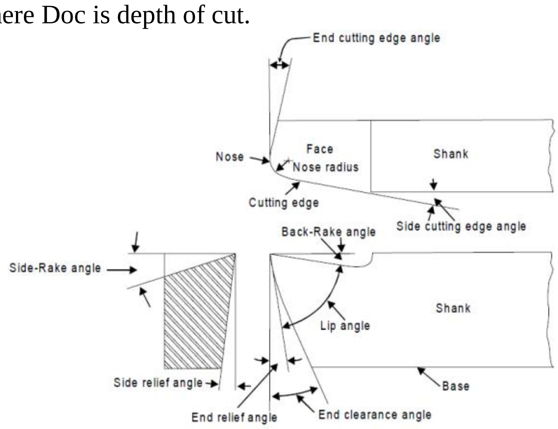


Figure 3.Nomenclature of single point cutting tool

The turning operation performed is orthogonal type. So tool approach angle ψ is taken 90^0.
The above parameters are substituted in the formulae mentioned in the previous section and forces are obtained. These forces are applied to the tool using ansys and deflections are obtained. Calculations are done using excel and analysis is done using Ansys (ADPL).
Tool is created in solid works and imported into ansys as parasolid.

V. ANALYSIS IN ANSYS

The element type is taken as Brick8 node185 and model is linear-Structural-elastic-isotropic.
The properties are given as mentioned previously. Harmonic analysis is performed with frequency range varied from 0 to 300000Hz with 300substeps and boundary condition as stepped.

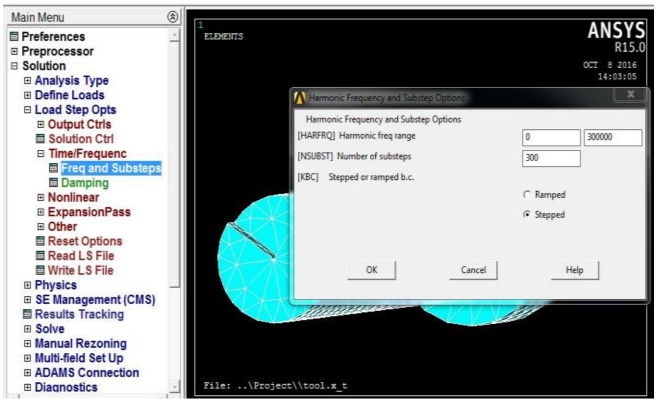


Figure 4.Selection of frequency and substeps

Meshing is Global smart size 5, shape is Tet-Free, refined at elements.

The forces calculated above are applied on the end of tool at contact point of tool and workpiece. The three forces are applied in three directions. The real part of the force is filled and the imaginary part is left blank.

After performing harmonic analysis on all 900 set of forces. The minimum displacement or deflection obtained is 2.50E-07metres at frequency 160600hzs for forces F_x=-49.61N, F_y=44.3026N ,F_z=81.1978N. These forces are obtained for input parameters back rake angle 20^0, side rake angle -10^0 and nose radius 0.4mm.

Table.1

Back rake	Side rake	Fx	Fy	Fz	Deflection
20	-10	-49.61	44.3026	81.1978	2.50E-07
20	-9	-51.137	44.354	81.216	2.57E-07
20	-8	-52.659	44.3998	81.2324	2.64E-07
20	-7	-54.177	44.4401	81.2468	2.71E-07
20	-6	-55.689	44.475	81.2593	2.78E-07
20	-5	-57.196	44.5044	81.2699	2.84E-07
20	-4	-58.696	44.5284	81.2786	2.91E-07
20	-3	-60.19	44.5471	81.2853	2.98E-07
20	-2	-61.677	44.5604	81.2902	3.05E-07
20	-1	-63.157	44.5684	81.2931	3.12E-07
20	0	-64.629	44.571	81.294	3.19E-07
20	1	-66.093	44.5684	81.2931	3.26E-07
20	2	-67.549	44.5604	81.2902	3.32E-07
20	3	-68.997	44.5471	81.2853	3.39E-07
20	4	-70.435	44.5284	81.2786	3.46E-07
20	5	-71.865	44.5044	81.2699	3.53E-07
20	6	-73.285	44.475	81.2593	3.59E-07
20	7	-74.696	44.4401	81.2468	3.66E-07
20	8	-76.097	44.3998	81.2324	3.73E-07
20	9	-77.489	44.354	81.216	3.75E-07
20	10	-78.871	44.3026	81.1978	3.85E-07
20	11	-80.243	44.2456	81.1776	3.92E-07
20	12	-81.605	44.1829	81.1556	3.98E-07
20	13	-82.956	44.1145	81.1317	4.05E-07
20	14	-84.298	44.0402	81.1059	4.11E-07
20	15	-85.629	43.96	81.0783	4.13E-07
20	16	-86.951	43.8739	81.0488	4.19E-07
20	17	-88.262	43.7816	81.0175	4.29E-07
20	18	-89.563	43.6832	80.9844	4.35E-07
20	19	-90.854	43.5784	80.9494	4.41E-07
20	20	-92.134	43.4673	80.9127	4.47E-07

