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Research Paper

DESIGN AND ANALYSIS OF A MACHINE TOOL STRUCTURE BASED ON STRUCTURAL BIONICS

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A 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.

Keywords: Lathe machine bed, Bionic structure, Design optimization, Ansys

INTRODUCTION

After several billion years of evolution, the structures of organism in nature have excellent properties and ingenious frames, which provide a large amount of innovative prototypes and creative approaches for solving engineering problems and improving design methods. Structural bionic has become a new method for mechanical design, which has made great progress in intelligent robots, aircrafts, watercrafts, Micro Air Vehicle (MAV), bionic bulldozer blades and other structural design fields (Chen *et al.*, 2008; and Ren and Liang, 2010). In lightweight design, structural bionic has created many inventions with high specific stiffness and toughness (Junior and Guanabara, 2005). Ma *et al.* (2008) sed composite-foam-resin concrete sandwich structures for precision machine tool column. Kim *et al.* (2006) suggested an innovative design method termed adaptive growth technique by studying the optimality and growth mechanism of branch systems in nature. Pflug *et al.* (2004) developed lightweight sandwich boards of honeycomb core, and it is useful to the automotive industry.

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Based on bamboo's mesostructure shape and its arrangement, Chen *et al.* (2008) designed the bionic reinforcing frame of aircraft, which increased structural specific stiffness and strength. Because of lacking of mature and scientific design theories, the application is not extensive. So it is necessary to study the design method and process systematically, which will be helpful for further bionic application. By mimicking biological structures, we can achieve optimal designs with minimum energy and material. It is significant for resources saving and long-term development of China, which is a big machinery manufacturing country. Then the traditional manufacture process can be improved and the "green products" will use limited resources efficiently.

There are many biological structures with outstanding performance in nature. They can use minimum material and resource to build optimized structure without loosing strength and stiffness, which inspires us to implement lightweight design with high SSE.

Figure 1: Photos of Biological Structures

Many biological structures have high strength, stiffness and anti-bending deformation ability with minimum weight, such as bulrush, sorghum, corn, bamboo, bones stems, etc. Their stems are characterized as cone-shaped column with many nodes and their cross-sections are hollow-core circle (Figure 1). For example, bulrush (Figure 1a) and bamboo (Figure 1b) have high culms with many nodes. The cross-section (Figure 1a) of bulrush includes a three-layered sandwich structure formed by the outer and inner ring of strengthening tissue connected by wedge-shaped struts.

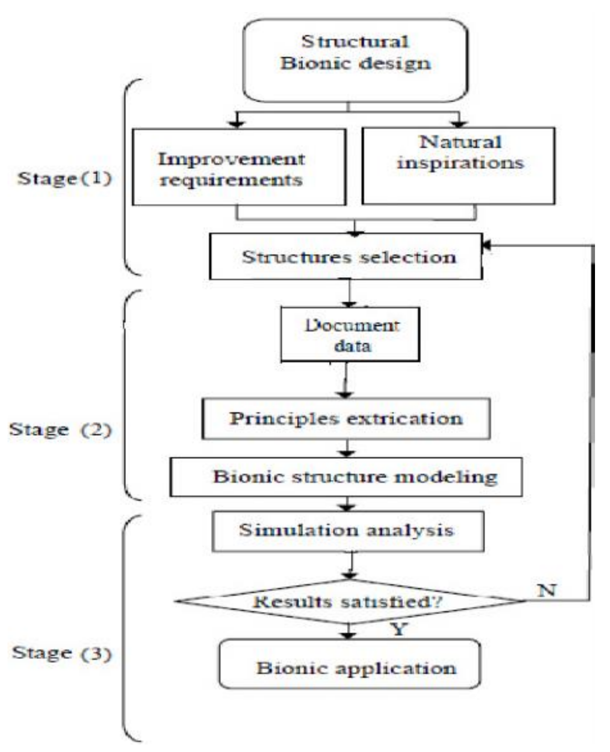
METHODOLOGY

Because bionic 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

Figure 2: Flowchart of Design Process



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.

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 ca 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.

