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Horizontal Milling Machine Arbor Optimization by Parametric Iterative Technique

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Abstract

Milling arbor is may be considered as an extension of the machine spindle on which milling cutter are securely mounted and rotated. The arbor is subjected to complex stress conditions such as combine's axial loads, bending and twisting moments and cyclic or dynamic loads [8]. So it is necessary to analyze the behavior of the spindle under different loading conditions and with the use of different theories of failure. In this research paper milling arbor is analyzed using ANSYS software and the different stresses such as bending stress, torsional shear stress, principal stress and von-misses stress are determined [6]. The results are validated against analytical solution and the errors are within the allowable limits, and shape optimization using iterative technique is done based on the stress valve obtained; an iterative process was carried out. A new Shape was formulated whose stress valve well within the limits.

Keywords: *Arbor, optimization, iterative technique, theories of failure*

1. Introduction

A milling machine shaft is often used on horizontal milling machine for mounting cutters. More than one cutter may be mounted on the same arbor according to requirements of surface to be machined.

In this research milling arbor is analyzed using ANSYS software and the different stresses such as bending stress, torsional shear stress, principal stress and von-misses stress are determined [9].

The results are validated against analytical solution [2] and the errors are within the allowable limits. And shape optimization using iterative technique is done based on the stress valve obtained; an iterative process was carried out. A new Shape was formulated whose stress value well within the limits.

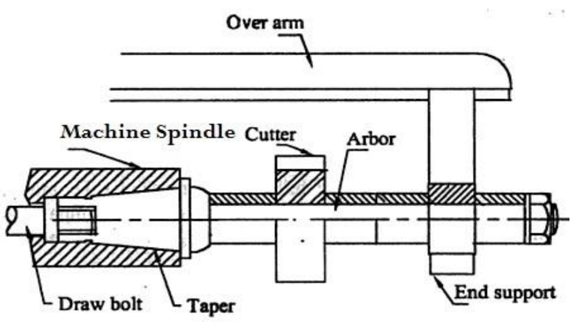


Fig. 1 Arbor & its Support

2. Analytical/Mathematical Formulation

=> For Shaft Stress System Subjected to Loading

Milling Machine Specification
Total motor power =5H.P = 3730 Watt
High Speed Cutter = 12dp
Cutting Speed = N = 60 rpm
No. of teeth on cutter =12
Shaft diameter (Milling Machine Shafts) = d_A = 25mm
Diameter of cutter = $3d_A$ =75mm
Shearing Strength of work material =σ_s = 40 N/mm^2
Job width = B = 25mm
Length of shaft = 90mm
Job (cutting) material= C.I.

Assumptions

Self weight of shaft = 4 kg =39.24N
Depth of cut = t = 5mm (from data book)
Feed = f ×z = 0.3 mm/rev for the cutter having 12 teeth.

I have considered the weakest cross-section for analysis purpose.

The self-weight of the shaft acting vertically downwards and the cutting force due to tool on the job acts horizontally [3] so that we have taken resultant of these two forces.

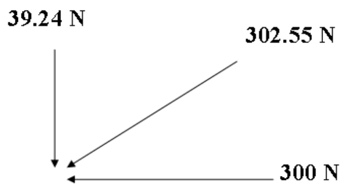


Fig. (c) Resultant dig

Calculation for cutting force

Cutting force = Fc_1+Fc_2 [7]

Since Fc_1= 0, because at the initial No. of teeth in contact is 1 [5]

Therefore, $Fc_2 = 2\times\sigma_s\times f\times z\times \sin\psi_2$ [8]

But $\psi_2 = \delta = \cos^{-1}$ (D/2-t)/ (D/2)

$= \cos^{-1}(32.5/37.5) = 29.920$

Now $Fc_2 = 2\times40\times0.3\times25\times0.4987 = 299.22 \approx 300$ N

Calculations for Bending moment

Bending moment to be calculated for simply supported beam with point load at mid –point.

