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STRUCTURAL ANALYSIS FOR WEIGHT OPTIMIZATION OF MACHINE TOOL BED

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ABSTRACT

With the increasing pace in the industrial and technological developments there is a phenomenal change in the trend of machine tool development that brings to the fore, the modern production requirements like higher speeds, closer tolerances and accuracy. The performance of a machine tool depends primarily upon the static and dynamic behavior of the basic structure. In the present day structural engineering, the designing of the machine tools to have high stiffness with optimum use of materials to its fullest capability.
Machine tool structures have been analyzed in the past to study and improve their rigidity using several methods like Analytical Methods, Strength of materials methods, Elasticity methods and simulation methods using packages. Under simulation method use of Finite Element Analysis has become one of the most powerful and popular tool for structural analysis. The same could be used in the analysis of machine tool. The performance of machine tool depends upon the static and dynamic behavior of the basic machine structure. The bed structure has to resist the deformations caused by the weight of the moving part of the machine and cutting forces. The machine tool must be made up of proper material with high static and dynamic stiffness to resist the deformations. In the present investigation structural analysis of the CNC machine tool main bed for weight optimization is carried out using FEA commercial package ANSYS 10.0. Modal analysis was carried out to determine the natural frequency to verify stiffness of the bed.

INTRODUCTION

A machine tool is a powered mechanical device, typically used to fabricate metal components of machines by machining, which is the selective removal of metal. The first machine tools offered for sale (i.e. commercially available) were constructed by one Matthew Murray in England around 1800. Machine tools can be powered from a variety of sources.
Machine tools can be operated manually, or under automatic control. Early machines used flywheels to stabilize their motion and had complex systems of gears and levers to control the machine and the piece being worked on. Soon after World War II, the NC, or numerical control, machine was developed. NC machines used a series of numbers punched on paper tape or punch cards to control their motion. In the 1960s, computers were added to give even more flexibility to the process. Such machines became known as CNC, or computerized numerical control, machines. NC and CNC machines could precisely repeat sequences over and over, and could produce much more complex pieces than even the most skilled tool operators.
The performance of machine tool also depends upon the static and dynamic behavior of the machine structure. This in turn depends upon the individual structure and joints that make up the machine tool. The structure has to resist the deformations caused by the weight of the moving part of the machine and cutting forces. The machine tool must be made up of proper material with high static and dynamic stiffness to resist the deformations.

LITERATURE REVIEW

Elsaie, Klindera [9], the purpose of this paper is to present a structural analysis tool that can be applied to many aircraft components. In the aircraft industry, there has been strong interest in this area because of the need of constantly enhancing structural and flight performance. However, structural optimization is not yet fully utilized as it should be. This may be attributed to the unfamiliarity of this method to the average engineer, among other reasons.

Kim, Mijar [15], Simplified models can be useful for up-front design of automotive structures for passenger safety during crash. Formulations based on the system identification approach are presented for development of simplified models for simulation and design for automotive crash environment. Numerical crash data available from experiments or simulations are used in the development of such models. Parametric as well as nonparametric formulations of the problem are investigated. Standard nonlinear programming optimality conditions and methods are used to solve the resulting nonlinear identification problem. Simple numerical examples are solved to illustrate the proposed formulations and methodologies. As a practical example, the front horn of an automotive structure is replaced by a single degree of freedom system (SDOF). Two basic functions that identify the given target data are studied: Hat functions (piecewise linear) and Chebyshev polynomials. Effects of the number of design variables on the final solution to the problem are investigated.

Ernst Hustedt, [13], he wrote a macro in 1999 to calculate distributed loads. The idea behind it is to define a profile using 3-noded shells above the surface to be loaded and calculate the height of the profile above each node of the surface. The nodal force is the height calculated for each node. In a second macro the point loads are scaled proportionally to the area associated with each node. ANSYS has some better functionality to do this sort of thing and added the code for what it's worth. It did the job at the time. This is a macro to calculate hydrostatic loads under an arbitrary profile. The procedure involves calculating the vertical distance from each point to be loaded to a ceiling of arbitrary shape, where the ceiling is defined by triangular patches.

