

Prediction of Axial Loads and Life of Bearings of the Spindle System through ANSYS Programming Approach

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Abstract- This paper deals with the study of stiffness, deformation and life of bearings by the programming approach. It is essential to estimate the rigidity of the spindle assembly with the shaft and the bearings while designing a spindle unit. Bearings have both radial and axial non-linear stiffness characteristics which depend upon the load on the bearing. Estimating the correct stiffness of the bearing is difficult by conventional analytical methods. It is due to the stiffness of the bearings varies nonlinearly with load. The FEM method is time consuming and needs expertise which is not available to most designers, hence we have used a new method based on a programming approach proposed for quick and reliable estimation of spindle stiffness. The method also outputs the reactions at the bearings which can be used for predicting the bearing life. The programming approach is based on ANSYS programming language.

Keywords – Spindle, Stiffness, Deformation, Life of Bearings, APDL, ANSYS.

I. INTRODUCTION

Machine tool spindles are rotating components that are used to hold and drive cutting tools or work pieces in drilling, milling, lathe, etc., machine tools. They are use, chain, belt, gear, pneumatic or hydraulic drives and they are available in different configurations. For example, cartridge assemblies are housed in a motionless boundary while angled spindles are configured to allow right angle or adjustable tool rotation. Some machine tool spindles are housed in a solid block. Others are bolted down via flanges or feet at the bottom of the housing.

Most spindles of machine tool that fit the heads of cutting tools feature Morse taper or other standardised machine tool taper. Number of spindle heads is used to speed machining operations and in repetitive precision of work such as close-tolerance center holes. A various types of bearings are used with machine tool spindles. Examples include air, roller, ceramic hybrid and hydrostatic, magnetic, angular contact and tapered roller bearings.

II. FINITE ELEMENT MODEL (FEM):

In this method of analysis, a complex region defining a continuum is discretised into simple geometric shapes called finite elements. The material properties and the governing relations are considered over these elements and expressed in terms of unknown values at element corner. An assembly process, duly considering the loading and constraints, results in a set of equations, solution of these equations give us the approximate behavior of the continuum.

III. PROGRAMMING APPROACH TO DETERMINE STIFFNESS OF THE SPINDLE

APDL stands for ANSYS Parametric Design Language, a scripting articulation that we can use to automate every-day tasks or even construct your model in conditions of parameters (variables). While all ANSYS commands can be treat as part of the scripting articulation, the APDL commands used here are the true scripting commands and encompass a broad range of other components such as repeating a command, macros, if-then-else branching, do-loops, and scalar, vector and matrix exercises. While APDL is the establishment for artificialized portions such as design optimization and adaptive meshing, this is also offers many conveniences that you can take advantage in your day-to-day analyses. In this guide we introduce you to the basic components - parameters; macros; branching, looping, and repeating; and array parameters - and show you some simple illustrations. As you become more adept at the articulation, you will begin to identify applications of APDL in our own environment.

This APDL covers the following topics:

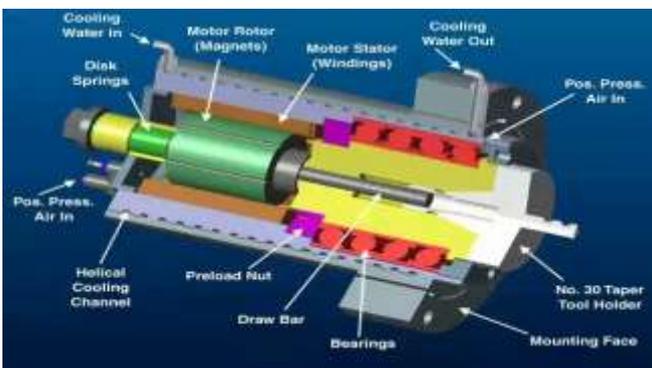


Fig.1 Machine tool spindle

- Working with the toolbar: We can extend repeatedly used ANSYS operations or macros to the ANSYS toolbar by specifying abbreviations, which are aliases for an ANSYS command, GUI function name, or macro name.
- Using parameters: Parameters are APDL changeable (they are more similar to FORTRAN variables than to FORTRAN parameters). ANSYS uses two types of parameters: scalar and array.
- Construction of APDL as a macro language, including creating a macro: we can record a repeatedly used series of ANSYS commands are in a macro file. Generating a macro enables us to, in effect; create our own custom ANSYS command. In addition to executing a sequence of ANSYS commands, a macro can call GUI functions or pass values into discussion.
- Interfacing with the GUI: Within an ANSYS macro, you have several methods to access components of the ANSYS GUI (toolbar, dialog box, *ASK command, etc.).
- Encrypting macros: ANSYS affords the power to encrypt macro files so that the origin is not "human-readable." Encrypted macros demand an encryption key to proceed. We can either place the encryption key categorically (in readable ASCII) in the macro or we can set it in ANSYS as a global encryption key

