DESIGN AND ANALYSIS OF MACHINE TOOL BED

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ABSTRACT: —Lathe bed acts as the base on which the different fixed and movable parts of the Lathe are mounted. Lathe beds are usually manufactured with Cast iron or Mild steel. In case of extremely large machines, the bed may be in two or more pieces, bolted together to from the desired length. Lathe Bed is heavy rigid structure which is having high damping capacity for the vibrations generated by machines during machining.

In this project, static structural and modal analysis is carried out on lathe bed at maximum load conditions. These simulation results are used to reduce the weight of the lathe bed without deteriorating its structural strength and damping capacity by adding ribs and removing mass where less deformation and stresses are induced. FEA analysis of modified lathe bed is carried out with Gray cast iron and Epoxy-granite which is a mixture of granite and epoxy resin hardener as an alternative material. Effectiveness of both materials is compared in terms of induced stresses, deformation and weight reduction. Lathe bed CAD models have been generated with SOLID WORKS modeling software. The FE model has been generated by ANSYS 14.0. The analysis is carried out using ANSYS. The results are shown in the form of contour plots and also tabulated, to analyze the effect of weight reduction on the structural integrity of the machine bed before and after the weight reduction and conclusions are drawn about the optimized design.

Keywords — Weight optimization, Lathe bed, FE Analysis, Cast Iron.

INTRODUCTION:

Iron and its alloys are widely used in almost all industry and their products reach almost every household. Mixing iron with different elements is varying proportions results in alloys with different properties. Each element added to iron gives it some special characteristic. Grey cast iron, so-called because of its fracture face, has some unique properties due to its composition. The most widely used cast iron; it is brittle with low tensile strength and is used in the manufacturing of engine cylinder blocks, flywheels, gears and many machine-tool bases. Lathe removes undesired material from a rotating work piece in the form of chips with the help of tool which is traversed across the work and can be fed deep in work piece. A lathe is used principally to produce cylindrical surfaces and plane surface, at right angles to the axis of rotation. A lathe basically consists of a bed to provide support, a head stock, a cross slide to traverse the tool, a tool post mounted on the cross slide. The carriage moves over the bed guide ways parallel to the work piece and the cross slide provides the transverse motion. A lathe bed is the area of the lathe that spans the distance from the headstock to the tailstock and is positioned underneath the workspace. Often referred to as the frame of the machine, the lathe bed is a very important component of the lathe and is responsible for keeping the tooling level and stable. Lathe bed is supported on broad sections columns. Its upper surface is either scrapped or ground and the guiding and sliding surfaces are provided. The bed consists of two heavy metal slides running lengthwise, with ways or V's formed upon them. Three major units mounted on bed are the head stock, the tailstock, and the carriage. Lathe bed material should have high vibration damping qualities as it is secured rigidly over cabinet leg and end leg and all other parts are fitted on it. Lathe bed being the main guiding member for accurate machining work, it should be sufficiently rigid to prevent deflection under cutting forces, should be massive with sufficient depth and width to absorb vibrations, should resist the twisting stresses set up due to resultant of two forces, should be seasoned naturally to relieve the stresses ser up during casting.

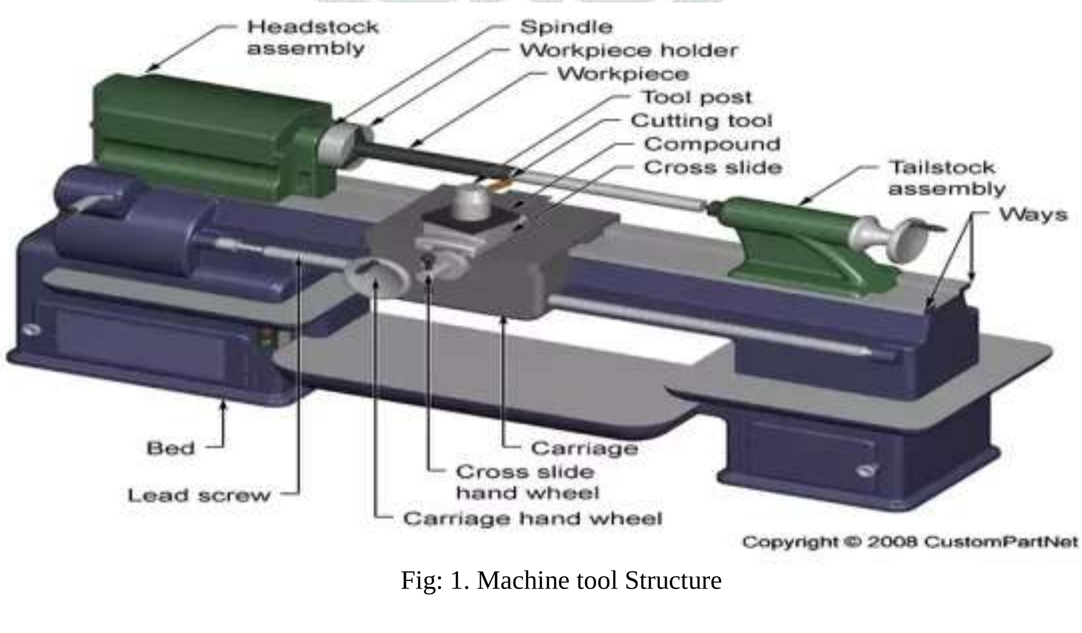


Fig: 1. Machine tool Structure

Pig iron is a semi-finished metal produced from iron ore in blast furnace, containing 92 percent iron, high amounts of carbon (typically up to 3.5 percent), and balance largely manganese and silicone plus small amounts of phosphorus, sulfur, and other impurities. Pig iron is further refined in a furnace for conversion into steel. It gets its name from the shape of trough (resembling a pig) in which it used to be cast in the 19th century. Pig iron is a byproduct of the melting process to make pure iron. The iron ore is heated using high carbon fuel coke, which results in pig iron with a very high carbon content, usually around 4 percent. During the Industrial Revolution, pig iron was widely used. Pig iron is now normally forged into wrought iron, which is a more useful material. Grey cast iron has following properties due to which it is best suitable for lathe machine bed.

