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DESIGN EVALUATION USING CAE TOOLS FOR A 3-AXIS VERTICAL MILLING MACHINE FOR SCULPTURED SURFACE MACHINING

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ABSTRACT

CNC technology has proved to be of great importance for manufacturing sector. The use of contemporary CNC systems along with higher computational and memory storage capacity of modern computer systems has redefined the shop floor automations strategies for modern manufacturing sectors. One of the biggest challenges today is how to make the CNC technology affordable, simpler and available to an extent that even a hobbyist/ occasional user can think of owing such technology. The aim of the present work is to evaluate the design of a new 3-axis CNC milling machine tool structure designed for sculptured surface machining using Finite Element Method (FEM) analysis in ANSYS .

Conceptual design for the machine tool which was achieved after a number of iterations, has been analyzed using finite element method (FEM) using ANSYS for its stability under different loading conditions. The detailed FEM study has been carried out in two main phases, for analysis of overall machine structure and secondly for router assembly. As discussed in results and discussion, it has been found that the machine structure design is safe and the maximum level of deflections and stresses found during FEM analysis are in safe limit. The logical conclusions drawn from the present study have also been discussed along with the future scope of work in this area.

1. INTRODUCTION

Automation is associated with advancements in technology. In Mass production units, since the volume of production is very high with little or limited variety, special purpose machines, automated transfer lines have been developed and used. However for job or batch production general purpose machines are being used with the large variety of components and discontinuous demand of products. In the conventional general purpose machines, skilled operator is responsible for many inputs to the machine. The operator, in addition to the physical work of handling the machine, has to do a lot of information processing like reading the drawing and checking dimensions etc. Although the general purpose machines are very flexible but this flexibility is the cost of time and productivity. With the advent in NC technology the productivity on shop floor has been enhanced, but still the NC technology is a costly affair for small scale enterprises, especially the artisans and handicraft workers.

Main components in cnc machining centre: The figure 1 shows the schematic diagram depicting the overall organization of CNC system.

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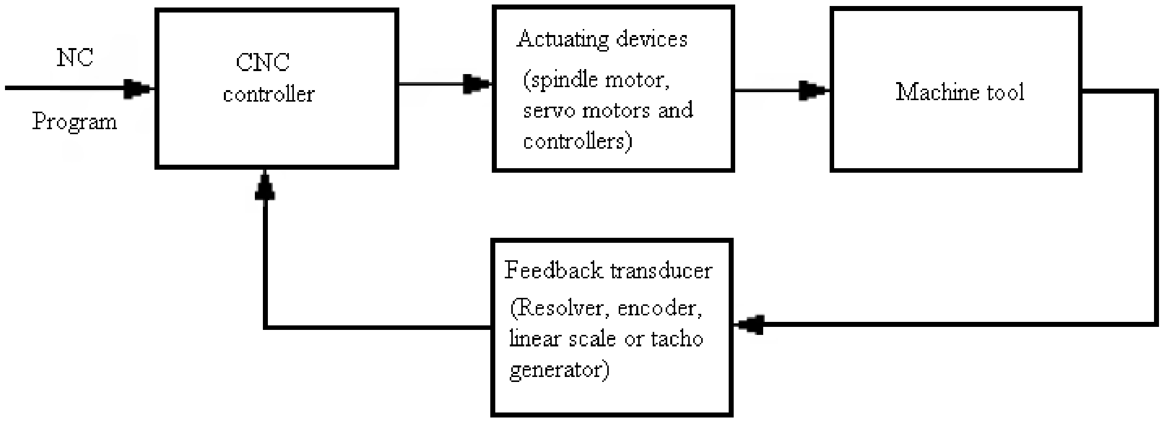

Figure 1: Schematic diagram of CNC

2. LITERATURE REVIEW

Jo¨nssonet al [1] highlighted that while designing CNC machine tools it is important to consider the dynamics of the control, the electrical components and the mechanical structure of the machine simultaneously. This paper describes the structure and implementation of a concept for real-time simulation of such machine tools using a water jet cutting machine as an application. The concept includes a real control system, simulation models of the dynamics of the machine and a virtual reality model for visualization. However, already from the initial simulation results presented in the paper it could be concluded that the influence of structural flexibility on manufacturing accuracy is of importance at desired feeding rates and accelerations. The fully automated implementation developed in this work is a promising base for dealing with this trade-off between productivity and accuracy of the manufacturing process through multidisciplinary optimization.