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

Figure 3: CAD Model of Existing Lathe Bed

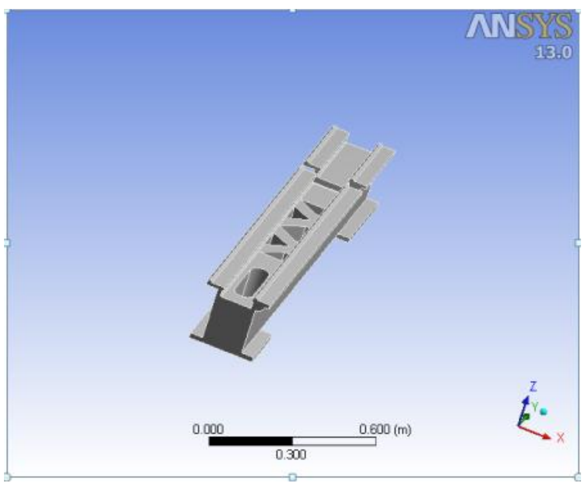


Figure 4: Meshing of Existing Model

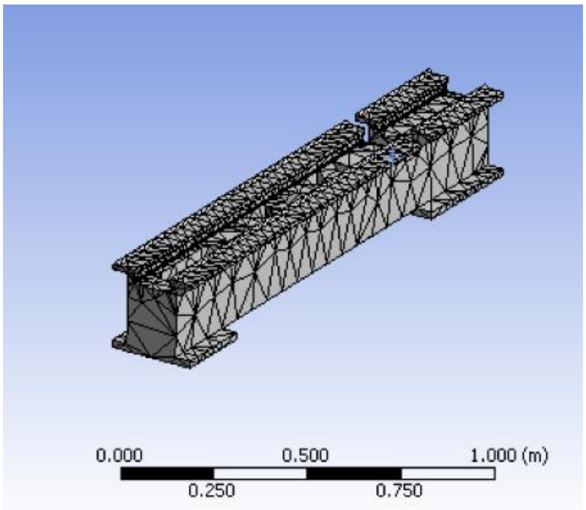
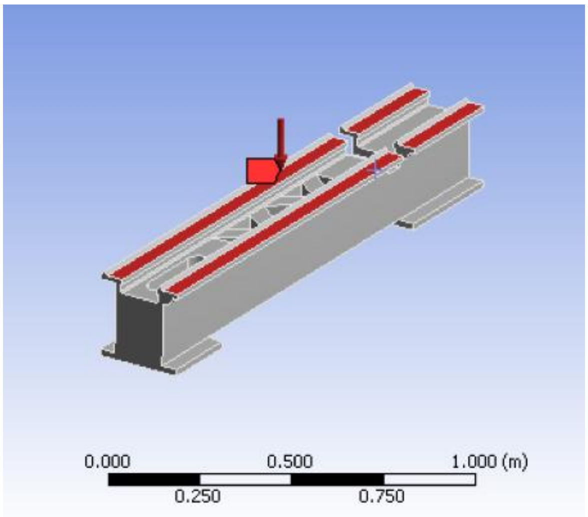


Figure 5: Applying Boundary Condition of Load 1000 N



Y-direction), Width = 246 mm (in X-direction), Height = 242 mm (in Z-direction) (total height).

STRUCTURAL MODIFICATION OF MACHINE TOOL BED

In nature there are many biological structures with excellent performance, such as bamboos, bones, stems and leaf veins. They can use

Figure 6: Vonmesis Stress of Lathe Machine Bed of Cast Iron

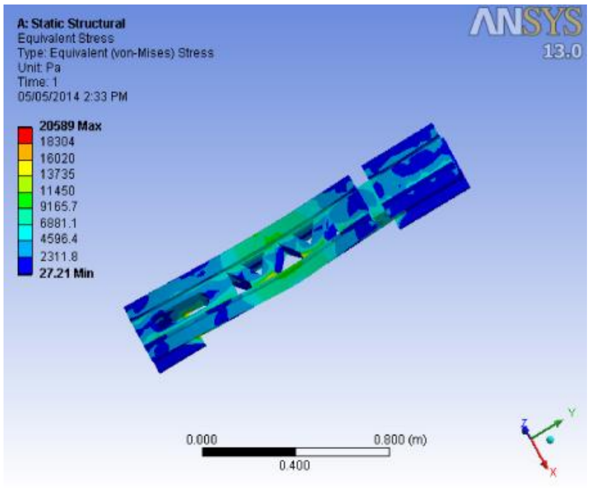
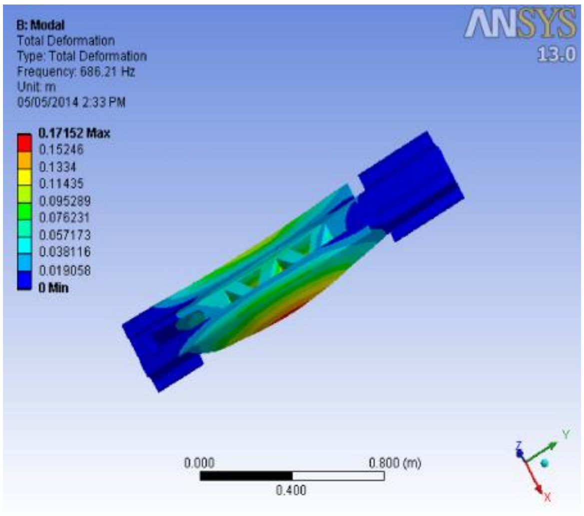