High Compressive Strength:

This strength is defined by the endurance of any metal or alloy to withstand its compressive forces. Grey Cast Iron has a high compressive strength and that's why, it is widely used in posts and columns of buildings. In addition, their compressive strength can be as high as that of some Mild Steels.

Tensile Strength:

There are different varieties of Grey Cast Iron and their tensile strength varies accordingly. Some varieties show the tensile strength of 5 tons per square inch, some show 19, but on an average their strength is 7 tons per square inch. However, addition of vanadium can increase the strength of Grey Cast Iron. Grey Cast Iron is highly resistant to deformation and provides a rigid frame.

Low Melting Point

Grey Cast Iron has low melting point – 1140 ºC to 1200 ºC.

Resistance to Oxidation

Grey Cast Iron is highly resistant to rust, which is formed by the reaction of oxygen and Iron. It is a perfect solution to avoid the problem of corrosion.

Uses of Grey Cast Iron:

Class 300 Grey Iron: Can be used in producing heavy-duty machine tools, bed, presses, high pressure hydraulic parts, frame, gears, bushings, piston rings, cams, crankshaft, cylinder block, cylinder head, etc.

- **Class 200 and class 250 Grey Iron:** Can be used in producing gear, cylinder, base, bed, flywheel, cylinder liners, cylinder block, pistons, brake wheel, gear boxes, pressure valve, coupling plate, etc.

- **Class 100 and class 150 Grey Iron:** Suitable for producing cover body, protective cover, frame, hand wheels, hammer, floor, handle, box, frame, bed, bearing, pulleys, bench, pump body, pipe, valve, etc. According to IS:210-1965, grey iron casting are designated by letter FG followed by ultimate strength in Kg /mm^2 e.g., FG 15, FG 20, FG 25, FG 30 , FG 40. The basic composition of grey cast iron is described in terms of carbon equivalent which is equal to total carbon % + 1/3 (silicon % + phosphorus %). This factor gives the relationship percentage of carbon and silicon in the iron to its capacity to produce graphite.

Objectives:

The Weight reduction of the machine tool Bed can have a certain role in the general Weight reduction of the Lathe machine and is a highly desirable goal, if it can be achieved without increase in cost and decrease in quality and reliability.

1. To Design a CADD model of Machine tool Bed.

2. To analyze for the maximum possible weight reduction.

Review of Literature:

Migbar Assefa (2013) found that the performance of a machine tool is eventually assessed by its ability to produce a component of the required geometry in minimum time and at small operating cost. It is customary to base the structural design of any machine tool primarily upon the requirements of static rigidity and minimum natural frequency of vibration. The operating properties of machines like cutting speed, feed and depth of cut as well as the size of the work piece also have to be kept in mind by a machine tool structural designer. This paper presents a novel approach to the design of machine tool column for static and dynamic rigidity requirement. Model evaluation is done effectively through use of General Finite Element Analysis software ANSYS. Studies on machine tool column are used to illustrate finite element based concept evaluation technique. This paper also presents results obtained from the computations of thin walled box type columns that are subjected to torsional and bending loads in case of static analysis and also results from modal analysis. The columns analyzed are square and rectangle based tapered open column, column with cover plate, horizontal partitions and with apertures. For the analysis purpose a total of 70 columns were analyzed for bending, torsional and modal analysis. In this study it is observed that the orientation and aspect ratio of apertures have no significant effect on the static and dynamic rigidity of the machine tool structure.

Kore *et al.* (2014) investigate that the structural bionic design process is systematically presented for lightweight mechanical structures. By mimicking biological excellent structural principles, the structure of lathe bed or the stiffening ribs of a lathe bed were redesigned for better load-bearing efficiency. In this paper, a machine bed (Manufacturer: Indira Machine Tools Ltd.) is selected for the complete analysis for static loads. Then investigation is carried out to reduce the weight of the machine bed, reduce the stress induced in the lathe bed and to reduce the displacement. In this work, the 3D CAD model for the existing bed model and the optimized bed model has been created by using commercial 3D modeling software SOLID EDGE V20. The analyses were carried out using ANSYS 13. The results were discussed.

Vivek *et al.* (2016) found that the structural material in machine tool plays important role in deciding the machine tool precision. It shares a major part in dampening the vibration generated during machining. Hence, for precision machine tools, vibration damping of structural material has become an important property along with stiffness and strength for designing the structure. Recent trend in research shows that polymer composites are replacing cast iron and steel as they provide improved damping accompanied with comparable stiffness and strength. Among all the polymer composites, polymer concrete has found to be the promising material. This study presents a literature survey on polymer concrete for machine tool structural application. Cast iron, steel and other conventional materials are compared with polymer concrete. The review summarizes the research findings reported by different authors by using polymer concrete in different types of machine tool structures. Different varieties of particulate reinforcement, matrix and other fillers, reported in literatures are studied as to understand their influence on final properties of polymer concrete for machine tool structures.

