Scientific Journal of Impact Factor(SJIF): 3.134

e-ISSN(O): 2348-4470
p-ISSN(P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 2,Issue 7, July -2015

Scope of Design Modification in CNC Vertical Milling Machine with improved Structure Stiffness & rigidity- A review

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Abstract —*Need of continuous improvement in a product or process in this era of global competition leads to apply value engineering for functional and aesthetic improvement in consideration with economical aspect too.*

In this paper many alternative technologies such as: using alternative materials, applying ribs and cut outs, obtaining a box type shape, filling the interior space with metallic aluminum foam etc., are studied & observed for drawing bright suggestions for improving structure stiffness & Rigidity.
Emphasis is certain on Structural ribs with hollow offers a method to improve the conventional design of machine structure. Based on structural modifications, ribs parameters and distributions can be further optimized.

*Keywords- NC,**CNC Vertical Milling Machine, column, base, saddle, the stiffness & rigidity of structure.***

I. INTRODUCTION

Modern precision manufacturing demands extreme dimensional accuracy and surface finish. Such performance is very difficult to achieve manually, if not impossible, even with expert operators. In cases where it is possible, it takes much higher time due to the need for frequent dimensional measurement to prevent overcutting. It is thus obvious that automated motion control would replace manual "hand wheel" control in modern manufacturing. Development of computer numerically controlled (CNC) machines has also made possible the automation of the machining processes with flexibility to handle production of small to medium batch of parts.
In the 1940s when the U.S. Air Force perceived the need to manufacture complex parts for high speed aircraft. This led to the development of computer-based automatic machine tool controls also known as the Numerical Control (NC) systems. Commercial production of NC machine tools started around the fifties and sixties around the world. Note that at this time the microprocessor has not yet been invented.
Initially, the CNC technology was applied on lathes, milling machines, etc. which could perform a single type of metal cutting operation. Later, attempt was made to handle a variety of work pieces that may require several different types machining operations and to finish them in a single set-up. Thus CNC machining Centers capable of performing multiple operations were developed. To start with, CNC machining centers were developed for machining prismatic components combining operations like milling, drilling, boring and tapping. Gradually machines for manufacturing cylindrical components, called turning centers were developed.

II. HISTORICAL BACKGROUND OF CNC MILLING MACHINE:

The development of NC machine tools started from a task supported by the US Air Force in the early 1950's, involving MIT and several machine-tool manufacturing companies. The need was recognized for machines to be able to manufacture complex jet aircraft parts.

As computer technology evolved, computers replaced the more inflexible controllers found on the NC machines; hence the dawn of the CNC era. In 1980 CNC machine are introduced. In which the computer used to link directly to controller.CNC milling is a specific form of computer numerical controlled (CNC) machine. Where the programmer feed the pre-generated program.CNC machine tools use software programs to provide the instructions necessary to control the axis motions, spindle speeds, tool changes and so on. CNC machine tools allow multiple axes of motion simultaneously, resulting in 2D and 3D contouring ability.

CNC milling devices are the most widely used type of CNC machine. Virtually every type of material that can be drilled or cut can be machined by a CNC mill, although most of the work performed is done in metal. CNC technology also increases productivity and quality control by allowing multiple parts to be produced using the same program and tooling.

2.1 NUMERICAL CONTROL:

Automatically controlling a machine tool based on a set of pre-programmed machining and movement instructions is known as numerical control, or NC. In a typical NC system the motion and machining instructions and the related numerical data, together called a part program, used to be written on a punched tape. The part program is arranged in the form of blocks of information, each related to a particular operation in a sequence of operations needed for producing a mechanical component. The punched tape used to be read one block at a time. Each block contained, in a particular syntax, information needed for processing a particular machining instruction such as, the segment length, its cutting speed, feed, etc.

These pieces of information were related to the final dimensions of the workpiece (length, width, and radii of circles) and the contour forms (linear, circular, or other) as per the drawing. Based on these dimensions, motion commands were given separately for each axis of motion. Other instructions and related machining parameters, such as cutting speed, feed rate, as well as auxiliary functions related to coolant flow, spindle speed, part clamping, are also provided in part programs depending on manufacturing specifications such as tolerance and surface finish. Punched tapes are mostly obsolete now, being replaced by magnetic disks.