Zulaikaet al [2] has presented an integrated approach for designing large milling machines, taking both mass reduction of mobile structural components and the maximum material removal rate into account. This approach considers milling operation and a productivity target as a starting point, and then deals with the design of the machine to achieve the targeted productivity with structural components of minimum mass. The procedure is based on modelling the interactions between process and machine by means of a stability model of the milling process in modal coordinates. The model allows the identification of the mechanical design parameters that limit the productivity as well as the threshold values that must be met to ensure the targeted productivity. Those values are reached in an iterative procedure that minimizes the mass of the critical structural components of the machine.

Son et al [3] described the development of a three-degrees-of-freedom (DOF) desktop reconfigurable machine tool. In this paper, the conceptual design of a desktop reconfigurable machine, which is capable of controlling the three DOF orientation of a spindle, was presented. Then, static and dynamic structural analyses were performed to characterize the effect of vibration on the manufacturing performance. The results demonstrated the feasibility of simultaneously controlling the position and orientation of the machine tool during the machining operation. Dynamic simulations and experimental results using a closed-loop control with position feedback were presented to illustrate the performance and features of the system. Unlike conventional full-scale manufacturing machines, the developed machine provided a number of advantages, including fast dynamic response, have simpler design, low cost, and a compact but relatively large workspace without motion singularities.

Dong et al [4] discussed the development and performance evaluation of a high-speed, 3- axis milling machine using a novel parallel kinematics x-y table. The x-y table is based on an inversion of the Oldham coupling. The advantages of this kinematic configuration include low inertia, uniform kinematic conditioning, and dynamically matched axis. The design of the x-y table makes this system particularly well suited for high-speed contouring in the x-y plane. The kinematics, dynamics, and mechanical design of the system have been evaluated. On the basis of linear and circular contouring experiments conducted to

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evaluate the system capabilities. The stiffness of both the mechanism as well as the direct drive actuation system were measured and reported. The experimental results demonstrate that the proposed mechanism offers an attractive combination of performance characteristics for high-speed contouring and high-speedmachining.

Padayacheeet al [5] developed reconfigurable Manufacturing System (RMS) paradigm address challenges in the design of manufacturing systems and equipment that will meet the demands of modern manufacturing. This research involved the development of Modular Reconfigurable Machines (MRMs) as an emerging technology in reconfigurable manufacturing. MRMs are mechanically modular machines. It focuses on aspects of the mechanical design and the development of a control system that supported the modularity and configurability of the mechanical platform. This is complemented by a software architecture that has been developed with a focus on hardware abstraction for the management of an augmented mechanical and electronic architecture. The implications of MRMs for RMSs were discussed and key inhibitors to industrial implementation were identified.

Youssef et al [6] stated that modularity and configurability of the building blocks of modern manufacturing systems have to be considered when evaluating their performance. The paper proposed a model for evaluating system availability and expected production rates for manufacturing systems that were composed of unreliable modular machines with multiple functionally parallel production units. The results show that machines with a larger number of modules, usually thought of as having lower availability, provided higher overall system availability in the case of machines with multiple spindles. Based on the new analysis and results, it is recommended that system designers favorably consider machines with multiple spindles rather than increasing the number of machines in parallel. These results provide an important support for the use of modular/ reconfigurable equipment compared with traditional equipment, in spite of the highercost.

Gallardo et al [7] addressed the kinematics, including position, velocity and acceleration analyses, of a modular spatial hyper-redundant manipulator built with a variable number of serially connected identical mechanical modules with autonomous motions. First, the kinematics of the base module, a three-legged in-parallel manipulator, was formulated using the theory of screws. After that, the results thus obtained, were applied recursively for accomplishing the kinematic analyses of the hyper-redundant manipulator at hand.

Eymaet al [8] explained that the correlation between density and cutting forces in wood machining was not perfect and that some exceptions could not be explained. These difficulties have easily been explained by the anisotropy of wood material. It is appeared that mechanical properties could explain some exceptions in the relationship between density and cutting forces. The mechanical properties lead to further information on the wood species behavior during machining and improve the accuracy of the relationship between cutting forces and wood species. Moreover, it appears clearly that parameters links to wood elastic behavior were best factors to explain wood machining and strains involved (and not failure strainorfractureenergy).Infact,woodmachiningseemedtobemoreaphenomenalinksto elastic stresses than to failure strains. These tests must be allowed to take into account the quickness and the impact during machining. So it is possible that this kind of tests leads to new information on wood behavior during machining. Moreover, it appeared clearly that the measure of mechanical properties was done at low deformation quickness, in opposition to machining (high quickness). This difference could perhaps explain why correlations were not perfect and so give limits of the use of simple mechanical characteristics.