Xudong *et al.* (2017) represent that Hydraulic transmission bed stand is one kind of the most commonly used in engineering machinery companies, and the bed structure is the most important part. Based on the original hydraulic transmission bed stand bed structure and the CAE technology, the original bed structure is improved. The optimized bed greatly saves the material of the production bed and improves the seismic performance of the bed. In the end, the performance of the optimized bed was compared with the original bed.

Saidaiah1 *et al.* (2017) investigate that the lathe bed acts as the base on which the different fixed and movable parts of the Lathe are mounted. Lathe beds are usually manufactured with Cast iron or Mild steel. In case of extremely large machines, the bed may be in two or more pieces, bolted together to from the desired length. Lathe Bed is heavy rigid structure which is having high damping capacity for the vibrations generated by machines during machining. In this project, static structural and modal analyses are carried out on lathe bed at maximum load conditions. These simulation results are used to reduce the weight of the lathe bed without deteriorating its structural strength and damping capacity by adding ribs and removing mass where less deformation and stresses are induced. FEA analysis of modified lathe bed is carried out with Gray cast iron and Epoxy-granite which is a mixture of granite and epoxy resin-hardener as an alternative material. Effectiveness of both materials are compared in terms of induced stresses, deformation and weight reduction. Lathe bed CAD models have been generated with Creo modeling software. The FE model has been generated by ANSYS APDL. The analyses are carried out using ANSYS APDL. The results are shown in the form of contour plots and also tabulated, to analyze the effect of weight reduction on the structural integrity of the machine bed before and after the weight reduction and conclusions are drawn about the optimized design.

METHODOLOGY:

Because design is a multidisciplinary science that researches the principles, properties and mechanisms of natural systems (structures, processes, functions, organizations and interrelations), with the aim of applying in the development of new products or solving technical problems. So it is necessary to study a systematic method to provide fundamental information, which can assist designers in searching for efficient solutions in nature.

Structural bionic is a creative alternative for mechanical design to learn from natural perfect and efficient structures. Based on the successful bionic designs, the method of structural bionic design can be summarized as shown in Figure 1. The design process is divided in three stages:

Requirements Identification:

Many structural bionic designs come from designers' inspiration. Then the natural structural characteristics can be mimicked, for example lotus effect and self-cleaning surface. And technical requirements for improvement can also excite natural structures research. When the bionic requirements are identified, analogous structures must be selected for function and **Structure analysis.**

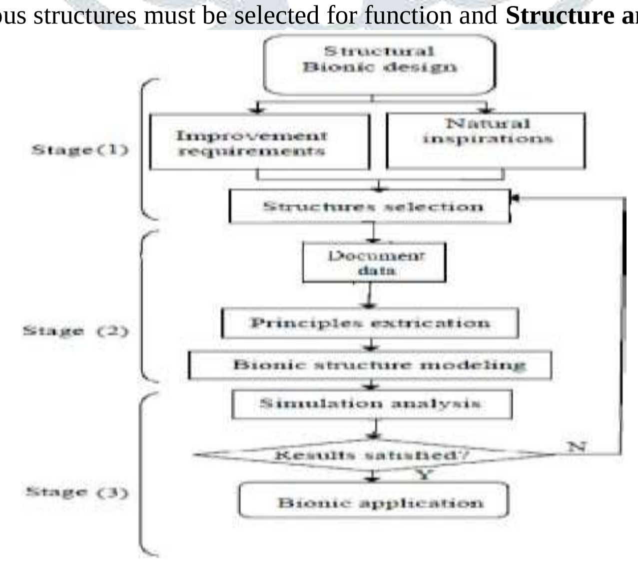


Fig: 2. Layout of Methodology

FEM Analysis: Published articles and other documents will assist designer to learn basic principles of biological structures. But experiments are necessary for detailed observation and investigation. Then the principles can be extracted and mathematical models can be established. The modeling and FEM simulation can verify the effectiveness of structures. If the results are not satisfied, new biological structures must be used.
Experiments Verification: If the simulation results are satisfied, bionic models should be fabricated for structural experiments. After the bionic effectiveness is validated, those biological structures can be used for practical application. Otherwise, another design procedure should be carried out, until the most reasonable structure is found. And bionic principles can be concluded.

Structural bionic design is one creative method by mimicking biological structural principles. The design flowchart is reliable and effective. FEM simulation and experiments verification can be used for practical application. The natural lightweight, hollow and sandwich structures can contribute to updating conventional distribution of stiffening ribs.
Structural parameters need further optimization, which may achieve higher specific stiffness.

FORCE APPLIED ON LATHE BED

To design a lathe bed, initially we have to analyse, the stresses and deformations inducing in lathe bed due to cutting forces generated by cutting tool and work piece interaction. The design of lathe bed is preceded by analysis of forces that are acting on the system due to tool work piece interaction. In current analysis we considered the maximum torque which is supplied by electric motor of lathe machine. Cutting forces will be transferred to lathe bed at carriage region. So we applied force at carriage region (while in machining process, carriage slides over lathe bed. We simplified analysis by fixing its location. We considered its location near to the head stock because in most manufacturing cases we don't slide carriage beyond middle portion lathe bed) as shown in fig.
The following forces are applied on lathe bed.

