SPINDLE DESIGN AND ANALYSIS OF A SPINDLE USING EPOXY MATERIALS

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ABSTRACT

In the present study, a general purpose internal grinding spindle was used as reference. The spindle material was replaced by ***Kevlar epoxy****,* ***E-glass epoxy*** *and* ***Carbon epoxy*** *respectively. From the experimentation it was found that the life of spindle, load bearing strength and torsional strength increases substantially. The spindle being light also experiences lesser vibrations and fluctuations. The second whirling due to substantially lower weight is prevented. In general using epoxy in place of standard materials improves performance, life of the spindle and is cost efficient.*

Keywords: Spindle, Kevlar epoxy, E-glass epoxy, Carbon epoxy.

I.INTRODUCTION

Over the decades, the basic principles of metal cutting and the main mechanical components of the machine tools remained same. Same as 30 years ago, a machine tool is still composed of the basic components: spindle, moving axes and a cutting tool. Among these components, spindle is almost the most critical one due to its vital duty in the metal cutting process. Even though the spindles differ in structure and design for different machine tools (milling, internal grinding, etc.) they all serve to the same basic purpose: rotating either the work piece or the grinding wheel with enough torque and speed against the other which is fixed to enable the grinding happen.

II.PURPOSE

The main purpose of this paper is to design analysis and develop an internal grinding spindle that will meet the design requirements listed and explained below. These requirements are defined based on the market trends and other technological developments.

The design requirements are:

2.1. The spindle should run with an internal synchronous motor. Synchronous motor to be used can be selected from any spindle motor producer company.

2.2. In this paper, necessary calculations and component selection process are studied to generate a preliminary spindle design. The analysis of the preliminary design is also presented to understand the static and dynamic behavior of the spindle.

2.2.1. Internal grinding spindle design

2.2.1.1. Material specifications

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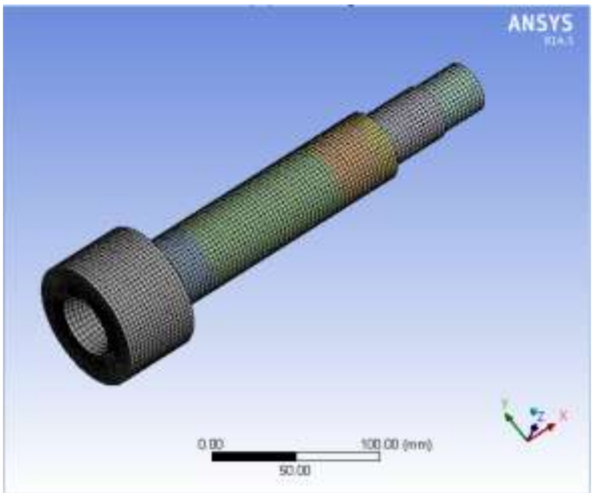
- E-glass
- Kevlar-29
- Kevlar- 49
- Carbon epoxy



"Fig. 1. Meshing of the spindle"

2.2.1.2. Given Data:-

- Pulley dimensions:-
- D_{max} = 500 mm
- D_{min} = 125 mm
- Motor Specification:-
- Power = 5HP =3728.5 Watt
- Max. Speed = 18000 rpm
- Cutting Forces for grinding operation:- (Considering **20MnCr5** steel) (From manufacturing book)
- Feed =0.35 mm
- Depth =2 mm
- Assume, For pulley power transmission,
- Coefficient of friction = 0.3
- Inner diameter of spindle is D_i = 45mm (By considering form existing model)

2.2.1.3. Design:-

Torque transmitted by Motor,

$$Pmotor = \frac{2 * \pi * N * T}{60}$$

$$3728.5 = \frac{2 * \pi * 18000 * \text{Tmotor}}{60}$$

$\text{Tmotor} = 1.9780\ \text{N.m}$

$\text{Tmotor} = 1978\ \text{N.mm}$

Tension on Belt

$$\frac{\mathbf{F1}}{\mathbf{F2}} = \mathbf{e}^{\mu * \theta}$$

$$\frac{F1}{F2} = e^{0.3*2.87979}$$

$F1 = 2.3714 * F2$

Torque Transmitted by pulley from motor side:-

$$\mathbf{Tmotor} = (\mathbf{F1} - \mathbf{F2}) * \mathbf{Dmin/2}$$

$1978 = (2.3714\ F2 - F2) * 125/2$

$F2 = 23.07714\ N$

$F1 = 54.725\ N$

Torque Transmitted by pulley from Internal grinding spindle:-

$$\mathbf{Tspindle} = (\mathbf{F1} - \mathbf{F2}) * \frac{\mathbf{Dmax}}{\mathbf{2}}$$

