



## Design and Analysis of Machine Tool Spindle for Special Purpose Machines (SPM) and Standardizing the Design Using Autodesk Inventor (I-Logic)

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### ABSTRACT

The work focuses on designing a machine tool spindle for SPM to carry out Face-milling operation on the given work-piece. The machine tool spindle is one of the major mechanical components in any machining center. The main structural properties of the spindle generally depend on the dimensions of the shaft, motor, tool holder, bearings and the design configuration of the overall spindle assembly. The bearing arrangements are defined by the type of operation, the cutting forces acting and the life of bearings. The forces which are affecting the machine tool spindle during machining are Tangential force ( $F_z$ ), Axial force ( $F_x$ ), radial force ( $F_y$ ) will be estimated. Based on maximum cutting force incurred the analysis will be carried out. Design calculations are performed for bearing and spindle shaft using Analytical approach for determination of bearing life and the rigidity of the spindle shaft respectively. The spindle is then modeled using Autodesk Inventor modeling software. Finite Element method is used on Spindle shaft, critical and structural components to determine total deformation and von-Mises stress in the components. In Finite Element Method, Static structural analysis is performed to determine stress and total deformation in the components. Validation of the result is obtained by comparing of Analytical result with Finite Element Analysis using ANSYS.

Here, in this project we use iLogic, a program in Autodesk inventor to design the different sizes of machine tool spindle as per the requirement at a faster rate. iLogic permits rules-driven design, which provides a simple way to obtain and reuse your work. Use of iLogic helps in standardization and automation of the design processes and configures virtual products. It also supports design optimization.

**Keywords** – iLogic, von-Mises Stress, FEA, Tangential, Milling Operation.

### 1. INTRODUCTION

Special purpose machines (SPM) are designed to perform special machining operations or testing of components, as per the requirements. Examples include milling machines, boring machines, broaching machines, lapping and honing machines, test rig for fuel injection pump calibration, profile checking equipment for camshafts, axial play testing for gear box testing auto electric test rig for motors and alternators, nozzle testers and so on.

The SPM's are developed by Bosch Limited and is being supplied to various renowned customers depending on their requirements. The SPM's consists of base, drive systems, mechanism, slides, machine tool spindle and so on. They are manufactured to carryout special particular tasks like mass production, super finishing operations, testing rigs, inspection benches and so on with at most accurately.

#### 1.1 Background

In a milling machine the cutter having one or more cutting teeth is mounted on the spindle shaft, which rotates at different speeds and machines the workpiece held on the machine table. Thus, the spindle speed, the direction of rotation of the cutter, the depth of cut and the table feed becomes the key parameters of the milling process. Thus good results of machining a workpiece can only be achieved in the milling process with a well-balanced setting of these parameters.

Among all the component of a machine tool, the spindle system is the most important critical part, since its dynamic properties directly affects the cutting ability of the whole machine tool. Spindle is the major key

component of all the machine tools. The productivity and the finish quality of the workpiece directly depend on the structural properties of the spindle. The dimension of the shaft, bearings, tool holder and the overall spindle assembly plays a crucial role in the structural properties of the spindle.

A Precision machine tool spindle that will be used must be designed to provide the required performance features. The important performance features include:

1. Achieving the desired Spindle Power, highest and Continuous.
2. Capable of withstanding the Maximum Spindle load both axial and radial.
3. Reaching the Maximum Spindle Speed Allowed.
4. Tooling Style, Size and Capacity for Automatic Tool Changer.
5. Belt Driven or Integral Motor-Spindle Design.

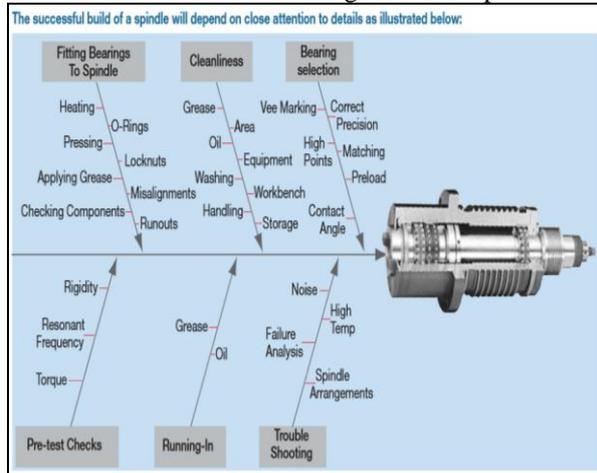


Fig 1: Parameters Effecting the Successful Build of a Spindle

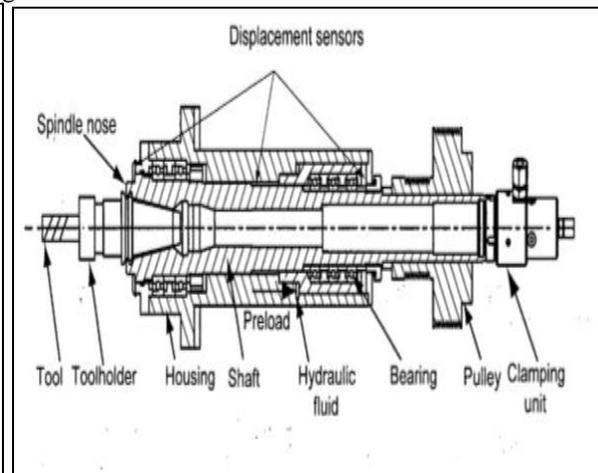


Fig 2: A Spindle System.