3. COMPUTER AIDED ANALYSIS OF MACHINE STRUCTURE

In this paper design evaluation of a 3-axis vertical milling machine has been discussed. “ANSYS 10.0” has been used as CAE tool for design analysis. Basic aim of the present work is to develop a low cost CNC 3-axis vertical wood carving machine. The machine grade steel materials are very costly and further the machining cost is higher for these machine grade steels. Also a number of post machining operations like heat treatments and surface grinding are required to get the components made from such materials to their final usable shape. Considering the factor of cost for CNC machining of machine grade steel and the associated cost of post machining treatments it was decided to use mild steel as material for making components for the present prototype. It would be helpful to the future users of the machine (artisans in remote locations) as for replacement of machine parts/ spare parts can be made available using conventional machining with fair accuracy as well as cost effectively.

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Table 1:Properties of different materials

S. No.	Description/ Material Property	Value/ Magnitude (for hardened steel)	Value/ Magnitude (for AluminumAlloy)	Value/ Magnitude (for High SpeedSteel)
1	Density	7.85×10^{-6} kg/mm^3	2.77×10^{-6} kg/mm^3	7.85×10^{-6} kg/mm^3
2	Young's Modulus	$2.08e \times 10^5$MPa	71000 MPa	2.04×10^5MPa
3	Poisson's Ratio	0.33	0.33	0.31
4	Compressive Yield Strength	250 MPa	280 MPa	250 MPa
5	Tensile Yield Strength	250 MPa	280 MPa	250 MPa
6	Tensile Ultimate Strength	460 MPa	310 MPa	260 MPa
7	Reference Temperature	22°C	22°C	22°C
8	Bulk Modulus	2.0392×10^5MPa	69608 MPa	1.7895×10^5MPa
9	Shear Modulus	78195 MPa	26692 MPa	77863 MPa