1. Maximum torque which can be generated by prime mover is converted into force and applied on carriage region. as shown in calculation.
2. Weight Of Head Stock - 246 – 105.8 = 140.2 kg / 1375 N (Carriage and tailstock weights are not subtracted due to unavailability of individual weights. It does not affect FEA results because we are not reducing loads and as compared to lathe bed weight these weight are very less in magnitude)
3. Self weight of the lathe bed due to gravitational force.
4. Maximum Weight between Centres - 36.2 kg / 355 N. This force is divided into 2 equal parts (i.e., 177.5 N). This force is applied on headstock and tailstock.

Spindle bore (Diameter)	34.5 mm (r =17.25 mm)
Spindle speed range	55 - 2200 rpm (N)
Electric motor	2 Hp or 1.5 kW (P)

Technical specifications of lathe machine

$$P = \frac{2\times\pi\times N\times T}{60}$$

$$1500 = (2 \times \pi \times 55 \times T) / 60$$

$$T = 260.33 \text{ N-m}$$

$$T = F \times r$$

$$260.33 = F \times 0.01725$$

$$F = 15092 \text{ N}$$

This force applied at region of carriage for simulating actual locations from where cutting forces transferred to lathe bed. Since number of nodes are 700 at this region, hence force is divided into 700 parts (21.6 N). The forces applied as shown in below figure.

MODELING OF LATHE BED:
Before redesigning, the existing bed is created by part modeling and subjected to static analysis. In this project the existing bed is taken from the manufacturer by company name INDIRA MACHINE TOOLS. The major dimensions of the machine bed are as follows: Length = 1540 mm (in Y-direction), Width = 246 mm (in X-direction), Height = 242 mm (in Z-direction) (total height).

Fig: 3. Model of machine tool bed

Meshing: Meshing of solid model is done by the Element chosen, element edge length have been adjusted to 0.02 m in order to obtain a regular uniform mesh. Automatic sizing creates elements of wide range of dimensions. Therefore manual sizing is done.

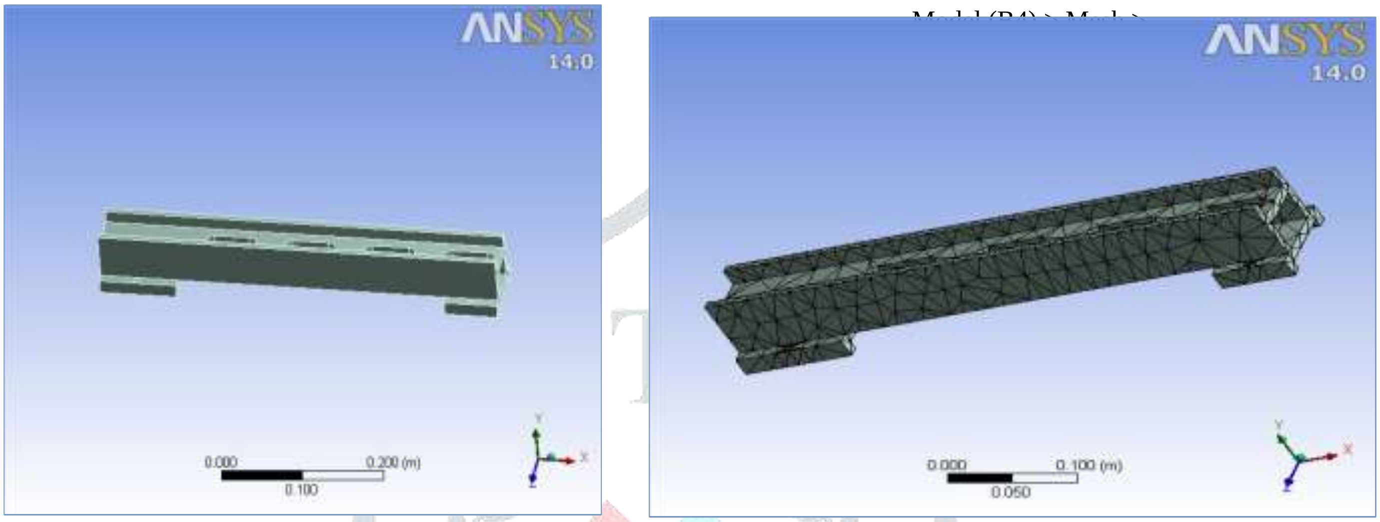


Fig: 4. Meshing of Existing Model

BOUNDARY CONDITIONS:

1. The base of the lathe machine bed is fixed to the floor. Therefore base of lathe bed is Constrained in all directions (UX=UY=UZ=0).

2. Gravitational force is applied, to add stress distribution and deformation due to self weight. Below figure shows the boundary conditions applied on the FE model.