Jim Patterson [14], a set of macros to generate toolbars based on the defined components in the db. You can then call these toolbars from the main toolbar to aid in the selecting of the components. This includes "select", "also select", and "unselect". You can also "remake" the components from the toolbar. As someone who works with assemblies of shell models almost constantly, this has been a huge time saver, tested on 5.7 through 6.1.

Hursha Narayan [16], he has written a macro that calculates the total force along the three axes from applied pressure. He find this macro to be useful just to make sure that the pressure he is applying on a curved surface is accurate and also it gives a feel for the mesh discretisation where the pressure is applied. The user has to basically identify the elements with a particular magnitude of pressure and save the list file (SFELIS.lis). The macro does everything else automatically.

Duffin, Zener and Peterson [1] developed geometric programming in the 1967 Gomory did pioneering work in integer programming, which is one of the most exciting and rapidly developing areas of Optimization. The reason for this is that most of the real-world applications fall under this category of problems.

Dantzig and Charnes [2] developed stochastic programming techniques and solved problems by assuming design parameters to be independent and normally distributed. The desire to optimize more than one objective or goal while satisfying the physical limitations led to the development of multiobjective programming methods. Goal programming is a well Known technique for solving specific types of multiobjective Optimization problems. In recent years some of the macro’s developed in various fields have surveyed by referring to various web sites and some of the related macro’s in various field of engineering and interrelated to my field of work has gone through and their surveys are listed below.

Wei Liu, Ming Liang [17], this paper focuses on reconfigurable machine tools design optimization considering three important yet conflicting factors: configurability, cost and process accuracy. The problem is formulated as a multi-objective model. A mechanism is developed to generate and evaluate alternative designs. A modified fuzzy-Chebyshev programming method is proposed to achieve a preferred compromise of the design objectives.

Lee and Lim [11], this paper is concerned about modal and structural analysis of a high speed transfer type laser cutting machine. In order to analyze the machine by finite element method, external force is assumed by acceleration and mass of the gantry of the machine. Modal analysis for finding Eigen-values and mode shapes of the system is performed and it is shown that the dynamic analysis is unnecessary for this system under its operating condition. Bed and gantry part of the developed machine a high speed transfer type laser cutting machine is developed for precise cutting of sheet metal.

In this work an attempt has been made to carryout optimization of Machine Tool main Bed without compromising with deflection and stiffness. The machine bed is analyzed keeping the values of deflection within 10 microns, such that the stresses in the structure are well within the safe values.

METHODOLOGY

GENERAL DATA

Work piece material = Cast iron
Work piece hardness = 200
Cutting tool material = Carbide 4030

Table 3.1: Fundamental data for calculations

Dia. of cutter	D	Mm	125mm
Revolution per min	N	Rpm	600rpm
Feed per tooth	S_z	Mm	0.35mm
No. of teeth	Z		5
Feed per min	S_m	Mm/min	1050mm/min
Depth of cut	T	Mm	5mm
Width of cut	b	mm	100mm
Metal removal rate	S_m	Cm^3/min	525cc/min
Approach angle	x	Deg	75

Table 3.2: Information from the CMTI Data hand book

Avg chip thickness	M_m		0.8mm
Unit power	U	Kw/cm^3/min	18e-3kw/cc/min
Correction factor for flank wear	K_h		1.17
Radial rake angle	γ	Deg	-10^o
Correction factor for radial rake angle	K_γ		1.29

The mesh tool was used for meshing purpose. The bed structure is meshed with 4 nodded tetrahedral elements. Maximum of 129398 elements and 40699 nodes are used. The details of the element are described above.

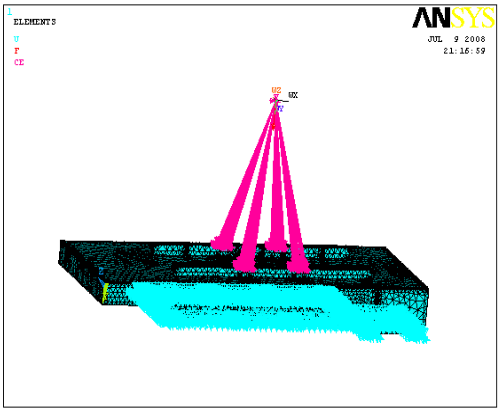

FIG 3.1: Boundary conditions for the analyses of the structure.