4. FEM ANALYSIS OF MAIN MACHINE STRUCTURE CONSIDERING ALL COMPONETS

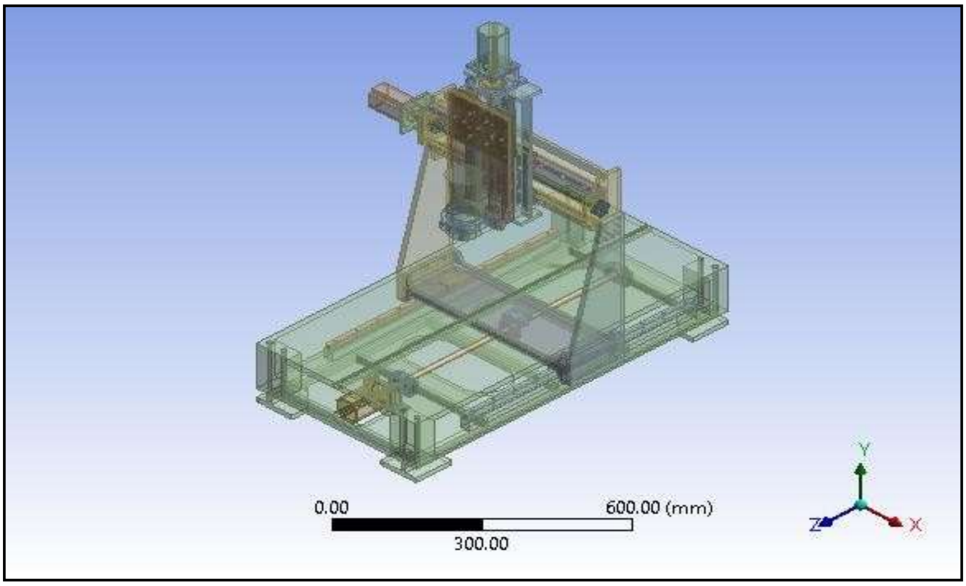

Figure 2-Axis Machine Tool model for Analysis

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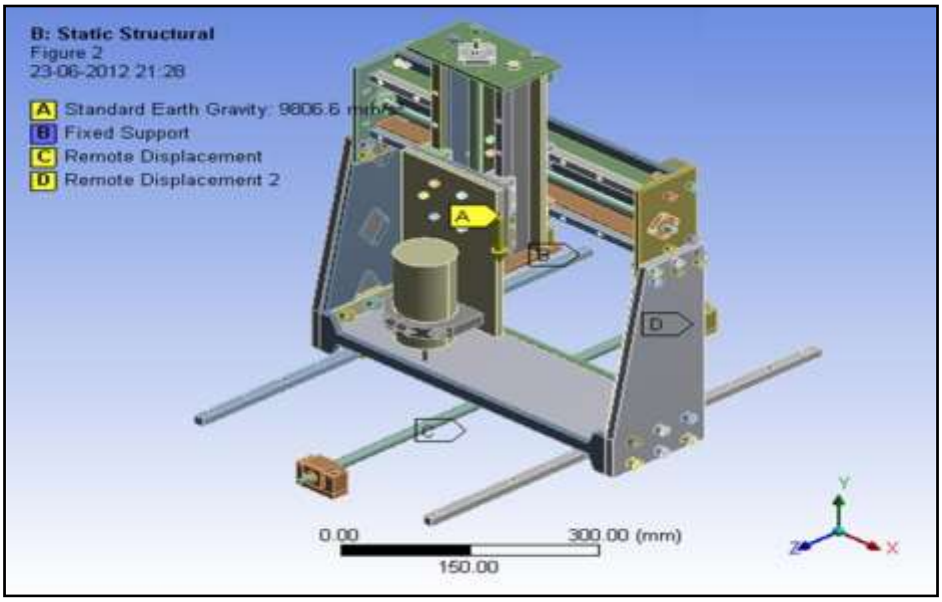