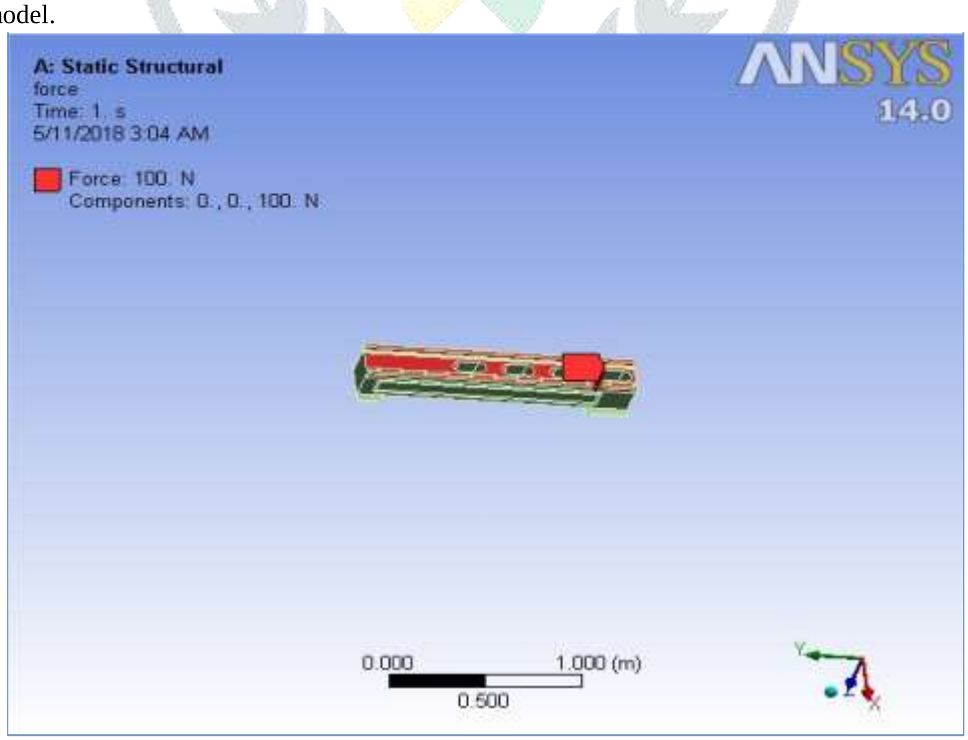


Fig: 5. Fixed boundary conditions and gravitational force applied on lathe bed

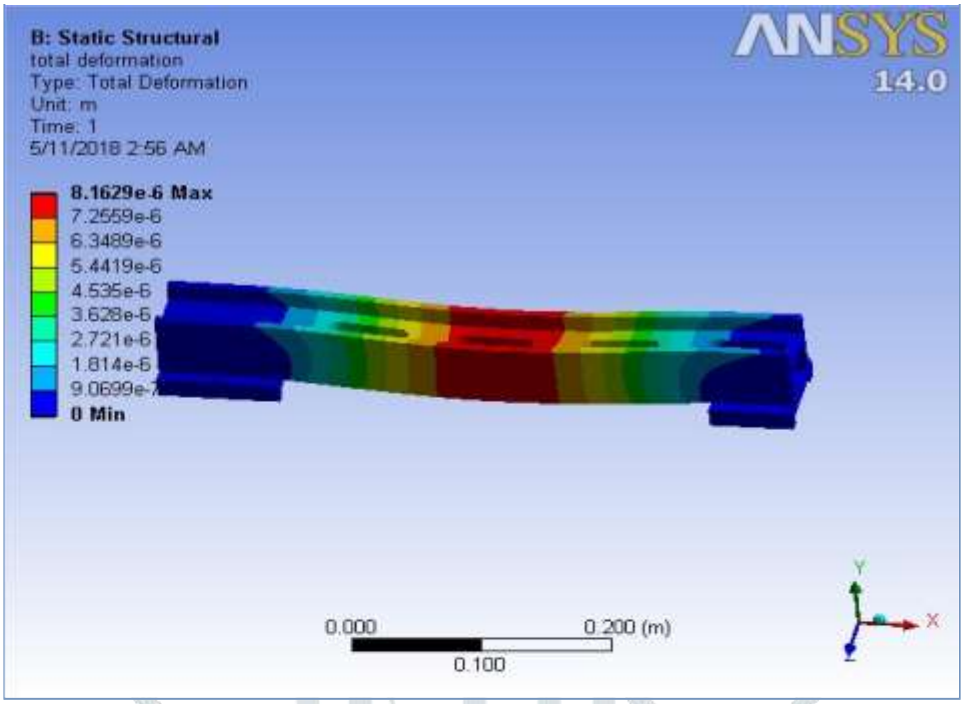


Figure 6: Total Deformation of Lathe Machine Bed of Cast Iron

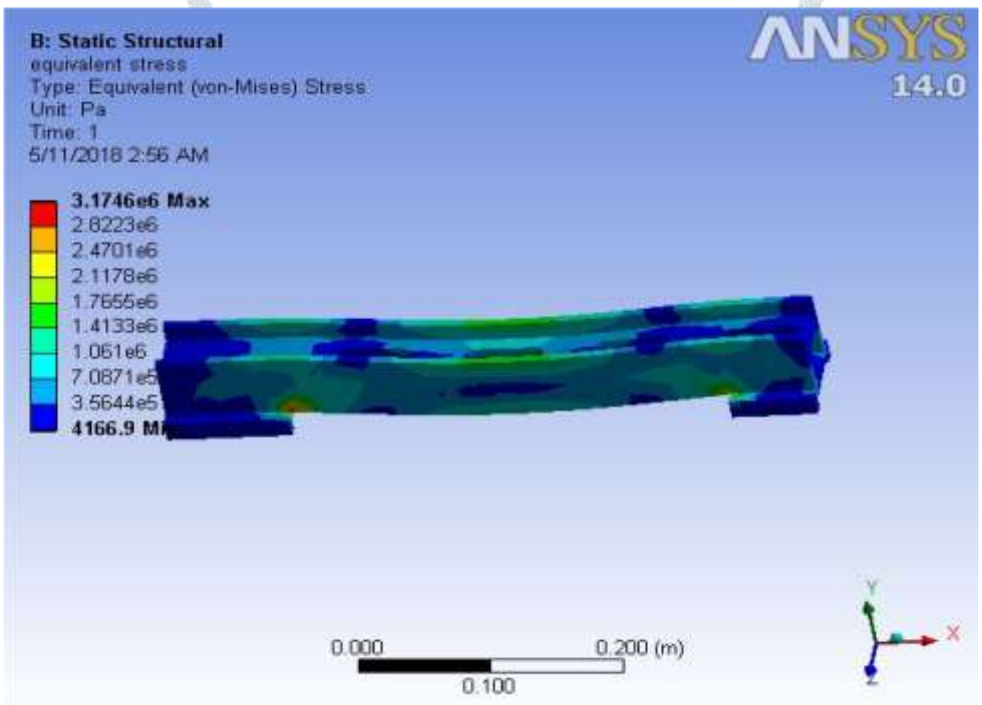


Fig 7: Von misses Stress of Lathe Machine Bed of Cast Iron

FINITE ELEMENT ANALYSIS

Introduction

Finite Element Analysis (FEA) is a computer-based numerical technique for calculating the strength and behavior of engineering structures. It can be used to calculate deflection, stress, vibration, buckling behavior and many other phenomena. It also can be used to analyze either small or large scale deflection under loading or applied displacement. It uses a numerical technique called the finite element method (FEM). In finite element method, the actual continuum is represented by the finite elements. These elements are considered to be joined at specified joints called nodes or nodal points. As the actual variation of the field variable (like displacement, temperature and pressure or velocity) inside the continuum is not known, the variation of the field variable inside a finite element is approximated by a simple function. The approximating functions are also called as interpolation models and are defined in terms of field variable at the nodes. When the equilibrium equations for the whole continuum are known, the unknowns will be the nodal values of the field variable. In this project finite element analysis was carried out using the FEA software ANSYS. The primary unknowns in this structural analysis are displacements and other quantities, such as strains, stresses, and reaction forces, are then derived from the nodal displacements.

Modeling Linear Layered Shells

SHELL99 may be used for layered applications of a structural shell model as shown in Fig 3.14. SHELL99 allows up to 250 layers. The element has six degrees of freedom at each node: translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z-axes.

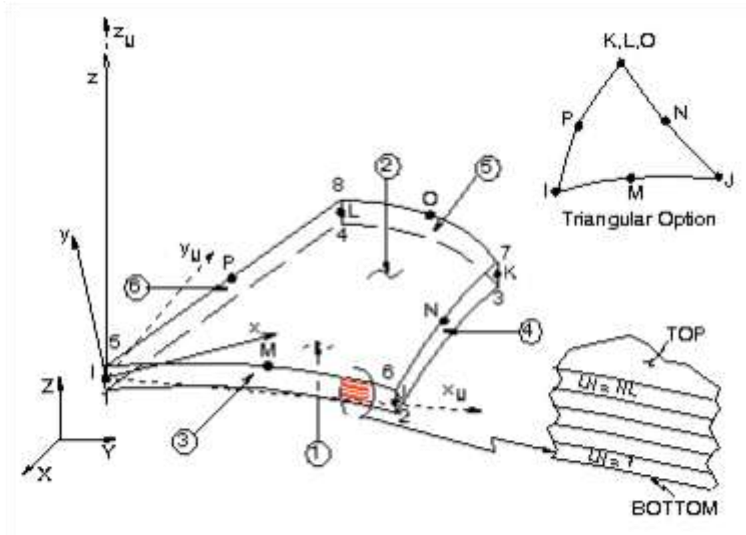


Fig: 3.14: SHELL99 Linear Layered Structural Shell