But, Load

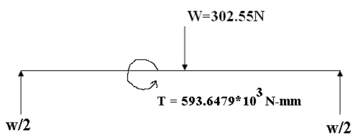
$$w=\sqrt{(self\ weight)^2+(Fc_2)^2} \quad =\sqrt{(39.24)^2+(300)^2}$$

= 302.55N

Calculation of Torque or Twisting Moment

$$P = \frac{(2\pi NT)}{60} \qquad T=\left(\frac{(P\ (60))}{(2\pi N)}\right)$$

T = 593.6479×103 N-mm



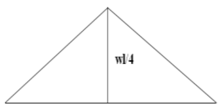


Fig. (a) Loading Dia. **Fig. (b)** Bending Moment Dia.

Now, Bending Moment = $\frac{WL}{4} = \frac{((302.55)90)}{4}$ = 6807.37 N-mm

Calculation of Bending stress from Bending moment

$$M=\frac{\pi}{32}(\sigma_b)(d)^3 \qquad 6807.37=\frac{\pi}{32}(\sigma_b)(25)^3$$

σ_b = 4.4377 N/mm^2

Calculating of equivalent bending stress and equivalent shear stress

According to maximum shear stress theory, shear stress due to combined effect of Bending and Torsional Moment.

Calculation of Torsional Shear Stress

$$T=\left(\left(\frac{\pi}{16}\right)(\tau)(d^3)\right)$$

593.6479×10^3 = (∏/16) × τ × (25^3)

τ = 193.49 N/mm^2

Analysis by ANSYS

Types: Structural analysis

Element Type: PIPE 16

Real Constant: OD=25mm, Thickness=12.5mm

Material: Alloy Steel E=200 x 10^{3}N/mm^2 μ=0.3

Load: Apply Torque UY= 0, UZ= 0

Bending Load ROTX, UY, UZ=0

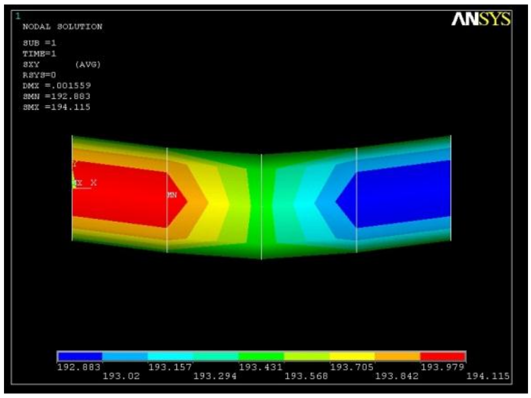


Fig.2 Result showing Torsional shear stress [9]

Solution for Torsional Shear Stress by ANSYS

General Post Proc. -> Plot result -> Contour Plot -> Nodal sol -> XY Shear Stress

Calculation of equivalent bending stress and equivalent shear stress

According to maximum shear stress theory, shear stress due to combined effect of bending and torsional moment,

$$\tau_{\max}=\frac{1}{2}\sqrt{\sigma_b{}^2+4\tau^2}$$

$$=\frac{1}{2}\times\sqrt{(4.4377^2+4\times193.49^2)}$$

τ_{max} = 193.5027 N/mm^2

According to Principal stress theory, bending stress due to combined effect of bending and torsional moment,