$\text{Tspindle} = (54.725 - 23.07714) * 500/2$

$\text{Tspindle} = 7911.965\ \text{Nmm}$

$\text{Tspindle} = T2 = \text{Torque on internal grinding spindle spindle}$

2.2.1.4. Cutting force calculation

Feed = 0.35 mm

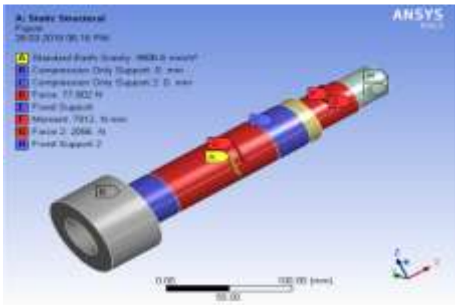
Depth = 2 mm

Cutting force on spindle (Fc) (Formula from manufacturing book)

$$\mathbf{Fc} = \mathbf{2900} * (\mathbf{Feed})^{\mathbf{0.85}} * (\mathbf{Depth})^{\mathbf{0.98}}$$

$Fc = 2900 * (0.3)^{0.85} * (2)^{0.98}$

$Fc = 2055.635\ N$



"Fig. 2. Static Loading on the spindle"

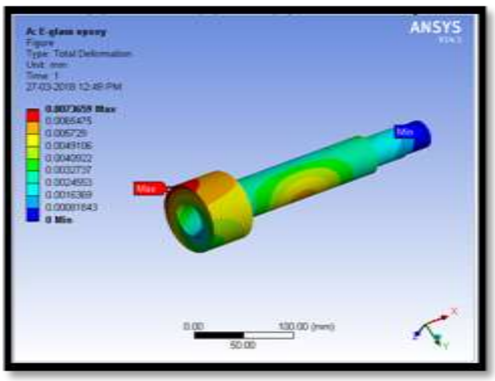
III.PROCEDURE AND RESULT

3.1 Calculation of Cutting Forces and Power Requirements In most cases spindle motor defines the maximum power and torque specs of the spindle, unless there is a transmission system (belt, gear drive, etc.) without 1:1 ratio. Hence the calculations of the cutting forces and required motor power for the spindle will help to select the integral motor with correct specifications. Power and force calculations will be made for a possible worst case scenario, which is a sample case challenging enough to push the spindle. The machining case, where a specific material with specified dimensions is to be machined with certain cutting conditions of speed, feed rate, cutting depth, etc., is studied.

3.2 Selection of the components and preliminary design following the calculations of spindle power requirement, first preliminary design can be made by choosing the appropriate motor and bearings based on the speed, power and size limitations. The motor will be selected from the product ranges of motor supplier companies. Companies such as Siemens, Fanuc, and etc. produce synchronous spindle motor. Similar to the motor, bearings will be selected from spindle bearing producing companies such as NSK, SKF, FAG, etc.

3.3 Verification of preliminary design before designing the spindle assembly further, preliminary mechanical design should be checked and verified through static and dynamic analyses. An analytical model will be created to understand the spindle static behavior under cutting forces. The analytical model results will be compared with FEM results to validate the models and the method.

3.4 Detail design and finalization Spindle design now can be finalized following the verification of the preliminary design and optimization of the bearing positions. There are more factors to consider for the further steps of spindle design such as design of other components in the arrangement, appropriate fits and mounting methods, design for manufacturing, sealing of the system, measurement system adaptation, mounting and dismounting methods, coolant circulation system design.



"Fig. 3. Total deformation-E glass"

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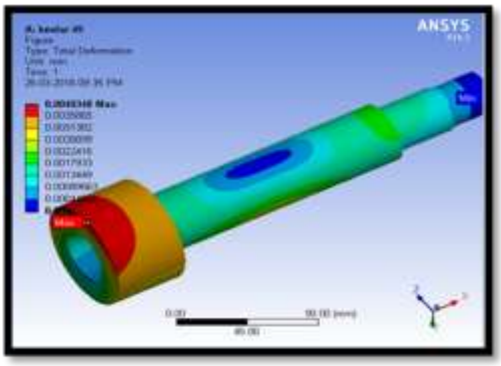
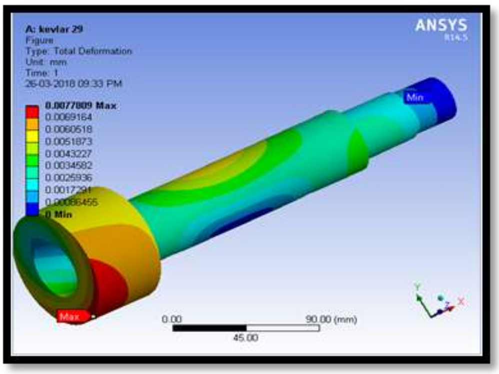
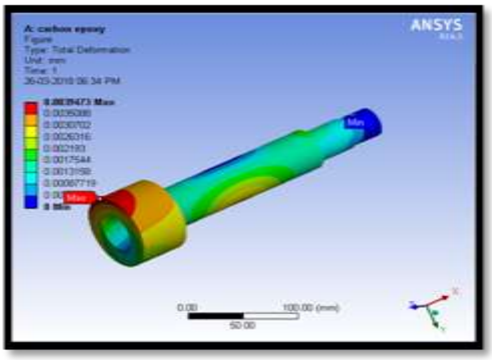