The finite element analysis is a numerical technique for finding approximate solutions of partial differential equations as well as of integral equations. The solution approach is based on either eliminating the differential equation completely (steady state problems) or rendering the partial differential equation into an approximating system of ordinary differential equations, which are then numerically integrated using standard techniques such as Euler's method, Runge-Kutta method etc., In the finite element method, a structure is broken down into many small simple blocks or elements. The behavior of an individual element can be described with a relatively simple set of equations. Just as the set of elements would be joined together to build the whole structure, the equations describing the behaviors of the individual elements are joined into an extremely large set of equations that describe the behavior of the whole structure. The commercial FEA software ANASYS 14.0 was used to model the entire of the composite drive shaft. The 3-D model was developed and a typical meshing was generated by using Shell 99 element.

The following steps summarize the general procedure for finite element analysis.

Step 1:

The continuum is a physical body, structure or solid being analyzed. Discretization may be simply described as process by which the given body is subdivided into equivalent system of finite elements.

Step 2:

The selection of displacement or temperature models representing approximately, the actual distribution in the displacement or temperature. The three factors which influence the selection of shape functions are,

- The type and degree of displacement model
- Displacement magnitudes
- The requirements to be satisfied which ensuring correct solution.

Step 3:

The derivation of the stiffness matrix which consists of the coefficients of the equilibrium equations derived from the geometric and material properties of the element. The Stiffness relates the displacement at nodal points to applied forces at nodal points.

Step 4:

Assembly of the algebraic equations for the overall discredited continuum includes the assembly of overall stiffness matrix for the entire body from individual element stiffness matrices and the overall global load vector from the elemental load vectors.

Step 5:

The algebraic equations assembled in step 4 are solved for unknown displacements by imposing the boundary conditions. In linear equilibrium problems, this is a relatively straightforward application of matrix algebra techniques.

Step 6:

In this step, the element strains and stresses are computed from the nodal displacements that are already calculated from step 5.