$$\sigma_{b\max}=\frac{\sigma_b}{2}+\frac{1}{2}\sqrt{(\sigma_b{}^2+4\tau^2)}$$

$$=\frac{4.4377}{2}+\frac{1}{2}\times\sqrt{(4.4377^2+4\times193.49^2)}$$

σ_{bmax} = 195.72 N/mm^2

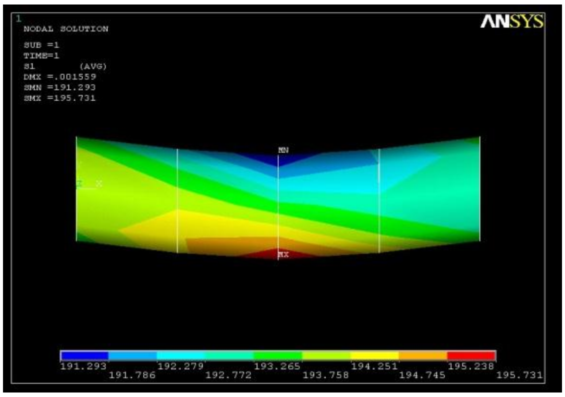


Fig.3 Result showing Principal Stress

Solution for Principal Stress by ANSYS
General Post Proc. -> Plot result -> Contour Plot -> Nodal sol -> 1st Principal Stress

Calculation of VON-MISES stress

$$\sigma_{vonmises} = \sqrt{\sigma_b{}^2 + 3\tau^2}$$

$$= \sqrt{(4.4377^2 + 3 \times 193.49^2)}$$

$\sigma_{vonmises}$ = 335.1638 N/mm^2

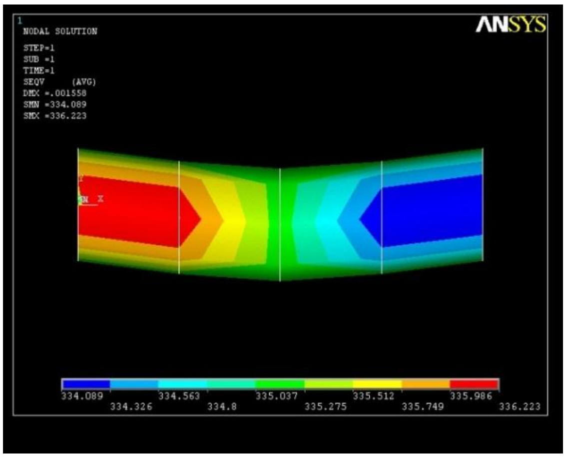


Fig.4 Result showing Von Mises Stress

Solution for VON-MISES Stress by ANSYS
General Post Proc. -> Plot result -> Contour Plot -> Nodal sol -> VON MISES Stress

Now, % Error= (ANSYS result – Analytical result) x 100 / Analytical result

Table 2 Comparison of result of arbor shaft by analytically and ANSYS

Type of stress	Analytical method N/mm^2	Using ANSYS N/mm2	% error
maximum bending stress	195.72	195.734	0.00715
maximum shear stress	193.5027	194.119	0.31885
von-mises stress	335.1638	336.223	0.31602

3. Geometrical Optimization of a Shaft by Parametric Iterative Technique

Calculation for the Milling Machine Shaft diameter of 22mm.

Bending moment to be calculated for simply supported beam with point load at mid-point.