The above table.1 shows variation of deflection with back rake angle constant and varying side rake angle.The deflection increases with increase in side rake angle.

Figure 5. Deflected state of cutting tool:

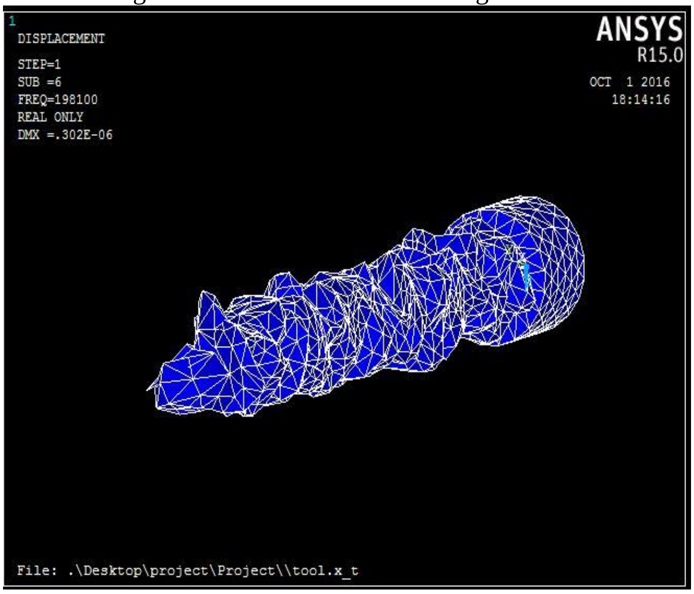


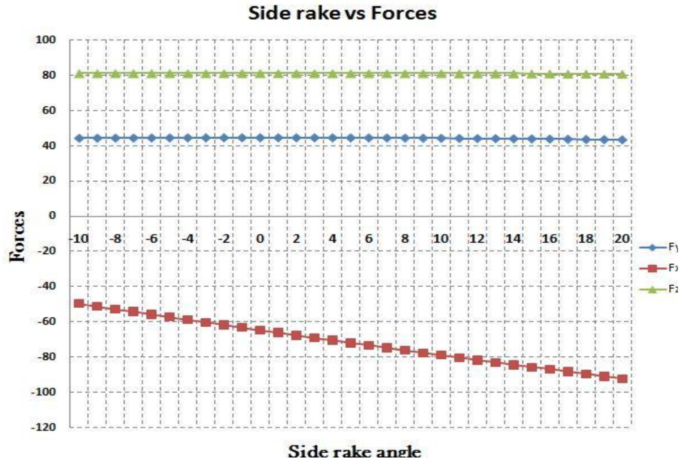
Table.2

Side rake	Back rake	Deflection	Frequency
-10	-10	4.38E-07	160600
-10	-9	4.21E-07	160600
-10	-8	4.16E-07	160600
-10	-7	4.05E-07	160600
-10	-6	3.95E-07	160600
-10	-5	3.85E-07	160600
-10	-4	3.67E-07	160600
-10	-3	3.67E-07	160600
-10	-2	3.59E-07	160600
-10	-1	3.51E-07	160600
-10	0	3.43E-07	160600
-10	1	3.36E-07	160600
-10	2	3.29E-07	160600
-10	3	3.22E-07	160600
-10	4	3.16E-07	160600
-10	5	3.10E-07	160600
-10	6	3.04E-07	160600
-10	7	2.98E-07	160600
-10	8	2.93E-07	160600
-10	9	2.88E-07	160600
-10	10	2.85E-07	160600
-10	11	2.79E-07	160600
-10	12	2.75E-07	160600
-10	13	2.67E-07	160600
-10	14	2.67E-07	160600
-10	15	2.64E-07	160600
-10	16	2.61E-07	160600
-10	17	2.61E-07	160600
-10	18	2.55E-07	160600
-10	19	2.52E-07	160600
-10	20	2.50E-07	160600