A. Meshing:

The meshing is the method in which the geometry is divided into small number of elements. We have selected area mesh for the meshing with the element size of 4, which will provide us fine meshing. Also we have selected quadrilateral mesh element for accurate and uniform meshing of component.

B. Loading and boundary conditions:

One end of the drive shaft was fixed at all six degrees of freedom and the torque of 100Nm was applied at other end with positive ``z`` direction.

C. Static analysis:

A static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those carried by time varying loads. A static analysis is used to determine the displacements, stresses, strains and forces in structures or components caused by loads that do not induce significant inertia and damping effects. A static analysis can however include steady inertia loads such as gravity, spinning and time varying loads. If these values exceed above the allowable values, then component is going to fail. Hence static analysis is necessary while analyzing the machine tool Bed.

D. Modal Analysis:

The modal analysis is one of the important analysis for drive shaft the modal analysis is required as the 1st mode frequency of vibration must be less than shaft operating frequency to avoid failure of drive shaft.

E. Buckling analysis:

The objective of buckling analysis is to obtain critical buckling load. In buckling analysis, the model was fully fixed in all six degrees of freedom at one end and subjected to torsion load at other end.

Result and Discussion:

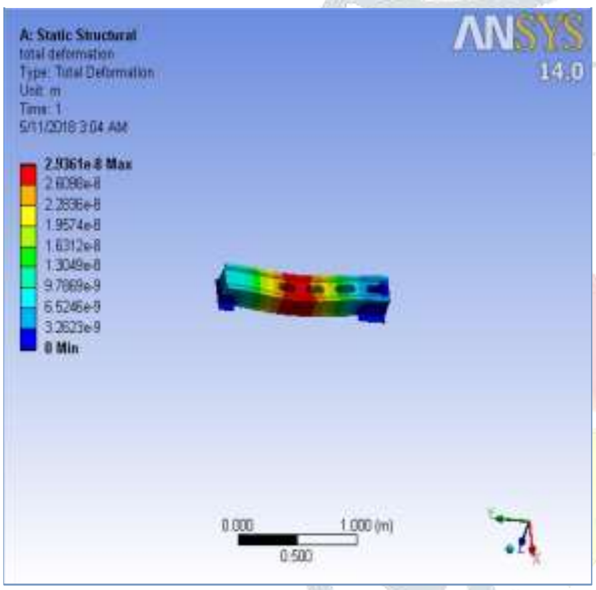


Fig: 8. Deformation of lathe bed before weight Optimization

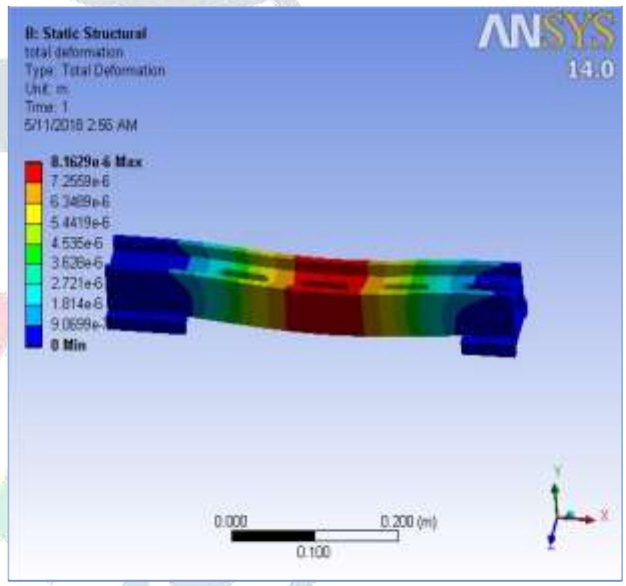


Fig: 9. Deformation of lathe bed after weight optimization

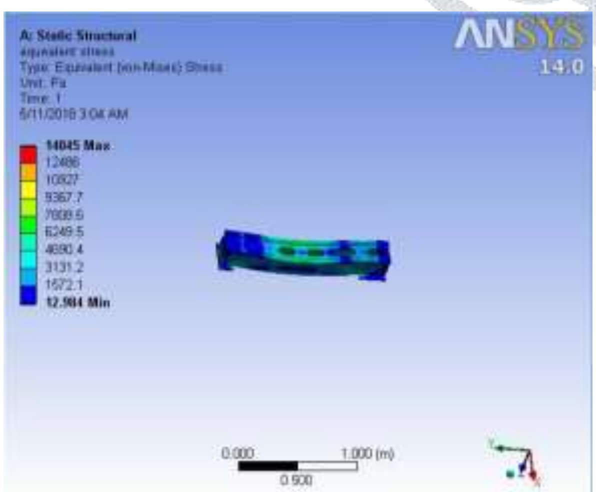


Fig: 10. Von-mises stress Distribution of lathe bed before Modification

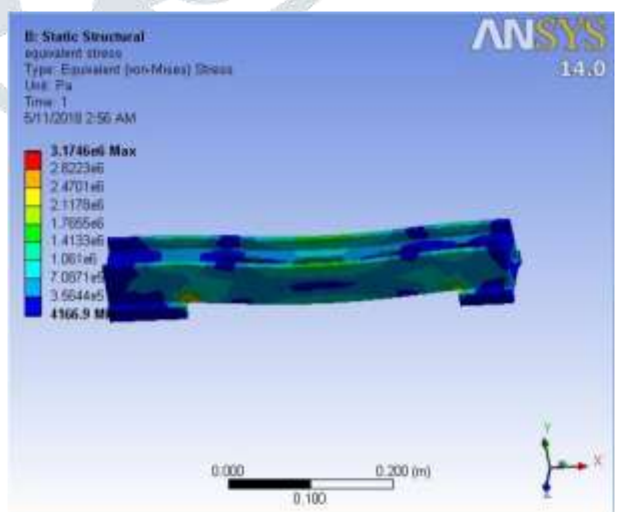
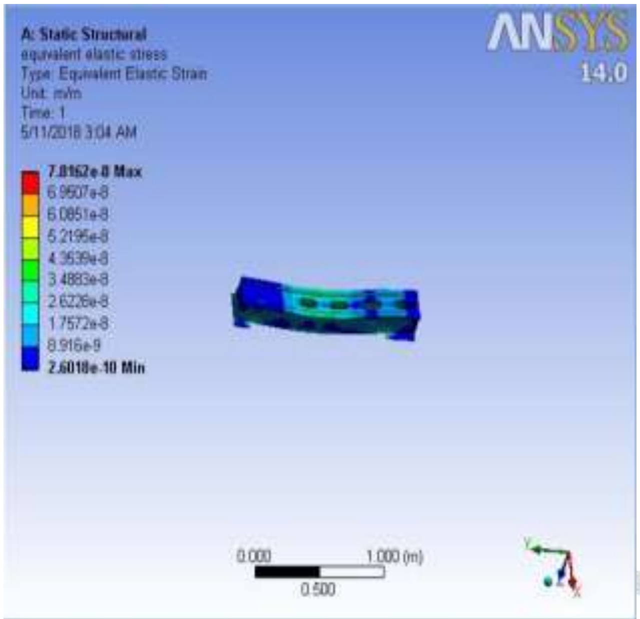


Fig: 11. Von-mises stress Distribution of lathe bed after modification



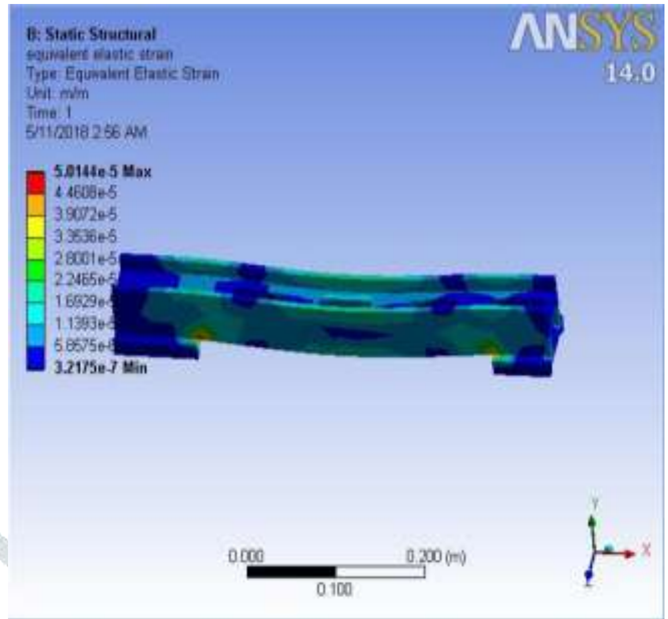


Fig: 12. Equivalent elastic strain of lathe bed before weight Optimization

Fig: 13. Equivalent elastic strain of lathe bed before Weight optimization