Now, Bending Moment = $\frac{WL}{4}$ = $\frac{((302.55)90)}{4}$ = 6807.37N-mm

Calculation of Bending stress from Bending moment

$$M = \frac{\pi}{32}(\sigma_b)(d)^3$$

$$6807.37 = \frac{\pi}{32} \times \sigma_b \times (22)^3$$

σ_b = 6.5119 N/mm^2

Calculation of Torque or Twisting Moment

$$P = \frac{(2\pi NT)}{60} \qquad T = \left(\frac{(P\ (60))}{(2\pi N)}\right)$$

T = 593.6479×10^3 N-mm

Calculation of Torsional Shear Stress

$$T = \left(\left(\frac{\pi}{16}\right)(\tau)\ (d^3)\right)$$

$$593.6479 \times 10^3 = \frac{\pi}{16} \times \tau \times (22)^3$$

τ = 283.942 N/mm^2

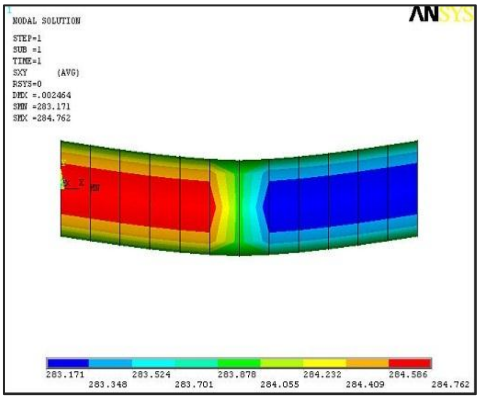


Fig.5 Result showing Torsional Shear Stress

Solution for Torsional Shear Stress by ANSYS
General Post Proc. -> Plot result -> Contour Plot -> Nodal sol -> XY Shear Stress

Calculation of equivalent bending stress and equivalent shear stress

According to maximum shear stress theory, shear stress due to combined effect of bending and torsional moment,

$$\tau_{\max} = \frac{1}{2}\sqrt{\sigma_b^{\,2} + 4\tau^2}$$

$$= \frac{1}{2} \times \sqrt{(6.5119^2 + 4 \times 283.942^2)}$$

τ_{max} = 283.961 N/mm^2

According to Principal stress theory, bending stress due to combined effect of bending and torsional moment,

$$\sigma_{b\max} = \frac{\sigma_b}{2} + \frac{1}{2}\sqrt{\left(\sigma_b^{\,2} + 4\tau^2\right)}$$

$$= \frac{6.5119}{2} + \frac{1}{2} \times \sqrt{(6.5119^2 + 4 \times 283.942^2)}$$

σ_{max} = 287.2174 N/mm^2

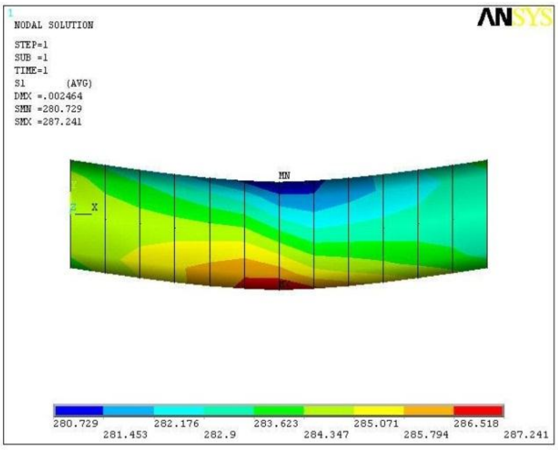


Fig.6 Result showing Bending Stress

Solution for Principal Stress by ANSYS
General Post Proc. -> Plot result -> Contour Plot -> Nodal sol -> 1st Principal Stress

Calculation of VON-MISES stress

$$\sigma_{vonmises} = \sqrt{\sigma_b^{\,2} + 3\tau^2}$$

$$= \sqrt{(6.5119^2 + 3 \times 283.942^2)}$$

$\sigma_{vonmises}$= 490.954 N/mm^2

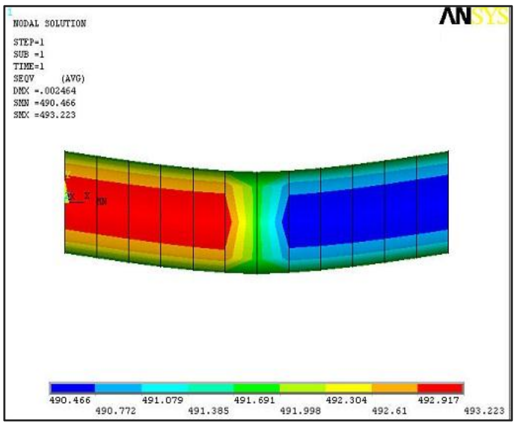


Fig.7 Result showing Von-mises Stress

Solution for VON-MISES Stress by ANSYS
General Post Proc. -> Plot result -> Contour Plot -> Nodal sol -> VON MISES Stress