NC equipment has been defined by the Electronic Industries Association (E1A) as "A system in which actions are controlled by the direct insertion of numerical data at some point. The system must automatically interpret at least a portion of this data." This is an old definition as is apparent from the terminology used in the definition.

Computer Numerically Controlled (CNC) machine tools, the modern versions of NC machines have an embedded system involving several microprocessors and related electronics as the Machine Control Unit (MCU). Initially, these were developed in the seventies in the US and Japan. However, they became much more popular in Japan than in the US. In CNC systems multiple microprocessors and programmable logic controllers work in parallel for simultaneous servo position and velocity control of several axes of a machine for contour cutting as well as monitoring of the cutting process and the machine tool. Thus, milling and boring machines can be fused into versatile machining centers. Similarly, turning centers can realize a fusion of various types of lathes. Over a period of time, several additional features were introduced, leading to increased machine utilization and reduced operator intervention.
Some of these are:
(a) Tool/work monitoring: For enhanced quality, avoidance of breakdowns.
(b) Automated tool magazine and palette management: For increased versatility and reduced operator intervention over long hours of operation
(c) Direct numerical control (DNC): Uses a computer interface to upload and download part programs in to the machine automatically.

2.2 ADVANTAGES OF CNC MACHINE:

1. Easier to program.
2. Easy to storage of existing program.
3. Avoids human efforts & human error.
4. Complex geometry is produced as cheaply as simple ones.

III. LITERATURE SURVEY:

1. **Title**: Design & structural analysis of CNC vertical milling machine bed.
   Author: B.Malleswara Sawami & K.Sunil Ratna Kumar
   Year: 2012

   Summary:
   - Investigation is carried out to reduce the weight of the machine bed without deteriorating its structural rigidity & the accuracy of the machine tool by adding ribs at suitable locations.
   - In this work 3D CAD model for the base line & the optimized design has been created by using commercial 3D modelling software CATIA.
   - The 3D FE model has been generated by using HYPERMESH.

2. **Title**: Structural Redesigning of a CNC lathe bed to improve its Static and Dynamic Characteristics.
   Author: S. Syath Abuthakeer, P.V. Mohanram & & G. Mohan Kumar
   Year: 2011

Summary:

- Results indicated that the cross and horizontal rib with hollow bed can increase the specific stiffness by 8% with 4% weight reduction and its dynamic performances is also better with increases in the first natural frequencies.
- The modified design is effective in improving the static and dynamic structural performances of high speed machine tools.
- Scale-down models were used to verify the improvements of vertical ribs with hollow bed design. Static and dynamic experiments show that the mass and deflection are reduced by 3.66% and 8.08%%respectively and the lower order natural frequencies are increased. Experimental results agree qualitatively with the FEM simulation.

3. **Title:** Optimization of cnc lathe saddle
   Author: Kunal Gajjar, Dr. Amit Trivedi
   Year: 2011

Summary:

- The present work illustrates how the topology optimization tools can be used in the structural design of machine tool components.
- The technological tools are very efficient and productive in the product design process and provide strength and stability to the components.
- The application of the topology optimization, optimum material layout for maximum stiffness with reduction of 30% weight of the CNC Lathe saddle is generated.
- The use of Altair OptiStruct in phase of design optimization process has helped in defining material layout for the light weight and stiffened structure for the CNC Lathe saddle.
- It also saved a lot of time when compared to that of traditional design process.

4. **Title:** Method for improving dynamic properties of large moving CNC machine tool components.
   Author: Mihai Simon, Lucian Grama, Macedon Ganea
   Year: 2012

Summary:

- Heavy moving machine parts means reduced dynamic performance of the CNC machine tools. This, in the context of increasing industrial demands for beater surfaces, is an impediment by elongating the time to machine the piece.
- The problem is that reduced mass means higher vibrations and deformations. This paper studied a method to reduce the mass by 50% and reduce the stress equivalent from 13,813 Mpa to 3,275 Mpa. Also deformations ware kept in acceptance limits, and beater comportment at different chattering frequency's was achieved.