Although these standards may seem evident, for the spindle designer to design they represent a broad range of needs that are rather demanding to meet and improve in one design. As we will determine, many of these conditions are inconsistent to one another, and in due course a compromise must be selected to achieve the best design. Earlier the spindle researches were concentrated mainly on static and quasi-static analysis, However the current research is been extended to optimize the design by utilizing the dynamic analysis. The spindles are generally designed based on the accumulated experience, the metal cutting mechanics, and the basic laws of machine design.

## 2. CALCULATION

Bearing life is the number of revolutions which one of the bearing rings makes relative to other ring before evidence of fatigue develops in either ring or any of the rolling elements.

Basic rating life ( $L_{10}$ ) is the life of an individual rolling bearing or a group of apparently identical rolling bearings operating under the same conditions associated with 90% reliability.

### 2.1 Basic Rating Life ( $L_{10}$ ) Calculation

The basic rating life ( $L_{10}$ ) of each bearing;

$$L_{10(1)} = \frac{16667}{n} * \left( \frac{C_r}{P_{r1}} \right)^3 \quad (1)$$

$$L_{10(2)} = \frac{16667}{n} * \left( \frac{C_r}{P_{r2}} \right)^3 \quad (2)$$

$$L_{10 \text{ for the unit}} = \frac{1}{\left( \frac{2}{L_{10(1)}^{1/3}} + \frac{2}{L_{10(2)}^{1/3}} \right)^3} \quad (3)$$

## 2.2 Spindle Design and Rigidity calculation.

The spindle of machine tools is an important element in influencing the accuracy of the machining and the productivity of machine tools. The running accuracy of the spindle is directly influenced by the elastic deformation of the spindle, its housing, bearings and other components of the system. Their critical properties, such as rigidity, are governed by the type, arrangement, preload, placement, etc., of the bearings. The overhang distance from the front bearing and the optimum bearing span will have a greater influence on the stiffness of the spindle. The maximum acceptable deformation of the spindle shaft will be considered w.r.t the required accuracy of the workpiece which is  $\pm 0.05\text{mm}$  in our project requirement.

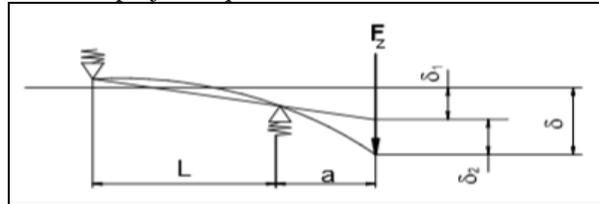


Fig 3: Deflectoion of the Spindle Nose.

The deflection of the spindle node “ $\delta$ ” for an unloaded spindle due to load  $F_z$  is given by:

$$\delta = \delta_1 + \delta_2$$

$$\delta = F_z \left[ \frac{1}{S_A} \left( \frac{a+L}{L} \right)^2 + \frac{1}{S_B} \left( \frac{a}{L} \right)^2 + \frac{a^2}{3E} \left( \frac{L}{I_L} + \frac{a}{I_a} \right) \right] \quad (4)$$

Where,

$\delta_1$ = Deflection due to radial yielding of the bearing in mm,

$\delta_2$ = Deflection due to elastic bending of the spindle in mm,

$a$ = length of the overhang in mm,

$L$ =bearing span in mm (Varying),

$E$ = Young's modulus of spindle material in  $\text{N/mm}^2$ ,

$P$ = Cutting force in N,

$S_A$ =Stifness of the front bearing in N/mm,

$S_B$ =Stifness of the rear bearing in N/mm,

$I_L$ =Mass Moment of inertia of the shaft at the bearing span in  $\text{mm}^4$ ,

$I_a$ =Mass Moment of inertia of the shaft at the overhang in  $\text{mm}^4$ ,

Calculation to find Optimum Bearing Span length is given by;

$$L_0 = \left( 6EI_L \left( \frac{1}{S_A} + \frac{1}{S_B} \right) + \left( \frac{6EI_a}{aS_A} \right) Q \right)^{\frac{1}{3}} \quad (5)$$

Spindle is designed on the following basis:

- Accuracy and the rigidity required.
- Critical speed vs. maximum speed of operation.
- Torsional, bending & buckling strength are rarely checked because the dimensions come due to above criteria have enough strength.

We have selected BT-30 as spindle taper. The spindle shaft is conceptualized and designed taking into consideration the spindle rigidity, and stiffness to withstand the load acting on it during machining operation. We have used front bearing as 7210X2TAU with light preload & rear bearing as 7210X2TAU & arrangement of 2TB. The values of axial stiffness of the bearing can be found and can be used to calculate the radial stiffness of the bearing selected by using the following approximations:

$$\begin{aligned} \text{Radial stiffness} &= 5 \times \text{axial stiffness for } 15^\circ \text{ contact angle.} \\ &= 2 \times \text{axial stiffness for } 25^\circ \text{ contact angle.} \end{aligned}$$

## 3. GEOMETRY AND FE MODELING

Now the design requirements for the spindle is calculated to the required specifications w.r.t the design standard values of the each parameters, the next process is to create the geometric model of the machine tool spindle. Here in this project we use the Autodesk Inventor professional 2012 software to create the geometric model of the milling machine tool spindle.