- **First Concept,** vertical members in the center is removed and the structure is executed with the above boundary conditions.
- **Second Concept,** vertical cross members is removed and thickness of the ribs is reduced to reduce the weight of the structure.
- **Third Concept,** along with cross members, the plate dimension of the top plates is also reduced form 32 mm to 20mm.
- **Fourth Concept,** structure is strengthened by the vertical ribs. But the top plates are maintained at 20mm.

RESULTS AND DISCUSSIONS

In the present work an attempt has been made to analyze and optimize the CNC machine tool bed subjected to maximum cutting force under static conditions from the point of view of obtaining weight and cost benefits.

WORKING FREQUENCY OF EXISTING BED

Maximum speed of the spindle = N = 600 rpm

Table 4.1: Details of different concepts

Concept No	Weight (Kg)	Vonmises Stress (Mpa)	Disp. (mm)	Remarks
Existing	3376	4.417	0.005805	- Feasible -
1	3161	4.348	0.006121	- Feasible -
2	2950	12.418	0.059197	-Not Feasible -
3	2840	30.817	0.06764	- Not Feasible-
4	3338.4	4.689	0.006388	- Feasible -

THE RESULTS LISTED ABOVE ARE DISCUSSED AS FOLLOWS,

1. Total numbers of four concepts were developed.
2. In the first and the fourth concept the deflection is well within the permissible deflection, therefore these concepts are feasible.
3. In the second and third concept the deflection is more than the permissible deflection; therefore these concepts are not feasible.
4. Out of the four concepts developed it was found that the first concept is the best possible alternative for the existing bed.
5. In the best optimized solution the maximum deflection produced is 6.1 microns which is almost equivalent to the deflection produced by the existing bed structure that is 5.8 microns.
6. The vonmises stress induced in the optimized structure is 4.348Mpa which is almost equivalent to the vonmises stress produced by the existing bed structure that is 4.417Mpa.
7. The weight of the structure was reduced from 3376kg to 3161kg. The reduction of weight compared to the existing bed is 215kg.