5. **Title:** Modeling and Analysis of CNC Milling Machine Bed with Composite Material
   Author: Venkata Ajay Kumar. G. V. Venkatesh
   Year: 2014

Summary:

- Structural materials used in a machine tool have a decisive role in determining the productivity and accuracy of the part manufactured in it. The conventional structural materials used in precision machine tools such as cast iron and steel at high operating speeds develop positional errors due to the vibrations transferred into the structure.
- To analyze the bed for possible material changes that could increase stiffness, reduce weight, improve damping characteristics and isolate natural frequency from the operating range.

6. **Title:** Design Optimization of Machining Fixture for the Slant Bed CNC Lathe (SBCNC80/2000)
   Author: Tom Zacharia and M.S. Steve
   Year: 2013

Summary:

- The design requirements of the fixture were studied and cutting forces were calculated. Strap clamp which is convenient to use the fixture at different machine beds is designed and modeled.
- The design suggested in steel by the company was found to be over designed and optimization was carried out to reduce the material as well as total weight keeping the maximum allowable deflection of the fixture as 4 microns.

7. Title: Measurement and Analysis of Forces During High Speed Milling of EN-30B Alloy Steel
Author: Khalid. H.Hashmi, Dr. Shahid Khalil, Atif Suleman, Dr. G Zakria, Muhammad Sharif
Year: 2013

Summary:

- High speed machining (HSM) is one of the more useful and helpful technology. HSM is being adopted to increase the productivity, reducing manufacturing costs and for machining of hard materials. This research covers the steps taken to gain insight into the measurement and analysis of cutting forces during high speed milling so that these forces should have minimum effect on cutting tool and rapid tool wear can be controlled. In order to measure and record the cutting forces during high speed milling, a dynamometer is designed and developed. An accurate and reliable dynamometer is manufactured for measuring and recording the cutting force components.

IV. TABULATED SUMMARY OF LITERATURE SURVEY

SR NO	PAPER TITLE	ABSTRACT	PAPER OUTCOME	CONCLUSION	AUTHOR	PUBLICATION
1.	Design And Structural Analysis Of CNC Vertical Milling Machine Bed	In this paper, a machine bed (Manufacturer: M/s Lokesh Machine Tools Ltd) is selected for the complete analysis for both static and dynamic loads. Then investigation is carried out to reduce the weight of the machine bed without deteriorating its structural rigidity and the accuracy of the machine tool by adding ribs at the suitable locations. In this work, the 3D CAD model for the base line and the optimized design has been created by using commercial 3D modeling software CATIA. The 3D FE model has been generated using HYPERMESH. The analyses were carried out using ANSYS and Design Optimization is done with the help of Optistruct. The results were shown with the help of graphs to analyze the effect of weight reduction on the structural integrity of the machine bed before and after the weight reduction and conclusions were drawn about the optimized design.	1. Investigation is carried out to reduce the weight of the machine bed without deteriorating its structural rigidity & the accuracy of the machine tool by adding ribs at suitable locations. 2.In this work 3D CAD model for the base line & the optimized design has been created by using commercial 3D modeling software CATIA. 3.The 3D FE model has been generated by using HYPERMESH	1. From the above results, the weight optimization of milling machine bed structure has been decrease by 16.1 Kg from 1056.31Kg to 1040.2 Kg (approximately 1.5%), hence the manufacturing cost also has been reduced. 2. From the above results, the G15 was selected as the best material due to low stresses and high natural frequencies, when it is compared with other materials. 3.The von-mises stress for G15 was increased from 26.1305 to 33.2082 N/mm2 in structural analysis. (Approximately 21.31%). 4. The natural frequency is also incresed.200 Hz to 215 Hz (approximately 6.9%). 5. The Effect of Vonmesis stress for G15 was increased and it is in permissible safe limit. 6. Structural ribs with hollow offers a method to improve the conventional design of machine structure Based on structural modifications, ribs parameters and distributions can be further optimized.	1.B.Malleswara Swami, Department of Mechanical Engineering, SIRC.R.R. College of Engineering. 2.K.Sunil Ratna Kumar Eluru-534007, West Godavari Dist, A.P	International Journal of Advanced Engineering Technology E-ISSN 0976-3945
2.	Structural	In the past, the design	1.Results indicated that	1. Based on the	1.S.Syath	International