Geometric modeling is a branch of applied mathematics and computational geometry that discusses the mathematical methods behind modeling the realistic objects for computer graphics and computer aided design. Geometric modeling of components of the machine tool spindle is carried out using Autodesk Inventor professional 2012 software. The software helps in geometric modeling of critical components and structural

assemblies. Components that are classified as Critical components in the machine tool spindle are Spindle shaft, bearings, spacers, Tenons, front cover, front arrester, rear cover, rear arrester, labyrinth cover, spindle housing, screw nut, screws.

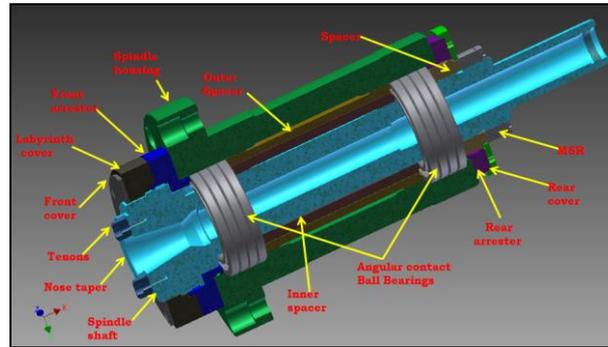


Fig 4: Assembly Drawing of the Spindle.

The above figure illustrates the assembly drawing of the milling machine tool spindle. The geometric models were prepared using the Autodesk Inventor software. Each part was created individually according to the calculated dimensions and their standard specifications. The standard parts such as screws, bearings are got from the library in-built in the software. The spindle shaft is modeled considering the standard specifications provided by the spindle manufacturers. Further static analysis is carried out on the critical components as, spindle shaft, Tenons, and spacer to predict the resulting deformations and stresses present in the elements.

### 3.1 Material Properties

Material properties of the Spindle shaft is illustrated in the below table. The material used to manufacture the spindle shaft is Structural steel- EN207, and is case hardened.

Sl. No.	Property	Magnitude	Unit
1	Modulus of Elasticity	$2.1 \times 10^5$	(N/mm <sup>2</sup> )
2	Poisson's ratio	0.3	
3	Density	7850	(kg/m <sup>3</sup> )
4	Tensile strength (Yield)	250	(N/mm <sup>2</sup> )
5	Ultimate tensile strength	410	(N/mm <sup>2</sup> )

Table 1: Material Properties of the Spindle Shaft.

### 3.2 FE Modeling

Meshing of the model is generated to approximate the geometry and reduces the degree of freedom from infinite to finite. This meshing process is vital in the finite element analysis as the quality of the results generated directly depends on the quality of the mesh. At the same time the computation time will be affected depending on the number of elements (number of nodes).

#### 3.2.1 Finite Element Analysis of Spindle Shaft

The below fig 5 illustrates the discretized/meshed, finite element model of the spindle shaft. The 3-D mesh is created throughout the entire length of the spindle shaft.

The below fig 6 illustrates the boundary conditions applied on the spindle shaft. The spindle shaft is fixed on the bearing assembly positions and is provided with axial and radial forces of 3500N and 2500N is applied in the X & Y direction respectively. The rotational velocity of 736 rpm is also provided in the clockwise direction.

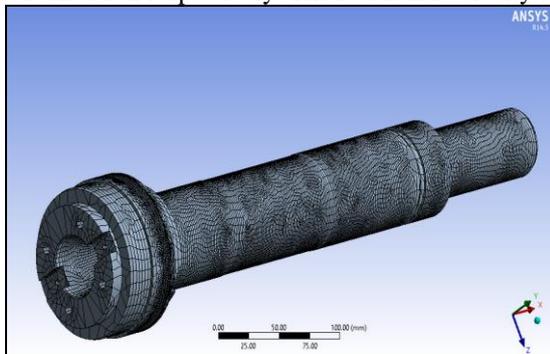


Fig 5: Discretized FEM Model of the Spindle Shaft.

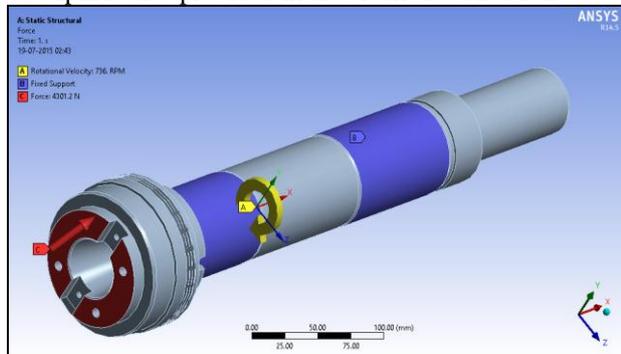


Fig 6: Boundary Conditions Applied on the Spindle Shaft.