Figure 7: Modal Shape 1 of Lathe Machine Bed of Cast Iron



minimum material and resource to build optimized structure without loosing strength and stiffness, which inspire us a lot for bionic design. A typical application is "Bamboo" has practical significance in lightweight design of machine tool structures. During growing period, plants or bones can adjust the materials according to stress distribution. The dangerous areas will be strengthened for damage prevention. And the optimal materials distribution will decrease the structural mass. Therefore by mimicking those characteristics or principles, lightweight improvement may be satisfactory and encouraging.

The different modified machine bed as shown below:

Optimized Model (1)

Figure 8: CAD Model of Optimized Model (1) of Cast Iron

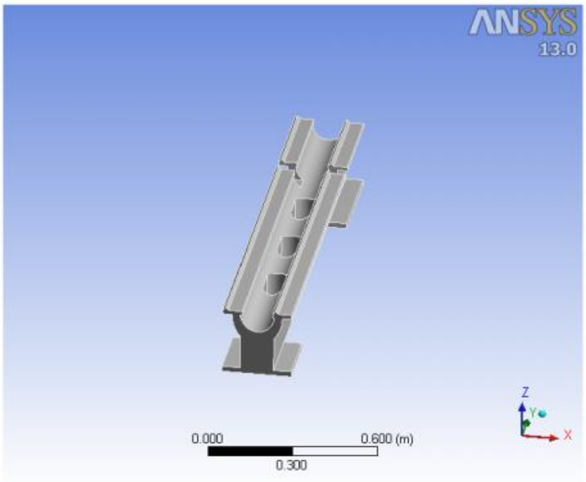


Figure 9: Vonmesis Stress of Optimized Model (1) of Cast Iron with Same Boundary Conditions (i.e., Load of 1000 KN)

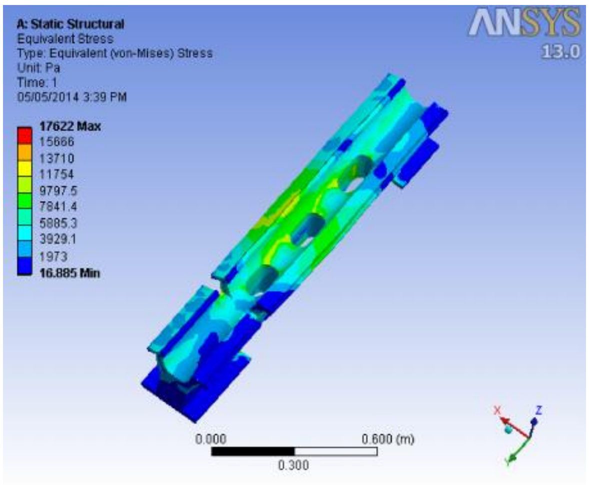
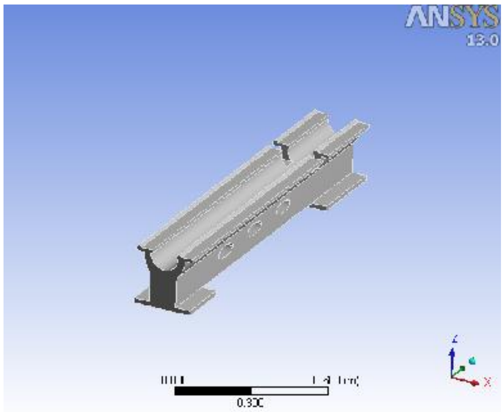


Figure 10: Modal Shape 1 of Optimized Model (1) of Cast Iron



Optimized Model (2)