	redesigning of a CNC lathe bed to Improve its static and dynamic characteristics	of CNC machine tools focused on their functional aspects and was hard to acquire any resonance with customers. Nowadays, despite the needs of low price, capabilities withstand at higher cutting speeds and operate at high acceleration and deceleration with high quality machine, many customers request good-looking machine. Regarding this, our study aims to provide various form designs of Machine tool structure with the help of structural modifications made in CNC machine tool bed. After the lightening effect was verified by finite element simulation, scale-down models of an original bed and vertical ribs with hollow bed models were fabricated using rapid prototyping method and tested. The dynamic characteristics of those different form designs of the bed were analyzed experimentally. Numerical analysis was done and results were validated with experimental results. Results indicated that the cross and horizontal rib with hollow bed can increase the specific stiffness by 8% with 4% weight reduction and its dynamic performances is also better with increases in the first natural frequencies. The modified design is effective in improving the static and dynamic structural performances of high speed machine tools.	the cross and horizontal rib with hollow bed can increase the specific stiffness by 8% with 4% weight reduction and its dynamic performances is also better with increases in the first natural frequencies. 2. The modified design is effective in improving the static and dynamic structural performances of high speed machine tools. 3. Scale-down models were used to verify the improvements of vertical ribs with hollow bed design. Static and dynamic experiments show that the mass and deflection are reduced by 3.66% and 8.08%%respectively and the lower order natural frequencies are increased. Experimental results agree qualitatively with the FEM simulation.	configuration principles, the existing bed was redesigned to improve the static and Dynamic performances. Simulation results show that the static and dynamic performances of vertical ribs with hollow bed have been improved. 2. Scale-down models were used to verify the improvements of vertical ribs with hollow bed design. Static and dynamic experiments show that the mass and deflection are reduced by 3.66% and 8.08%% respectively and the lower order natural frequencies are increased. Experimental results agree qualitatively with the FEM simulation. 3. Structural vertical ribs with hollow offers a method to improve the conventional design of machine structure. Based on structural modifications, ribs parameters and distributions can be further optimized.	Abuthakeer, Department Of Mechanical Engineering, Psg College Of Technology, Coimbatore. 2.P.V. Mohanra Department Of Mechanical Engineering, Psg College Of Technology, Coimbatore. 3.G.Mohan Kumar. Park College Of Engineering And Technology, Coimbatore.	Journal Of Engineering-HUNEDOARA
3.	Optimization of CNC lathe saddle	A machine tool structure has great influence on the precision of machine tool's operations. The present work involves the optimization of CNC Lathe saddle for minimum overall compliance and weight. The CNC Lathe sub-assembly is modeled, static analyzed using	1.The present work illustrates how the topology optimization tools can be used in the structural design of machine tool components. 2.The technological tools are very efficient and productive in the product design process and provide strength	The use of Altair OptiStruct in phase of design optimization process has helped in defining material layout for the light weight and stiffened structure for the CNC Lathe saddle. It also saved a lot of time when compared to that of traditional design process.	1.Krunal Gajjar, BVM, V.V.nagar, Gujarat, India. 2.Amit Trivedi, BVM, V.V.nagar, Gujarat, India	HTC 2011.