After applying the boundary conditions consisting of force and rotational velocity, the next step is to perform the structural analysis of shaft. In this structural analysis, the main concern is with the total deformation and the stresses acting on the shaft. Equivalent (von-Mises) stress and total deformation acting on the shaft are to be determined.

The stresses acting on the spindle shaft is shown in the below fig 7. The maximum equivalent stress (von-Mises) is 16.401 MPa.

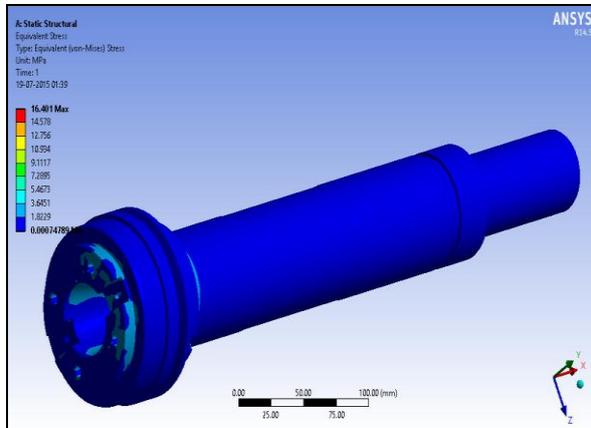


Fig 7: Equivalent (Von-Mises) Stress of the Spindle Shaft.

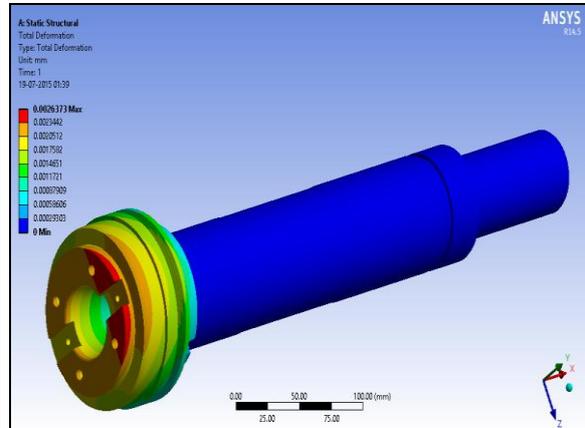


Fig 8: Total Deformation of the Spindle Shaft.

The total deformation of shaft is shown in fig 8. The deformation in the shaft is not same throughout. The portion with the maximum deformation is indicated by the color red and the portion with the minimum deformation is indicated by the blue color. The maximum deformation is 0.0026373 mm.

### 3.2.2 Finite Element Analysis of Tenons

The below fig 9 illustrates the discretized/meshed, finite element model of the Tenons along with the spindle shaft. As the Tenons are assembled on to the shaft and screwed to the face the shaft is also discretized.

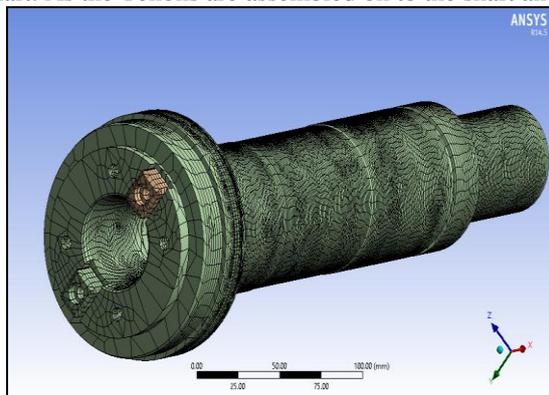


Fig 9: Discretized FEM Model of the Tenons with Spindle Shaft.

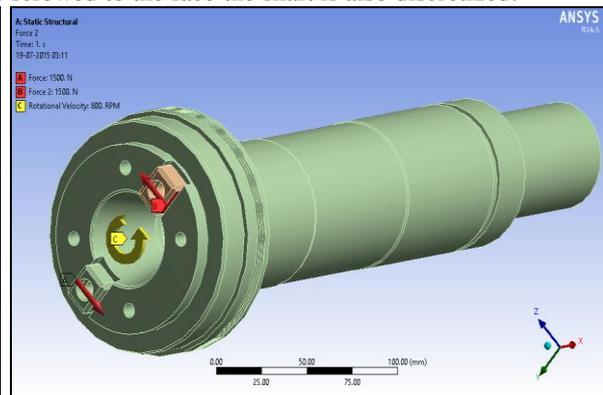


Fig 10: Boundary Conditions Applied on the Tenons.

The above fig 10 illustrates the boundary conditions applied on the Tenons. The Tenons are screwed on to the face of the shaft and are provided with radial moment force of 1500N in Y direction. The rotational velocity of 736 rpm is also provided in the clockwise direction.

After applying the boundary conditions consisting of force and rotational velocity, the next step is to perform the structural analysis for the Tenons. In this structural analysis, the main concern is with the total deformation and the stresses acting on the Tenons. Equivalent (von-Mises) stress and total deformation acting on the Tenons are to be determined.

The stresses acting on the Tenons is shown in the below fig 11. The maximum equivalent stress (von-Mises) is 19.469MPa.