A. The spindle modal mesh without bearing Using APDL programming language we can find out the stiffness and deformation and life of bearings used in the machine tool spindle. In APDL we use typical commands like, *if, *do, *ask, etc... in structural, 2 element types are used 1.beam188 and 2. Matrix27. The material properties like Young's modulus $E = 21000 \text{ kg / mm}^2$, Poisson's ratio $\nu = 0.3$, density $\rho = 7.85 * 10^{-10}$ first creating key-points by entering the co-ordinates of that and then lines are drawn by connecting those key points, and dividing the line into the element edge length and adding out the sections then meshing the beam element. The geometry of the spindle shaft, the spindle housing, and the tooling system is described by mass and stiffness matrices. A volumetric model of the spindle geometry and its corresponding FE mesh has been created in the ANSYS software using the APDL programming language. Guyana's reduction method for reduction of the number of DOFs has been applied on the FE mesh for selected nodes. The result is a one-dimensional model with elements having six DOFs in each node instead of the initial volumetric mesh with three DOFs in each node. The properties of other spindle components (bearings, tool holder-spindle interface) are described by corresponding stiffness matrices.

B. The spindle modal with bearing support In this paper, five bearings are supported for stepped bar. The finite element method was adopted to verify the effectiveness of two bearing support beam model. Adding the bearings with its parameters to the beam element and then generating the element of the bearing. User cannot give the stiffness value for complex problems because, it is not possible to define the stiffness value having 3 or more bearings, it becomes a continuous beam, hence it is difficult to define the stiffness value so the program

follows a predictor - corrector method, for 1st iteration it takes approximation reaction then it compute the correct stiffness value or subsequent iterations, it corrects the bearing reaction and then compute the new stiffness value. By finally applying the loads on the nodes of beam element and by using the given formulas, it will go for the solution to that beam element. In postprocessor we can know the deformation of the beam element.

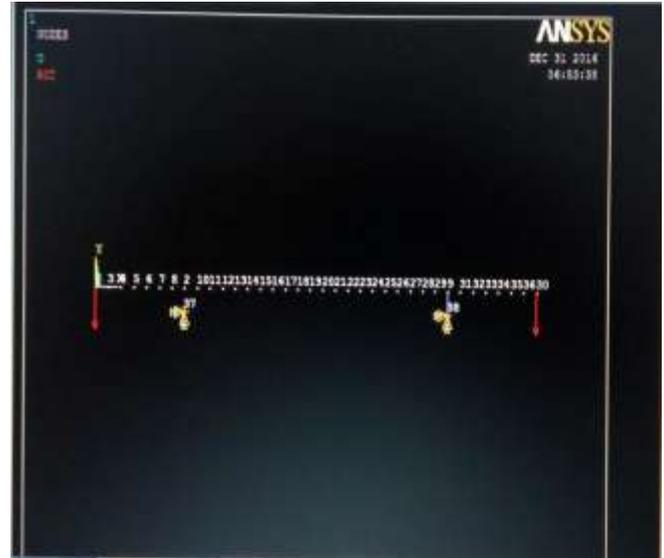


Fig 2: Two bearing system with two point loads

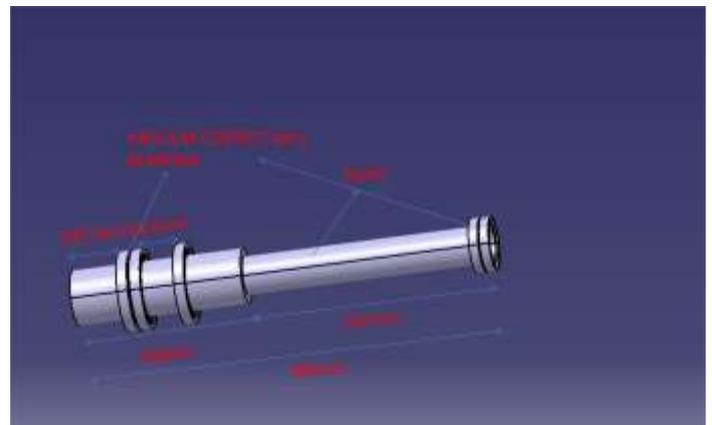


Fig.3 Five Bearing System with stepped spindle

IV. CALCULATION

Angular contact ball bearing

Nomenclature:

- F_r =radial load in kg, = 300;
- F_a =axial load in kg = 100;
- F_s =sum of radial load in kg = 300;
- D = outer dia of shaft in mm;
- d =inner dia of shaft in mm;
- α =contact angle in degrees;
- DW =element diameter in mm;
- Z =number of elements per row;
- i =number of rows;
- Q = Load acting on bearings in kg;