		OptiStruct and optimized the saddle for more stiffened and light w eight structure.	and stability to the components. 3. The application of the topology optimization, optimum material layout for maximum stiffness w ith reduction of 30% weight of the CNC Lathe saddle is generated. 4. The use of Altair OptiStruct in phase of design optimization process has helped in defining material layout for the light w eight and stiffened structure for the CNC Lathe saddle. 5. It also saved a lot of time w hen compared to that of traditional design process.			
4.	Method for improving dynamic properties of large moving CNC machine tool components.	This paper is part of a study for obtaining an experimental prototype of a large moving machine tool structural part, by reducing its weight and increasing rigidity properties. Weight reduction is necessary for better dynamic performance and energy efficiency. The problem is that by reducing mass, rigidity and vibrations dampening are affected. The developed method tries to eliminate this problem by applying alternative technologies such as: using alternative materials, applying ribs and cut outs, obtaining a box type shape, filling the interior space w ith metallic aluminum foam.	1.Heavy moving machine parts means reduced dynamic performance of the CNC machine tools. This, in the context of increasing industrial demands for beater surfaces, is an impediment by elongating the time to machine the piece. 2.The problem is that reduced mass means higher vibrations and deformations. This paper studied a method to reduce the mass by 50% and reduce the stress equivalent from 13,813 Mpa to 3,275 Mpa. Also deformations ware kept in acceptance limits, and beater comportment at different chattering frequency's was achieved.	1.Heavy moving machine parts means reduced dynamic performance of the CNC machine tools. This, in the context of increasing industrial demands for beater surfaces, is an impediment by elongating the time to machine the piece. 2. The method can be applied in other fields of performance engineering such as automotive, bridge constructions, ladders or other applications with good rigidity properties and low mass. 3. The results were used in the end for producing a high dynamic performance 3 axis CNC milling machine, completed with the experimentally improved spindle carrier.	1.Mihai SIMON, Industrial Engineering and Management Department, Petru Maior University Nicolae Iorga Street, No. 1, Targu Mures, Romania. 2.Lucian GRAMA, Industrial Engineering and Management Department, Petru Maior University Nicolae Iorga Street, No. 1, Targu Mures, Romania. 3.Macedon GANEA, Engineering and Management Department, University of Oradea Universitatii Street, No. 1, Oradea, Romania	The 6th edition of the Interdisciplinar ity in Engineering International Conference "Petru Maior" University of Tîrgu Mures, Romania, 2012.
5.	Modeling and Analysis of CNC Milling Machine Bed w ith Composite Material	Structural materials used in a machine tool have a decisive role in determining the productivity and accuracy of the part manufactured in it. The conventional structural	1.Structural materials used in a machine tool have a decisive role in determining the productivity and accuracy of the part manufactured in it. The conventional structural	Based on the configuration principles, the existing bed material w as replaced by HM CFRP material shows improvement in the static characteristics.	1.Venkata Ajay Kumar, Assistant Professor Department of Mechanical Engineering Annamacharya	IJSRD - International Journal for Scientific Research & Development| Vol. 2, Issue 09, 2014 |

		materials used in precision machine tools such as cast iron and steel at high operating speeds develop positional errors due to the vibrations transferred into the structure. Faster cutting speeds can be acquired only by structure which has high stiffness and good damping characteristics. Clearly the life of a machine is inversely proportional to the levels of vibration that the machine is subjected. The further process is carried out to undergo the deformation, natural frequency and displacement using Static analysis, Modal analysis and Harmonic analysis respectively. Since the bed in machine tool plays a critical role in ensuring the precision and accuracy in components. It is one of the most important tool structures which tend to absorb the vibrations resulting from the cutting operation. To analyze the bed for possible material changes that could increase stiffness, reduce weight, improve damping characteristics & isolate natural frequency from the operating range. This was the main motivation behind the idea to go in for a composite model involving High Modulus Carbon Fiber Reinforced Polymer Composite Material (HM CFRP). Though carbon has good strength and stiffness properties but it lacks in damping requirements. On the other hand polymer, though it lacks in strength but it has good damping characteristics and it is used to hold the carbon fibers. This makes it ideal to combine these materials in a proper manner. In this work, a	materials used in precision machine tools such as cast iron and steel at high operating speeds develop positional errors due to the vibrations transferred into the structure. 2.To analyze the bed for possible material changes that could increase stiffness, reduce weight, improve damping characteristics and isolate natural frequency from the operating range.	Simulations results show that the static characteristics of the machine bed have been improved. Generally Composite materials also offer high specific strength and high specific modulus with less weight in machine tool industries. This composite materials offers high accuracy and precession of the component manufactured in such machine tools made of composite materials. By considering all the results, the induced deformation and strain in HM CFRP machine bed is less than conventional cast iron machine beds because specific strength and specific rigidity of HMCFRP machine bed is more than cast iron. The work suggests that HM CFRP material is best suited for CNC milling machine bed.	Institute of Technology & Sciences, Rajampeta. 2.V. Venkatesh, Assistant Professor Department of Mechanical Engineering Annamacharya Institute of Technology & Sciences, Rajampeta.	ISSN (online): 2321-0613