“Fig. 4. Total deformation-carbon epoxy”



“Fig. 5. Total deformation-Kevlar 29”



“Fig. 6. Total deformation-Kevlar 49”

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IV.OBSERVATION TABLE

TABLE 1: OBSERVATION AND CALCULATION

MATERIAL	DIAMETER OF SPINDLE IN (mm)	EQUIVALENT VON-MISES STRESS (MPa)	EQUIVALENT VON-MISES STRAIN (mm/mm)	TOTAL DEFOR-MATION (mm)	ULTIMATE STRESS IN (MPa)	WEIGHT (Kg)
20MnCr5	**45**	**4.2664**	**2.25e+5**	**0.0027**	**682**	**41.34**
Kevlar 29 Epoxy	**45**	**4.2673**	**6.09e-5**	**0.007780**	**2800**	**7.568**
Kevlar 49 Epoxy	**45**	**4.2677**	**3.16e-5**	**0.0040348**	**2900**	**7.568**
E-glass Epoxy	**45**	**4.28**	**5.94e-5**	**0.00736**	**3445**	**10.296**
Carbon Epoxy	**45**	**4.2821**	**3.18e-5**	**0.0039**	**1500**	**8.237**

V.FRAME OF REFERENCE

5.1 Basic Spindle Structure: In this paper, the basic structure of a spindle and its major components are explained extensively. Additionally a literature review conducted on the spindle design and optimization is also presented. Machine tools have been an important part of various industries and technologies for over centuries. In the ancient Roman times simple internal grindings were used to machine big stone pillars of the wonderful buildings and artifacts. Almost 200 years old internal grindings to machine woods and metal can be found in the Deutsche Museum. Accordingly, the spindle unit of an internal grinding always existed but with different drive technologies behind it.

5.2 The main functions of spindles for grinding machine tools can be listed as: Grinding the workpiece to obtain high surface finish for precision applications. A precision spindle design is essentially made based on the below listed predefined requirements and constraints.

5.2.1 Desired spindle power

5.2.2 Maximum spindle loads,

5.2.3 The forces generated during grinding operation

5.2.4 Maximum spindle speed

5.2.5 Spindle type (externally or internally driven)

5.2.6 Abrasive of grinding wheel

5.2.7 Size and capacities

5.2.8 Dimensional constraints regarding the machine outer and inner space

5.2.9 Availability of the components to be purchased in the market

5.2.10 Cost

5.3 The model can predict the stiffness of the bearings, contact forces on the bearing balls, natural frequencies and mode shapes, frequency response functions and time history response under cutting loads.

5.4 Static and dynamic properties of a spindle affect the quality and the efficiency of the machining operation. Better static and dynamic properties of a spindle allow to increase MRR (material removal rate) while providing good surface finish and precise dimensions. Hence the design of a spindle should be definitely analyzed to investigate its static and dynamic behavior during machining.

VI.CONCLUSION

6.1. As the result of this paper, a spindle is designed and analysis for different material with the following specifications:

It is observed that high stresses may not be observed on spindle.

6.1.1. Max. Stress for E glass Epoxy- 4.28 MPa

6.1.2. Max. Stress for Carbon Epoxy-4.2821MPa

6.1.3. Max. Stress for Kevlar 29 Epoxy- 4.2673 MPa

6.1.4. Max. Stress for Kevlar 49 Epoxy- 4.2677MPa

Which are much lesser than its ultimate tensile strength of the standard material.

6.2. Maximum deformation is .00736mm, 0.007780 mm, 0.004035 and 0.003947mm for E glass epoxy, Kevlar29 epoxy, Kevlar 49 epoxy and carbon epoxy material spindle respectively.

6.3. In all the material maximum stress location is near the grinding wheel support.

6.4. From the observation table it is seen that maximum factor of safety is for the Kevlar 29 epoxy material with min weight for the spindle.

6.5. Carbon and E glass Epoxy spindle has same dia. But stresses and weight is lesser observed for the carbon epoxy spindle. So it is recommended that out of the two you can go for Carbon Epoxy spindle on the basis of stress, weight, and factor of safety.

VII.FUTURE WORK

The following are the possible ideas for future work:

7.1 Spindle bearing stiffness coefficients has substantial effects on the spindle static and dynamic behavior. To be able to get more accurate results and predict the spindle behavior, the stiffness values of the bearings can be found experimentally and included in the analysis.

7.2 Manufacturing drawings can be made for future prototype testing.

7.3 Prototype manufacturing and testing of the spindle can be made.

7.4 Bearings with different properties or precision levels and their effects on the rigidity and accuracy can be investigated.

7.5 Tolerance stack up in the assembly and its effects on the rigidity and accuracy can be investigate

7.6 Composites of various epoxy materials can be used for the same.

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7.7 The same loads can be machined while using smaller dimension spindles, thus reducing the overall machine size, hence opens the doorway to compact machining.

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