4.1MODAL ANALYSIS

4.1.1 MODE SHAPES OF EXISTING MODEL

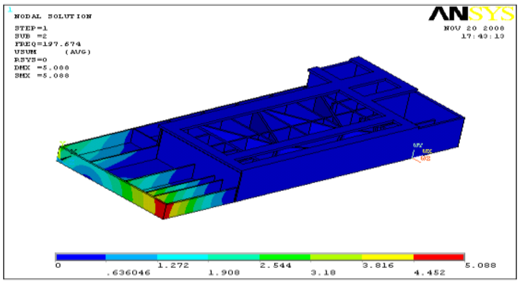

FIG 4.1 Mode shapes for first natural frequency

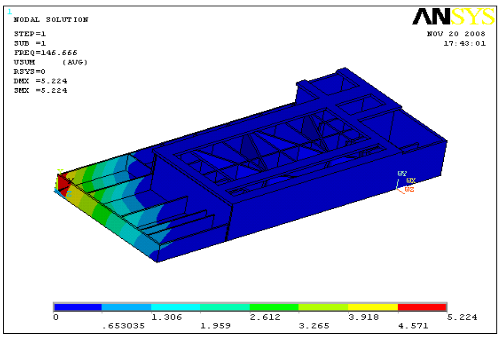

FIG 4.2 Mode shapes for second natural Frequency

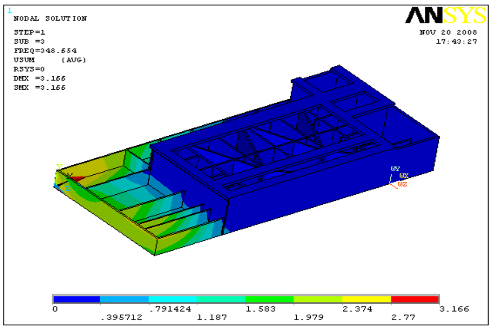

FIG 4.3 Mode shapes for third natural frequency

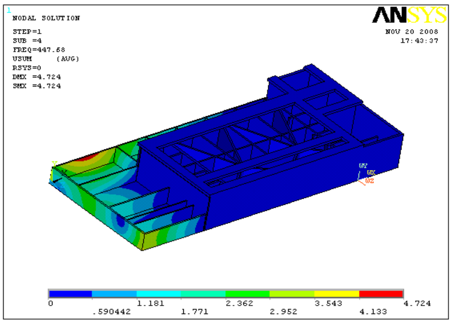

FIG 4.4 Mode shapes for fourth natural frequency

4.2.1 MODE SHAPES OF FIRST CONCEPT

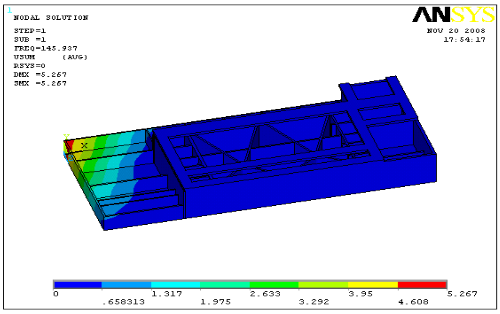

FIG 4.5 Mode shapes for first natural frequency

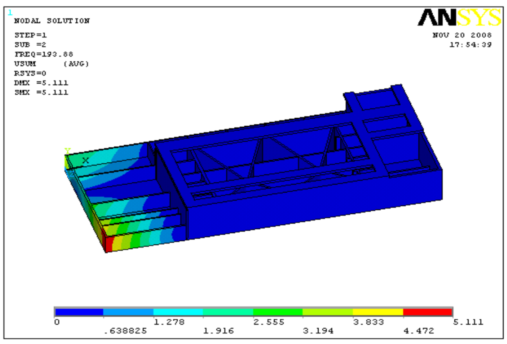

FIG 4.6 Mode shapes for second natural frequency

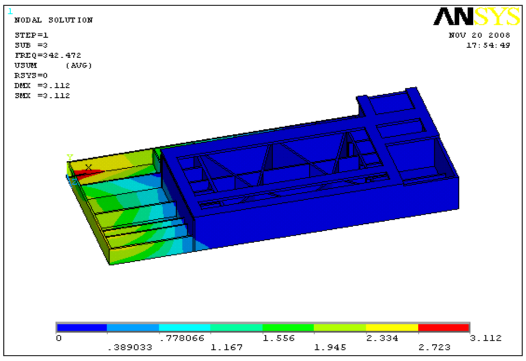

FIG 4.7 Mode shapes for third natural frequency

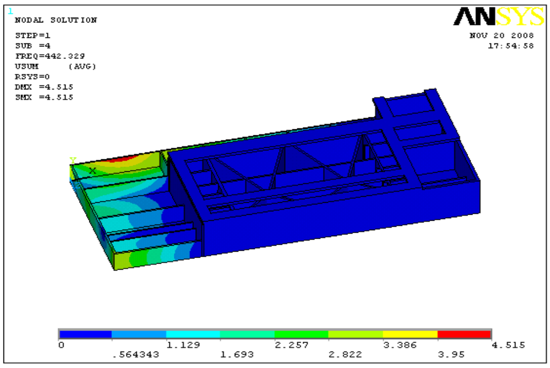

FIG 4.8 Mode shapes for fourth natural

Table 4.2: List of Natural frequencies of different concepts

Sets	Natural Frequencies				
	Existing Model	1st concept	2nd concept	3rd concept	4th concept
1	146.66	145.93	134.11	63.090	142.00
2	197.64	193.88	147.94	94.650	192.21
3	348.65	342.47	192.87	140.83	344.76
4	447.68	442.32	230.73	171.80	435.66
5	496.68	480.88	321.34	260.91	470.11

THE RESULTS LISTED IN THE ABOVE TABLE ARE DISCUSSED AS FOLLOWS,

1. The working frequency of the existing bed is well within the natural frequency of the bed, therefore the bed is safe for the resonance.
2. The natural frequency of the existing bed is 146.66cycles/sec which is almost equal to the natural frequency of the first concept that is 145.93cycles/sec.