Figure 3 Boundary conditions for the Model

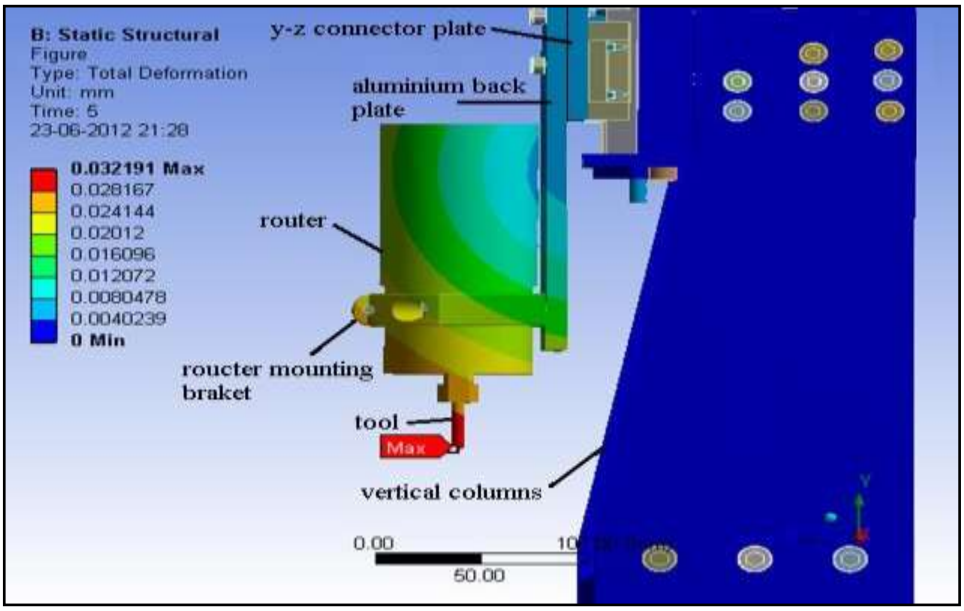

Figure 4 Deformation of whole structure

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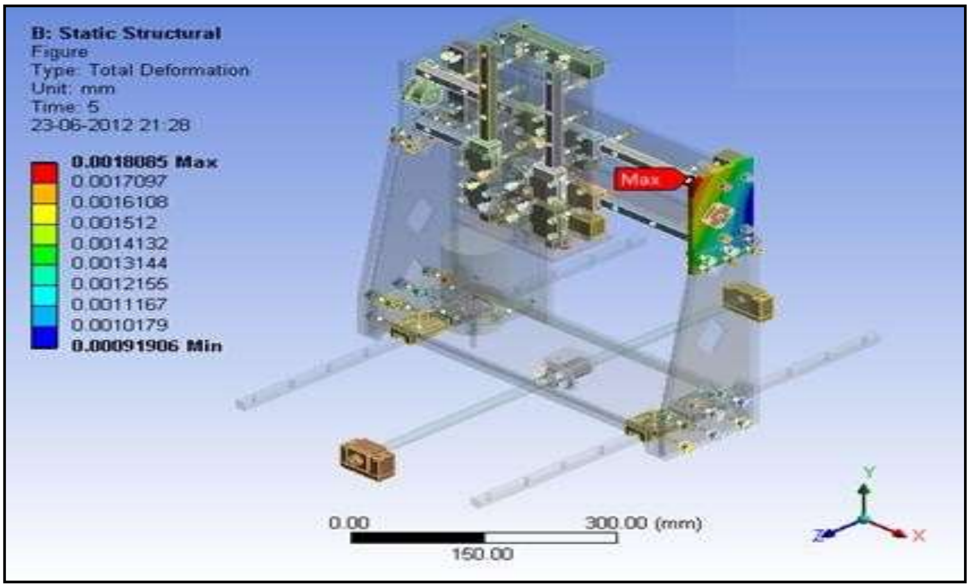

Figure 5. Deformation on the end plate of y-axis

Equivalent (Von-Mises) stress

As shown in figure 6, the maximum deformation has occurred only in router mounting bracket when a bolt pretention of 3400N is applied along with the cutting reaction force in upwards direction along Z-axis of 46N. The magnitude of the maximum stress is 202.41 MPa, whereas the safe limit for stress in aluminum is 280. Thus this design of router mounting bracket is safe under this loading condition.