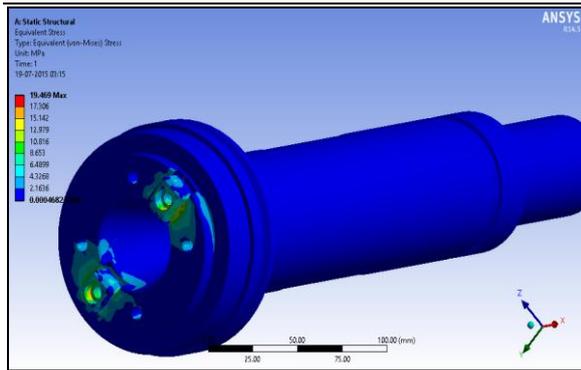


Fig 11: Total Deformation of the Tenons.

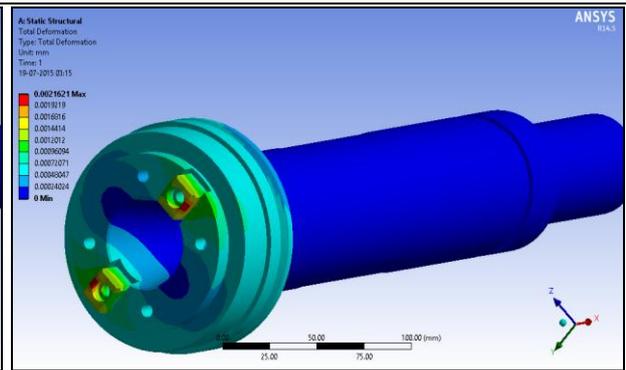


Fig 12: Total Deformation of the Tenons.

The total deformation of Tenons is shown in fig 12 and the maximum deformation found is 0.0021621mm.

## 4. I-LOGIC

### 4.1 Selection of Part:

The very first step in standardizing the design is the selection of the part to be standardized. Here in this project we have already designed the machine tool spindle for the face milling operation in an SPM. So here we are in the process of standardizing the design of the spindle to automate and optimize the design to other sizes of spindle. We will be standardizing the BT-40 size spindle and automate the spindle design of various other size spindles.

### 4.2 Defining the Total Number of Variants:

Here in this step of standardization of design we will be defining the total number of variants standardized in this project. We will be designing the spindle sizes of BT-30, BT-50 and BT-60 with reference to the standardized spindle design of the BT-40 sized spindle. The BT-30, 40, 50, & 60 indicates the self-releasing taper sizes of an milling machine tool spindle which locates and holds the cutting tool. Each taper will be of different sizes and are used to hold different sizes of cutters/tools. Now the designing of each individual spindle will be time consuming and waste of resources. In order to ease the design work and cost saving here in this project we will be standardizing the spindle design of the BT-40 sized spindle and automate the design of the spindles to the various other require sizes by writing the codes or rules using the iLogic function in Autodesk inventor software.

### 4.3 Create and Manage iLogic Parameters:

In this step we will be writing the iLogic parameters of the individual parts. Dimension and other measurements are known as iLogic parameters. In iLogic a parameter is a powerful entity that can be numerical, boolean and also textual. Inside an iLogic parameter we can store a numerical dimension value, a choice or also a textual sign. ILogic parameter is a multi-value contribution to users which provides a lot of choices. There are namely two types of parameters in iLogic, key parameters and not key parameters. A key parameter is a main parameter by which we can change the whole model behavior. A not key parameter, instead, is a secondary parameter that is less important than a key parameter because it is a driven parameter. You can also use parameters in iLogic rules, which can be used to drive changes to your model.

Each individual parts of the spindle assembly are selected and the iLogic parameter for the every individual parts are written separately. During the geometric modeling of the each individual parts of the spindle every individual features i.e., the diameters, lengths, hole, etc., will be given an individual separate names in order to avoid confusions while writing the iLogic parameters for the parts. Later the iLogic parameters are created for the each individual part for all the variants i.e., BT-30, BT-40, BT-50, & BT-60 spindles.

The below Fig 13 illustrates the geometric model created with different names given to the different dimensional entities of the spindle shaft. The same procedure is carried out while creating the geometric model for the other individual parts of the BT-40 spindle.

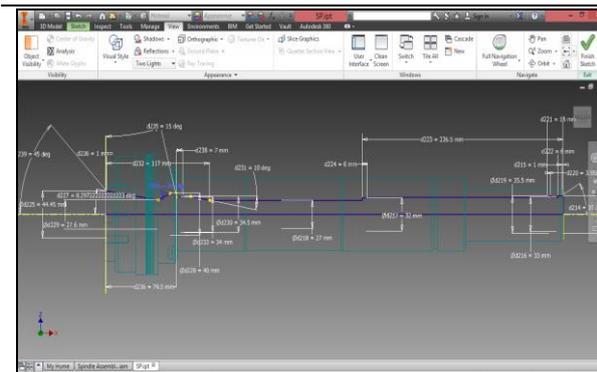


Fig 13: Wire frame of Spindle shaft.