K= Stiffness of bearing in kg/mm;
L=life of bearings in hours;
δ = Deflection of bearings in mm
L=Effective roller length in mm;
FRR =radial reaction in mm;
FRA = axial reaction in mm;
P=Equivalent dynamic load in kgf;
N = speed of the shaft in rpm;
C = dynamic load rating in kgf;
XF =Radial factor for dynamic load;
YF =Axial factor for dynamic load;

i. To find load on the bearing (Q),

$$Q = \frac{5 \times fs}{i \times z \times \cos \alpha} \quad \text{in kgf}$$

ii. To find deflection on bearing (δ)

$$\delta_s = \frac{0.002}{\cos \alpha} \times \left(\frac{Q^2}{DW}\right)^{0.33333} \quad \text{in mm}$$

iii. Stiffness of bearing (K)

$$K = \frac{F_{RR}}{\delta_s} \text{ in kg/mm}$$

iv. Life of the bearing

$$P = (XF \times FRR) + (YF \times FRA) \text{ in kgf,}$$

$$LIFE = L = \frac{1000000}{60 \times N} \times (C/P)^\epsilon \text{ in hrs}$$

Data's considered: (XF = 0.5, YF = 0.46)

Parameter	1 st Bearing 180x100	2 nd Bearing 180x100	3 rd Bearing 180x100	4 th Bearing 125x 70	5 th Bearing 125 x 70
A	15°	15°	15°	15°	15°
Dw in mm	18	18	18	16.5	16.5
Z	23	23	23	17	17
I	1	1	1	1	1
C in kgf	14850	14850	14850	8000	8000
N in RPM	4000	4000	4000	4000	4000
ε	3	3	3	3	3

V. RESULT AND DISCUSSION

This project deals with computation of deformations, stiffness, and life of bearings in spindle unit of machine through the programming approach. The finite element method was adopted to verify the effectiveness of the continuous beam model. The program was initially takes the stiffness approximately and finally it came with the exact stiffness through the number of iterative process, by using this stiffness values, deformation and some other parameters, like load, bearing parameters, spindle sections, etc.. are then used in life calculation of bearings in spindle. The results are shown in below table,

A. Deformation

Table 1: 1st iteration

Bearing no.	FX Axial deformation in mm	FY Radial deformation in mm
1	-33.420	-256.16
2	34.95	-168.59
3	-33.230	90.70
4	0	47.75700
5	0	-13.696

Table 2: 2nd iteration

Bearing no.	FX Axial deformation in mm	FY Radial deformation inmm
1	-38.8634	-259.922
2	-33.75	-147.56
3	-27.38	71.81
4	0	36.795
5	0	-1.113281

Table 3: 3rd iteration

Bearing no.	FX Axial deformation in mm	FY Radial deformation in mm
1	-40.3931	-262.71
2	-33.396	-141.6277
3	-26.2099	68.38
4	0	35.91839
5	0	0.374782*10 ⁻¹

Table 4: 4th iteration

Bearing no.	FX Axial deformation in mm	FY Radial deformation in mm
1	-40.836	- 263.85
2	-33.186	-139.75
3	-25.978	67.59
4	0	35.974
5	0	0.41799E-01

B. LIFE OF BEARINGS

Table 5: 1st iteration

Bearing no.	Equivalent dynamic Load on each bearing (kgf)	Life of bearing (hrs)
1	143.455	4621905.375
2	99.63	13797415.03
3	60.63	61221704.18
4	23.87	156856117.9
5	6.848	6643049128

Table 6: 2nd iteration

Bearing no.	Equivalent dynamic Load on each bearing (kgf)	Life of bearing (hrs)
1	147.83	4223576.731
2	89.31	19154369.07
3	48.501	119595830.8
4	18.39	343015331.3
5	0.5566	0.1237169239*10 ¹⁴

Table 7: 3rd iteration

Bearing no.	Equivalent dynamic Load on each bearing (kgf)	Life of bearing (hrs)
1	149.53	4081155.282
2	86.176	21321076.29
3	46.251	137912851.4
4	17.9591	368302793.7
5	0.1873×10^{-1}	$0.3246724118 \times 10^{18}$

Table 8: 4th iteration

Bearing no.	Equivalent dynamic Load on each bearing (kgf)	Life of bearing (hrs)
1	150.71	3986042.361
2	85.14	22108902.36
3	45.74	142586903.7
4	17.986	366652754.5
5	0.20899×10^{-1}	$0.2337126401 \times 10^{18}$

VI. CONCLUSION

The programming approach described above, together with the concept of very rapid calculation of stiffness (both radial and axial stiffness), deflection and life of complicated spindles with the number of steps on it multiple bearings. These spindles are statically indeterminate and hence the approach has many advantages. Comparisons with far more complex computer program this program show excellent agreement. It is thus possible to perform parameter optimization in a very short time and this is proving to be very attractive to designers who need to be able to operate interactively and also doesn't need more knowledge of ANSYS. The developed program also gives the same as classical approach.

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