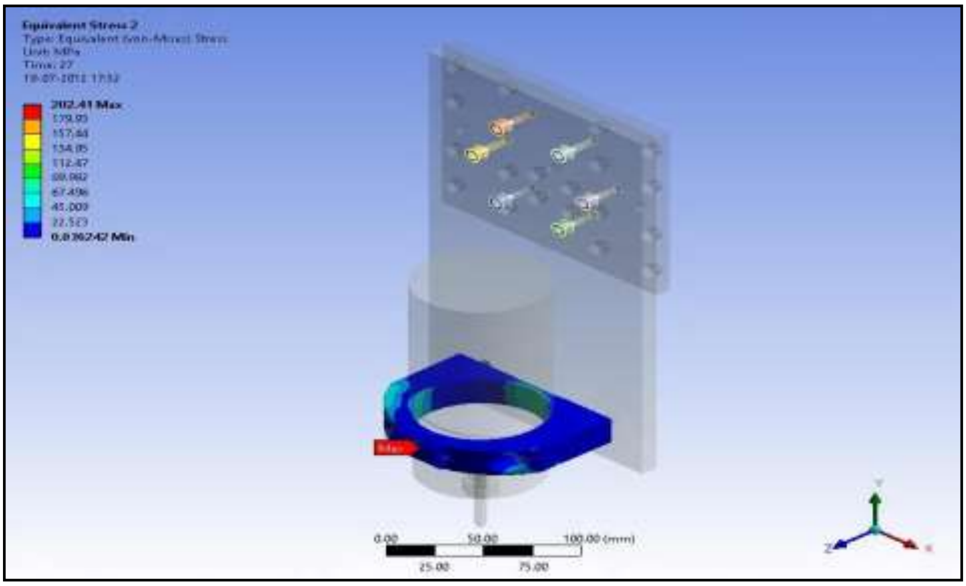

Figure 6 Equivalent stress on mounting bracket

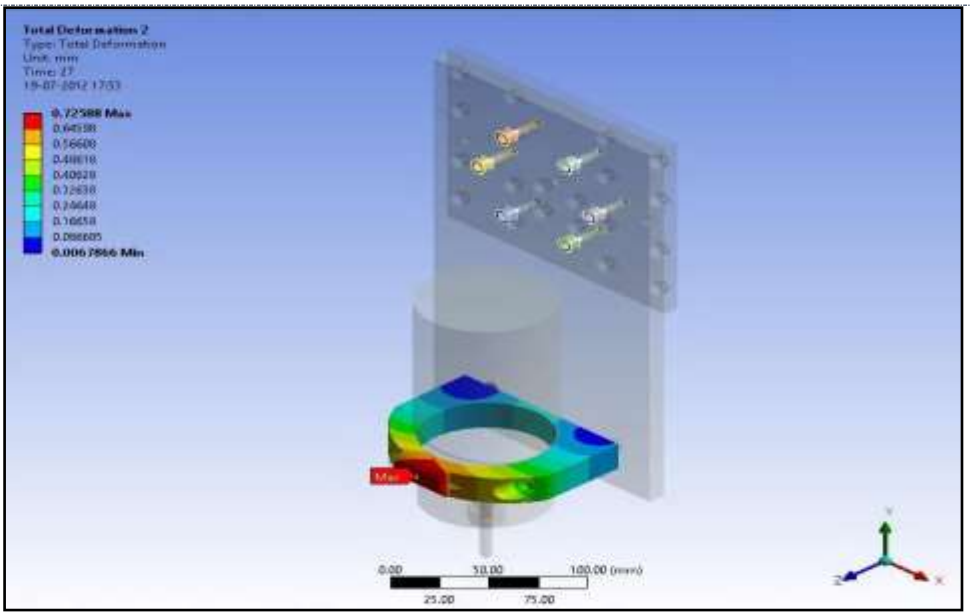

Figure 7: Deformation in mounting bracket

Slippage between router and mounting bracket in vertical direction

The maximum slip between router mounting bracket and router after 22 second when the bolt have been tightened with a pretention of 3400N is 0.083587mm and maximum slip after application of reaction of cutting force of 46N in upwards direction along z-direction is 0.082946 mm. The value of coefficient of sliding friction between two mating surfaces of aluminum has been taken as 1.35. If considering the time interval from 22 to 27 seconds when the reaction of cutting force is applied, the net slippage is 0.000641 mm in upwards direction which is also under safety limit, as compared to the deflection of 0.03mm at tool tip under the self-load condition as explained.

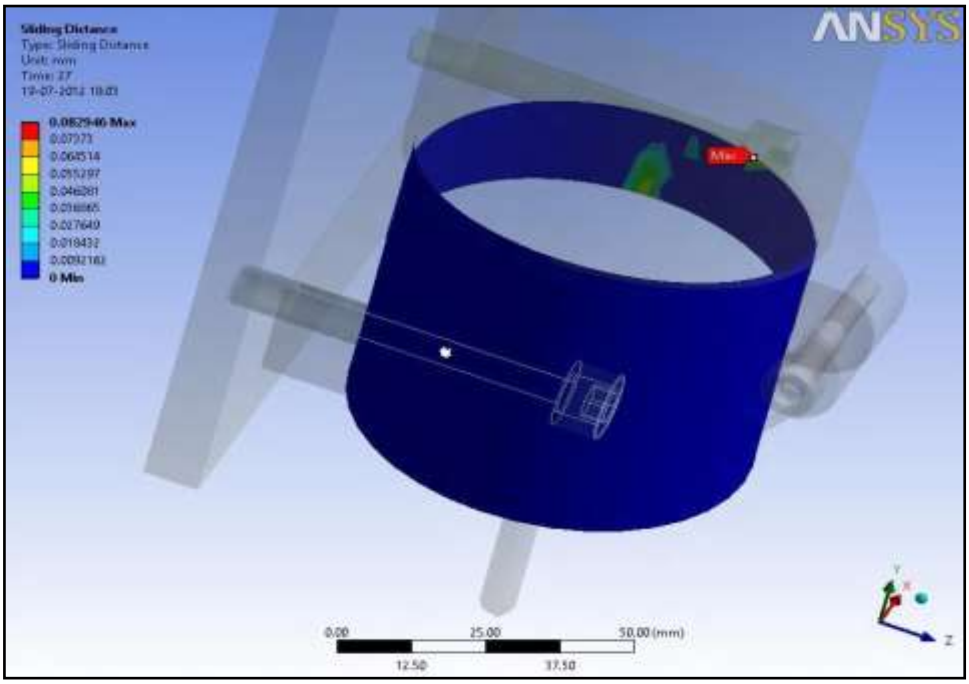

Figure 8: Slippage between router and bracket mounting when force in z–direction is applied

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5. CONCLUSION

In the present work a detailed study for the design development and evaluation has been done. The design of the machine structure is safe and suitable. One of the approaches followed for design of machine tool was modular design which has many advantages like simplification of constituent components in terms of their design, manufacturing and easy replacement after their service life. The conclusions drawn from the present study are as follows:

- The design of machine structure is safe for the standard gravity force..
- The design of machine structure is safe for maximum feed rate value of 300mm/min and maximum depth of cut of 8mm with tool of 12.7mm diameter, in addition considering a factor of safety is2.0.
- The maximum slippage observed in the router after application of reaction cutting force is also under safelimits

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