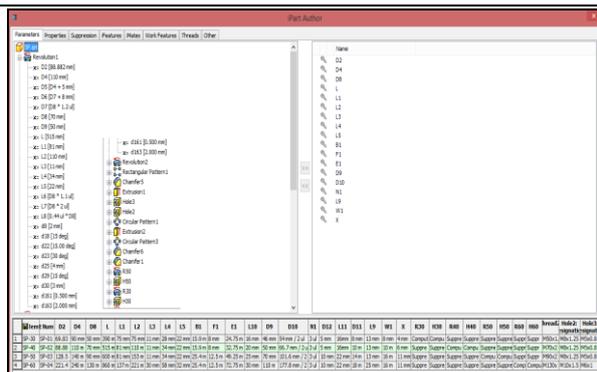


Fig 14: Creating iLogic parameters for Spindle shaft.

The above Fig 14 illustrates the iLogic parameters written for the spindle shaft. Each individual dimension entities are given the parametric values as per the standards calculated. Then the iLogic parameters are created for the other different size spindle variants in the same spreadsheet as shown below. This process is known as creating an iPart. The same process is carried out for the other individual parts of the BT-40 spindle.

#### 4.4 Assembly of the Spindle.

In this step the complete assembly of the spindle is done. The each individual parts of the spindle created are saved in a single project folder; this will help in ease of final assembly of the spindle. The BT-40 spindle is assembled with all the required parts of the spindle as per the specifications. Ensure that all the related files of the project including the iParts created are saved in a single project folder.

#### 4.5 Creating the iLogic Rules:

The final step in the iLogic is to create write the rules for the spindle assembly. The rules are the most important object in iLogic. They contain all the logical code and allow you to change the behaviour of whole document. It is based on Visual Basic.Net language, an object-oriented computer programming language which is implemented on the .Net Framework. In iLogic the rules can namely be of two types, Internal and External:

- Internal rules are those which are embedded inside the file. These rules belong to model and when we copy this file we receive the geometry but also the logical content namely rules. Basically an internal rule can be used to manage specific objects like parameters, features and also iProperties.
- External rules, instead, are the general rules. Basically they are useful to manage general features particular iProperty that is in all files. This kind of rules allows you to create a logical framework shared to all files. iProperties are used to track and manage files, create reports, and automatically update assembly bills of materials, drawing parts lists, title blocks, and other information pieces.

#### 4.6 Writing Rules in iLogic:

There are some basic statements used while writing the rules in iLogic. The statements are generally used for specified purposes.

The If-Then statement is used when you need to perform an action or a set of actions only when certain criteria or conditions are met. In case the condition is not met, no action is to be performed.

The If-Then-Else statement is used when you need to perform an action or a set of actions when a certain criteria or conditions are met and another set of actions in case that particular criteria/conditions are not met.

The 'if-Then-ElseIf' or the extended block 'if' statement allows you to insert an additional condition between the 'if' and the 'Else' parts of the code. The keyword to be used is 'ElseIf'.

The rules are written for the individual spindle assembly design as shown in the below figures. While creating the rules the iLogic parameters entered to create the iPart are named in the individual spindle assembly and are recalled as per the requirements of the spindle assemblies. In the rule line "Component. Replace iPart" command it clearly explains that the specified component must be replaced in this spindle assembly. And the True command stands for acceptance of the change. The below Figures illustrate the iLogic rules written for the different spindle variants of the project.

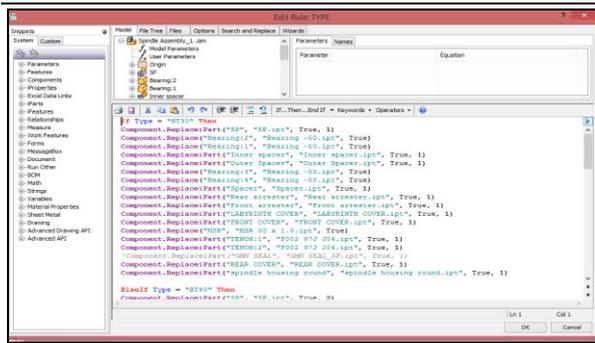


Fig 15: iLogic Rules for BT-30 Spindle assembly.

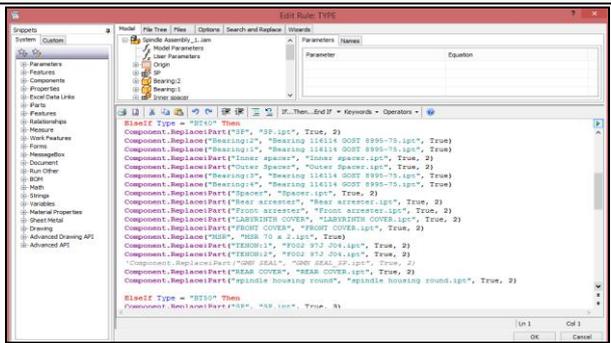


Fig 16: iLogic Rules for BT-40 Spindle Assembly.

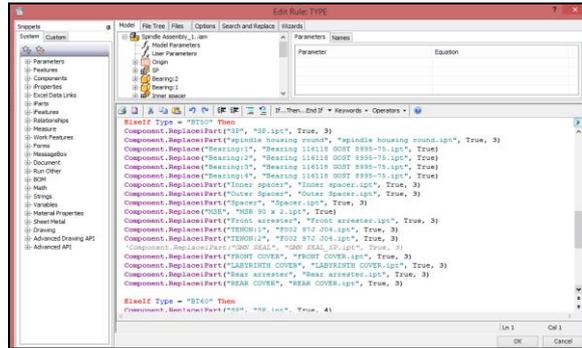


Fig 17: iLogic Rules for BT-50 Spindle Assembly.