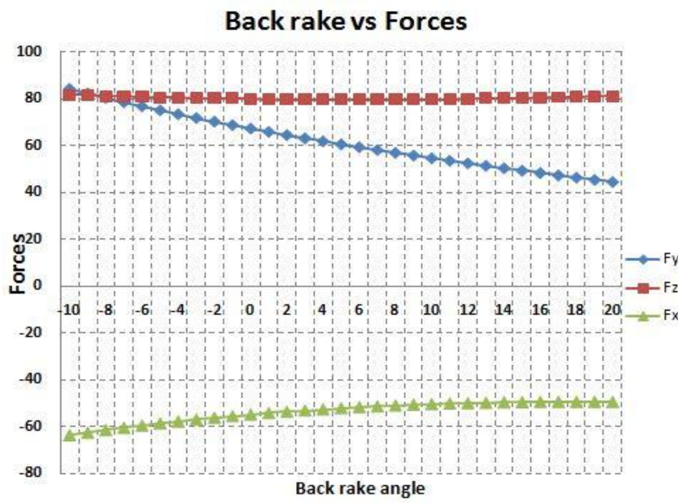
The above table.2 shows variation of deflection with Side rake angle constant and varying Back rake angle. The deflection decreases with increase in side rake angle.

The various graphs are obtained as follows

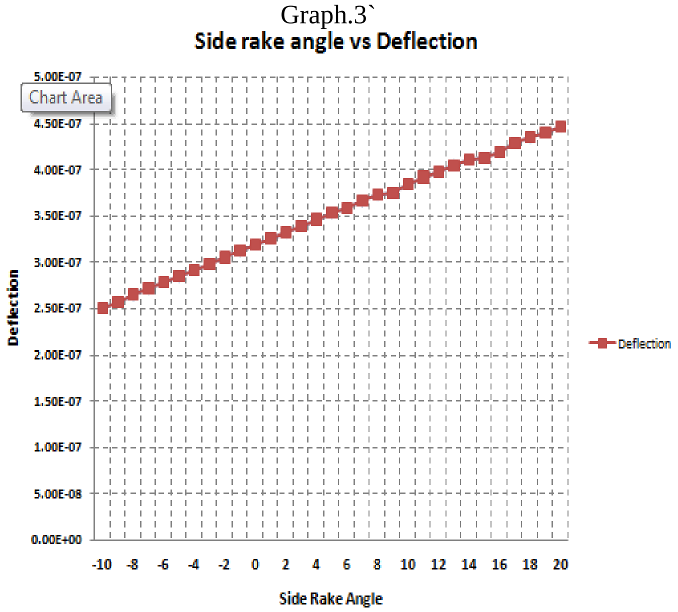
Graph.1



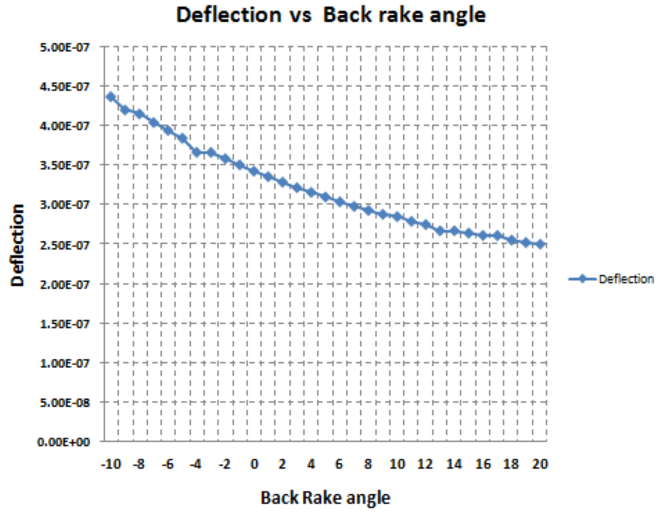
Graph.2



Graph.3`



Graph.4



VI. RESULTS AND DISCUSSION:

- The minimum displacement is obtained for forces with inputs parameters back rake angle 200and side rake angle -100.The value of minimum deflection is 2.50E-07 meters at frequency 160600 Hz. Hence these angles and nose radius are taken for manufacturing of boring tool.
- It is observed from graph 1 that feed force Fx increases with increase in side rake angle while other two forces remain constant for the given tool.
- It is observed from graph 2 that feed force F_x and radial force F_y decrease with increase in back rake angle while tangential force remains constant for the given tool.
- It is observed from graph 3 that deflection increases with increase in side rake angle for the given tool.
- It is observed from graph 4 that deflection decrease with increase in back rake for given tool.

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