CONCLUSION:

- From the above results, the weight optimization of lathe machine bed has been achieved (Approximately 15%) for all the three material, hence the manufacturing cost also has been reduced.
- The von-misses stress for Optimized model 2 and Optimized model 3 has been reduced. (Approximately 19%).
- The Natural frequency is also Improved (i.e., increased) for Optimized models.
- From the above results, Optimized model 2 selected as the best model due to low stresses, low weight, less displacements and high natural frequencies, when it is compared with original model.
- From the model analysis it was found that, the natural frequency was increased from 5538.92 Hz to 5621.59 Hz. This increase in the natural frequency, does not affect much on the lathe machine bed.
- From the above outcomes, the given press was chosen a role, as the best material because of low burdens and high normal frequencies, when it is contrasted on different materials.
- The structural analysis will improve the conventional design of the machine structure.
- Through these structural and modal analysis results, we can conclude that modified model with cast iron material is best in terms of weight, stresses and damping capacity.

REFERENCES:

1. Chen P Y, Lin A Y M, Lin Y S, Seki Y, Stokes A G, Peyras J, Olevsky E A, Meyers M A and McKittrick J (2008), “Structure and Mechanical Properties of Selected Biological Materials”, Journal of the Mechanical Behavior of Biomedical Materials, Vol. 1, pp. 208-226.
2. Junior W K and Guanabara A S (2005), “Methodology for Product Design Based on the Study of Bionics”, Materials and Design, Vol. 26, pp. 149-155.
3. Kim D I, Jung S C, Lee J E and Chang S H (2006), “Parametric Study on Design of Composite-Foam-Resin Concrete Sandwich Structures for Precision Machine Tool Structures”, Composite Structures, Vol. 75, pp. 408-414.
4. Ma J F, Chen W Y, Zhao L and Zhao D H (2008), “Elastic Buckling of Bionic Cylindrical Shells Based on Bamboo”, Journal of Bionic Engineering, Vol.
5, pp. 231-238. 5. Ren L Q and Liang Y H (2010), “Biological Couplings: Function, Characteristics and Implementation Mode”, Science in China Series Es: Technological Sciences, Vol. 53, pp. 379-387.