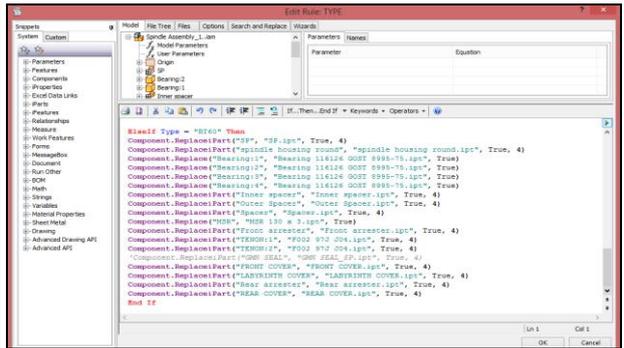


Fig 18: iLogic Rules for BT-60 Spindle Assembly.

#### 4.7 Running the iLogic Rules:

The final step in the standardization of the design using the iLogic is to run the written iLogic rules for the different variants of the spindle in the project. To run an iLogic rule we should open the iLogic browser window and then select the 'Forms' tab. Then later we should click on the 'Form 1' button and select the required spindle assembly i.e., BT-30, BT-40, BT-50, & BT-60. Now we can get the required spindle assemblies at just one click without any redesign or re-creating the geometric model for every different sizes of spindle.

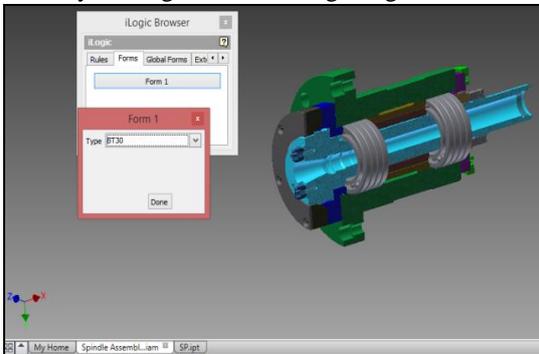


Fig 19: Assembly of BT-30 Spindle

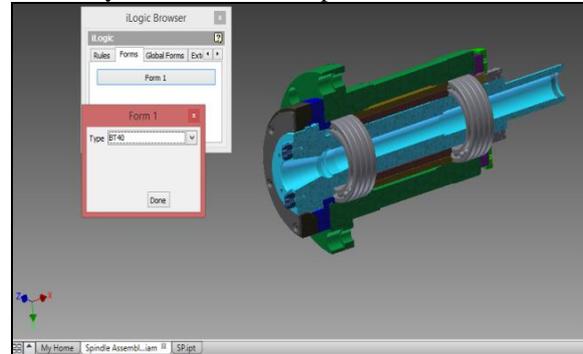


Fig 20: Assembly of BT-40 Spindle.

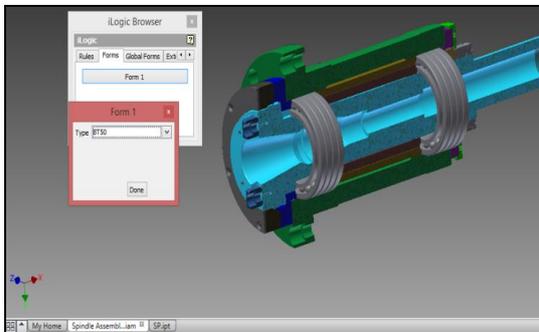


Fig 21: Assembly of BT-50 Spindle.

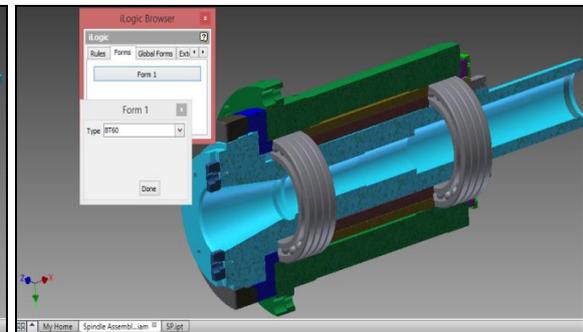


Fig 22: Assembly of BT-60 Spindle.

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## 5. RESULTS AND DISCUSSIONS

The design calculations are performed for the Machine tool spindle of the SPM for the Face milling application. The design calculations included the Power and Force requirements for machining, Bearing selection and bearing life calculation and the Spindle rigidity calculation for the required spindle design. Simultaneously, Finite Element Analysis was also done to critical components to find the resulting von-Mises stresses and total deformation. The analytical approach results are compared with Finite element analysis for validation of results for critical components the spindle shaft.

➤ The Power and force calculation for machining were performed with reference to the standard formulas provided in the Machine tool design handbook of CMTI, Bangalore. The forces calculated which effect on the machine tool spindle during the cutting operation:

Forces	Magnitude	Unit
Tangential cutting force (Pz)	7598.38	N
Axial cutting force (Px)	3799.19	N
Radial cutting force (Py)	2532.76	N

Table 3: Cutting Forces Acting During Machining.