		machine bed is selected for the analysis static loads. Then investigation is carried out to reduce the weight of the machine bed without deteriorating its structural rigidity. The 3D CAD model of the bed has been created by using commercial 3D modeling software and analyses were carried out using ANSYS.				
6.	Optimization of Machining Fixture for the Slant Bed CNC Lathe (SBCNC80/2000)	Design optimization of a special purpose fixture for a well advanced CNC lathe is carried out in Steel and Cast iron for a newly designed Slant Bed CNC lathe, SBCNC 80/2000. This lathe can handle work with diameters up to 80mm and 2000 mm turning length. Lathe bed machining is carried out by using face milling machines (vertical) and by using a newly purchased Danobat CNC surface grinding machine (SGD 2-6-12). As the lathe bed is slant type, it needs a fixture to keep the guide way suiting surface horizontal, while machining and assembly processes. The design requirements of the fixture were studied and cutting forces were calculated. Strap clamp which is convenient to use the fixture at different machine beds is designed and modeled. Fixture models were developed in 3D modeling softwares and analysis were carried out in Soild-Works 2013 in both materials. The design suggested in steel by the company was found to be over designed and optimization was carried out to reduce the material as well as total weight keeping the maximum allowable deflection of the fixture as 4 microns. The cast iron structures were analyzed and the result was deflection above 4	1.The design requirements of the fixture were studied and cutting forces were calculated. Strap clamp which is convenient to use the fixture at different machine beds is designed and modeled. 2. The design suggested in steel by the company was found to be over designed and optimization was carried out to reduce the material as well as total weight keeping the maximum allowable deflection of the fixture as 4 microns	The design requirements of the fixture were studied and cutting forces were calculated. Fixture models were developed in 3D modeling software Catia V5 and analysis were carried out in Soild Works 2013. The steel structure with 20 mm thickness showed enough rigidity as per basic design 2 and also found out the design suggested by the company is overdesigned. Basic design 2 is altered as per analysis and the result was excellent. So the optimized design is the modified basic design 2 with 18 mm thickness. The cast iron structures were analyzed and the result was poor and cannot be met by the design objectives. The minimum deformation obtained is above 4 microns and so cannot be suggested.	1.Tom Zacharia, Department of Mechanical Engineering, St. Joseph's College of Engineering and Technology, Mahatma Gandhi University, Kerala, India. 2. M.S. Steve, Department of Mechanical Engineering, St. Joseph's College of Engineering and Technology, Mahatma Gandhi University, Kerala, India.	International Journal of Mechanical Engineering and Research. ISSN No. 2249-0019, Volume 3, Number 4 (2013), pp. 421-430 © Research India Publications http://www.ripublication.com/ijmer.htm

		microns and so cannot be suggested. The design in steel was optimized by reducing the material to a larger extent.				

V. SCOPE OF CNC MILLIING MACHINE MODIFICATION

This above thorough Survey shows many methods of redesigning the components & parts of CNC vertical milling machine with certain improvement in structure stiffness & rigidity.

The most renowned & successful methods of improvement are:

1. By doing experiments on various material of structure & finding out most optimal & best suitable material for VMC with minimum stresses.

2. VMC structure designed with Cross & Horizontal ribs to reduce overall weight & so as the cost with improved stiffness & rigidity.

3. Design optimization process of lathe saddle helped in defining material layout for the light weight and stiffened structure for the CNC Lathe saddle.

4. Experimenting on test rig of bed manufactured with various composites.

5.Redesigning the bed of CNC milling machine with the concept of slant bed.

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