Since mass is reduced by 215kg in the first concept and natural frequency is same as the existing bed, the stiffness of the optimized bed is increased. The mass, natural frequency and the stiffness are related $F= 1/2\pi\sqrt{(k/m)}$.

CONCLUSION

The machine bed structure is optimized using iteration procedure using Ansys software. In all the iterations, structure is safe from stress point of view, but is varying with reference to the rigidity requirements of the machine. The total procedure of analysis is summarized as follows.

- The complex AutoCAD representation of model is represented in Ansys using scalar parameters for easier modification of the values.
- The structure is built using mixed approach of ANSYS
- The Bed structure is meshed using 4 nodded tetrahedral elements.
- The bottom of the bed structure is constrained and carriage location is linked to the load position at a height of 1500mm using RBE3 elements.
- All the necessasary boundary conditions are applied to solve the problem
- The results are obtained for weight, vonmises and deformations. The structure deformation is the main constraint of optimization.
- A detailed study was made to analyze and optimize the CNC machine tool bed to reduce the weight of the structure.
- From the results obtained and the discussions made, it has been found that the optimized structure resulted in a weight reduction of 215kgs with the original weight being 3376kgs, without compromising on the functional and design requirements.

Also it makes transportation and installation of the machine easier and cheaper, thus indirectly contributing to a further reduction of overall cost.

- The reduction in weight results in less inertia and helps in improving the performance of the machine running at high speeds.
- Modal analysis results are shown that the stiffness of the bed is increased, as the natural frequency of the existing bed is almost equal to the optimized bed with the reduction in weight.

REFERENCES

1) Duffin Peterson and Zener, Geometric programming: theory and applications, Wiley, New york, 1967.
2) Dantzig Linear Programming and Extensions, Princeton University Press.
4) Gettatly and Gallagher, “A procedure for automated minimum weight structural design, Part I - Theoretical basis, Part II - Applications,” Aero. Quart. Part I, Vol. 17, pp. 216-230 and pp.332-342, 1966.
5) Denn, Optimisation by variational methods, McGraw-Hill, New York 1969.
6) Beveridge and R.S. Schechter, Optimisation : theory and practice, McGraw-Hill, New York , 1970.
8) Kuester and Mize, Optimisation techniques with FORTRAN, McGraw-Hill, New York, 1973.
9) Panik, Classical Optimisation: foundations and extensions, North-Holland Publishing Co., Amsterdam, 1976.
10) Elsaie B. E. Klindera, “Optimization of Aircraft Structures Using Starstruc’ SAE International. 1990
11) Carmichael, Structural modeling and Optimisation, Ellis Horwood Chichester, 1981.
12) Lee and S.H. Lim, ‘Structural and modal analysis of High Speed Transfer type laser cutting machine, International Journal of Production Research, 1993.
13) Ramamrutham S, Narayan R, Strength of Materials. Dhanpatrai & Sons - 1993
14) Ernst Hustedt, Developed a macro in ANSYS, AMES Ltd. (Air New Zealand Engineering). 1999,
15) Jim Patterson, Developed a macro in ANSYS, AMES Ltd. 2000.
16) Kim, A.R. Mijar, ‘Development of simplified models for design and optimization of automotive structures for crashworthiness’ 2001
17) Hursha Narayan (Robert Bosch Corporation), Developed a macro in ANSYS, 2002.
18) Wei Liu, Ming Liang, ‘Multi-objective design optimization of reconfigurable machine tools’; International Journal of Production Research, Volume 46, 2004.
19) Joe Metrisin, Florida Turbine Technologies, Inc. International Journal of Production Research. 2002
20) Concepts and Application of Finite Element Analysis Rober D. Cook, David S – Joh Wiely & Sons Pte. Ltd. Fourth Edition 2003.
21) Finite Elements in Engineering – Tirupathi R. Chandrupatla, Ashok D. Belegundu, Prentice – Hall of India Pvt. Ltd, 2003.