Figure 11: CAD Model of Optimized Model (2) of Cast Iron

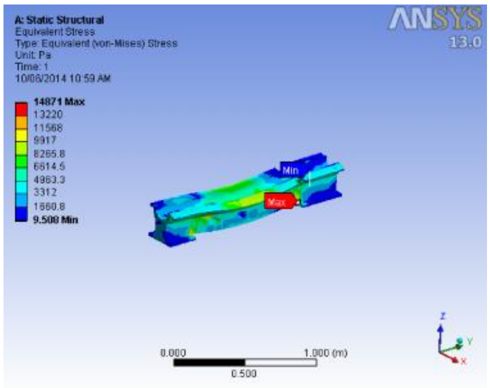


Figure 12: Vonmesis Stress of Optimized Model (2) of Cast iron with Same Boundary Conditions (i.e., Load of 1000 KN)

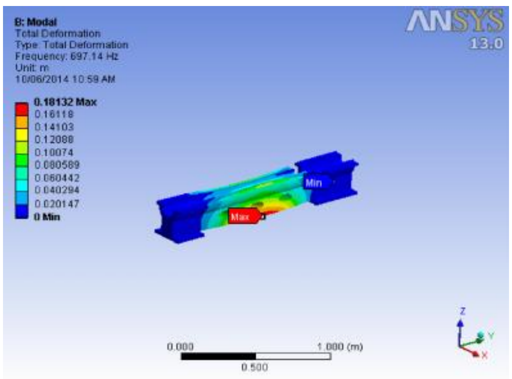
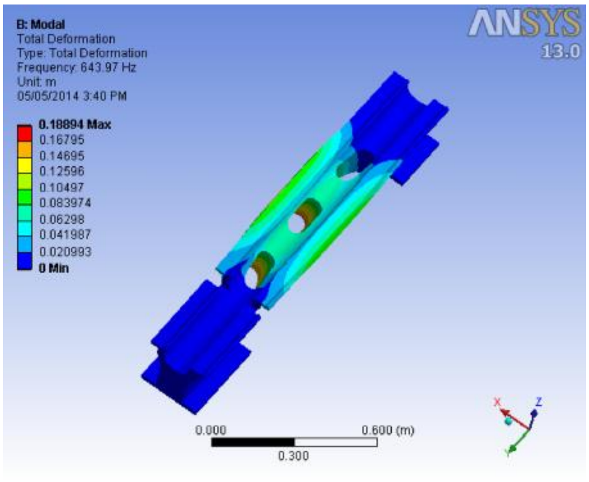


Figure 13: Modal Shape 1 of Optimized Model (2) of Cast Iron



RESULTS OF STATIC STRUCTURAL ANALYSIS

The results of static structural analysis using ANSYS for Existing model as well as other two optimized models are presented. The effects of some other materials (St.steel & Al-Alloy) for these models are presented and also Mass reduction on the machine bed is presented.

Table 1: Comparison of Weight of Lathe Machine Bed

Materials	Weight in (KG)		
	Existing Model	Optimized Model (1)	Optimized Model (2)
Cast Iron	307	257	276
St-Steel	334	281	300
Al-Alloy	118	99	106

Table 2: Vonmesis Stress of Lathe Machine Bed

Materials	Maximum Stress in (pa)		
	Existing Model	Optimized Model (1)	Optimized Model (2)
Cast Iron	20589	17622	14871
St-Steel	20403	17533	14716
Al-Alloy	20104	17423	14502

Table 3: Displacements of Lathe Machine Bed

Materials	Displacements in (μm)		
	Existing Model	Optimized Model (1)	Optimized Model (2)
Cast Iron	0.1084	0.1287	0.1071
St-Steel	0.0593	0.0706	0.0586
Al-Alloy	0.1660	0.1976	0.1638

Table 4: Modal Analysis Results for Cast Iron Materials

Mode Shapes	Existing Model (Hz)	Optimized Model (1) (Hz)	Optimized Model (2) (Hz)
1	686.2	643.97	697.14
2	767.0	814.8	789.58
3	1206	1203.4	1396.5
4	1375	1540.3	1514.1
5	1700	1793.2	1917.2
6	1814	1914.8	2107.2

Table 5: Modal Analysis Results for Structural Steel Materials

Mode Shapes	Existing Model (Hz)	Optimized Model (1) (Hz)	Optimized Model (2) (Hz)
1	883.5	828.46	895.75
2	998.9	1050.3	1018.2
3	1554	1550.9	1796.8
4	1772	1984.2	1950.7
5	2202	2322.9	2485.2
6	2343	2476.7	2720.1

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-mises 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.

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