The calculated forces are very much essential in the further design calculations of Spindle for bearing selection and to design the spindle for the best possible rigidity to perform well as per the requirement.

➤ Now the next step is the selection of bearing and its arrangement. During bearing selection we have to consider the spindle BT taper size also as it would affect the spindle shaft size and also the rigidity of the shaft. Here we use BT-30 size spindle arbor for the Ø80mm cutter. With reference, the spindle shaft major diameter is finalized and the bearing is selected with reference to the manufacturer's catalogue depending on the Static and dynamic loading conditions of the spindle. Here we use the RHP bearings for the spindle and with reference to the RHP bearing catalogue we select the bearing 'RHP 7210 X2TAU' a Light pre-loaded angular contact ball bearing with the specification of Outer diameter =90mm, Inner dia =50mm, thickness = 20mm, and contact angle  $\alpha = 15^\circ$ .

Now the bearing life is calculated using the standard formulas 1, 2 & 3

The total number of hours the selected bearing can run = 52228.91hrs.

The total number of years the bearing will serve if the machine run for 24 hours a day i.e., all the 3 shifts in a day = 5.9622years.

The bearing life results got are good as per the standard values provided in the CMTI design hand book which says 'The required life of a bearing / life expectancy of bearing used in the machine tool working continuously all the 24 hours of the day is between 50,000 to 60,000 hours. So the bearing selected holds good for our requirement.

➤ We have selected BT-30 as spindle taper. The spindle shaft is conceptualized and designed taking into consideration the spindle rigidity, and stiffness to withstand the load acting on it during machining operation. We have used front bearing as 7210X2TAU with light preload & rear bearing as 7210X2TAU & arrangement of 2TB. The spindle rigidity is the main important concern in the spindle design process. The required accuracy of the machine is directly influential on the resulting spindle rigidity. The accuracy of the work piece required is in between the tolerance of  $\pm 0.05$ mm. The spindle Total deflection and spindle stiffness is calculated using the formula 4 & 5 which is given above.

The total deflection of the spindle shaft = 0.00273996mm

The stiffness of the spindle shaft (P/δ) = 1342.64 N/μm

The total deflection of the spindle shaft is 0.00273996mm which is well below the required accuracy of the machine. So the design of the spindle shaft satisfies the required criteria to with stand the loads acting and provide the necessary accuracy in machining.

➤ These results are validated by comparing the results obtained in the Analytical method with the Finite element method. The geometric model of the spindle is created using the Autodesk Inventor Professional 2012 software. Then later the Finite element Analysis of the spindle shaft is done using the ANSYS software. The von-Mises stress and total deformation for components like Spindle shaft, Tenons, and spacer are solved using the Finite Element method. Analytical method is difficult to implement due to the geometry complexity of the components. So to solve the geometry complexity model the FEM analysis gives the clear deformation and stresses acting on the critical parts.

The maximum equivalent stress (von-Mises) is = 16.401Mpa and the maximum deformation is = 0.0026373mm.

Component	Analytical method	Finite element method		
		Stiffness, N/ $\mu$ m	Deflection at spindle nose, mm	Stiffness, N/ $\mu$ m
BT-30	0.00273996	1342.64	0.0026373	1394.41

Table 4: Comparison of Deflection and Stiffness by Analytical and FE Methods.

The Analysis of rigidity was carried out using ANSYS and there is a good correlation between the results obtained by theoretical calculation and ANSYS. So the design of spindle holds good and after the completion of Design and analysis of the components, the Machine tool spindle is manufactured.

Component	Finite Element Analysis	
	Total deformation, mm	Von-Mises Stress, MPa
Tenons	0.0021621	19.469
Inner spacer	$1.5776 \times 10^{-5}$	0.26763

Table 5: FEA Results of the Tenons and Inner Spacer.

➤ The Standardization of the machine tool spindle design was carried out using the Autodesk Inventor iLogic function. This iLogic function helps to standardization and automation of the design processes and configures virtual products. The design of the BT-40 spindle was standardized and with reference to that iLogic rules were written to automate the design of the BT-30, BT-50 and BT-60 size spindles. The design automation in iLogic helps to generate any required model immediately of the above variants with just a click of a command. The design automation helps in time saving, reduces wastage of man power, cost saving, and improves utilization of useful resources.

## 6. CONCLUSION

The aim of the project was to design the Machine tool Spindle for a Face milling SPM. The work involved calculation for power and forces of machining, bearing selection and spindle stiffness calculation. The spindle designed was BT-30 size machine tool spindle. The bearing life and the spindle rigidity were calculated and the results obtained were excellent and satisfy the standard rules of the design. The geometric modelling of components was done using Autodesk Inventor Professional software.

Static structural analysis was performed by applying the loads and boundary conditions on the components using ANSYS Workbench. Total deformation and Von-Mises stresses are obtained by performing the analysis. The results obtained by the Analytical design calculations are compared and validated with the results obtained by Finite Element Method. The comparison of results is in close variations done for critical components like shafts which are acceptable.

The design standardization and automation for the spindle was carried out using the Autodesk Inventor iLogic function, which helped to generate the automated model for the BT-30, BT-40, BT-50 and BT-60 size spindles.

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