Table 2 Stress induced in shaft by analytically and ANSYS

Type of Stress	Using Analytical Method (N/mm^2)	Using ANSYS (N/mm^2)
Maximum Bending Stress	287.2174	287.241
Maximum Shear Stress	283.9614	284.762
Von-Mises Stress	490.9548	493.223

From the result obtained for the milling machine shaft of 22mm diameter, clearly shown that the stress induced in the arbour shaft are maximum than the shaft of 25mm diameter [3]. So it can't be optimized shape, further we will do iteration by changing the diameter of the Milling Machine Shafts shaft until we get an optimized shape of the.

Table 3 Stress induced in arbor shaft by analytically and ANSYS

Iteration	Dia. of Arbor (mm)	Type Of Stress	Using Analytical Method (N/mm^2)	Using ANSYS (N/mm^2)
1	22.0	Maximum Bending Stress	287.2174	287.241
		Maximum Shear Stress	283.9614	284.762
		Von-Mises Stress	490.9548	493.223
2	22.5	Maximum Bending Stress	268.4920	268.514
		Maximum Shear Stress	265.4483	266.214
		Von-Mises Stress	459.7801	461.096
3	23.0	Maximum Bending Stress	251.3594	251.380
		Maximum Shear Stress	248.5100	249.243
		Von-Mises Stress	430.4414	431.701
4	23.5	Maximum Bending Stress	235.6542	235.674
		Maximum Shear Stress	232.9828	233.685
		Von-Mises Stress	403.5469	404.754
5	24.0	Maximum Bending Stress	221.2305	221.249
		Maximum Shear Stress	218.7226	219.395
		Von-Mises Stress	378.8470	380.004
6	24.5	Maximum Bending Stress	207.9603	207.978
		Maximum Shear Stress	205.6029	206.248
		Von-Mises Stress	356.1224	357.233
7	25.0	Maximum Bending Stress	195.7200	195.734
		Maximum Shear Stress	193.5027	194.119
		Von-Mises Stress	335.1638	336.223
8	25.5	Maximum Bending Stress	184.4413	184.457
		Maximum Shear Stress	182.3504	182.946
		Von-Mise Stress	315.8472	316.872

From the result obtained for the arbor shaft of 25.5mm diameter, clearly shown that the stress induced in the arbor shaft, are less than the arbor of 25mm diameter. Hence it holds good the analytical as well as FEA method [6] so an optimized geometry of component is achieved.

Conclusions

For The Arbor Shaft Diameter = 25mm			For The Arbor Shaft Diameter = 25.5mm		
Type of Stress	Using Analytical Method (N/mm²)	Using Ansys (N/mm²)	Type Of Stress	Using Analytical Method (N/mm²)	Using Ansys (N/mm²)
Max. Bending Stress	195.72	195.734	Max. Bending Stress	184.441	184.457
Max. Shear Stress	193.502	194.119	Max. Shear Stress	182.350	182.946
Von-Mises Stress	335.163	336.223	Von-Mises Stress	315.847	316.872

From the result obtained for the arbor shaft of 25.5mm diameter, clearly shown that the stress induced i.e. torsional shear stress, principal stress, von misses stress in the arbor shaft are lesser than the predicted values for an arbor of 25mm diameter. Hence the analytical as well as FEA method so an optimized geometry of component is achieved, as shown in Fig 7.

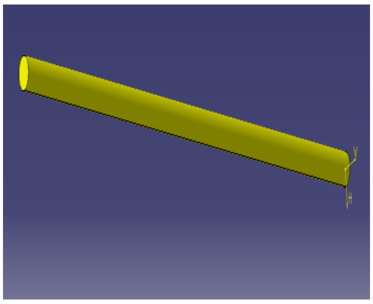


Fig.8 Optimized geometry

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