International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-08, Issue-02, MAY 2022

Design and Optimization of CNC Milling Machine's Structural bed using parametric analysis

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Abstract **In the area of engineering, the solution of many complex issues is virtually endless, and analytical methods are almost always ineffective. Machine tools are utilized in industrial operations for high precision and reproducibility. Several components, such as the base, machine table, saddle, knee, headstock, and column, are often the essential pieces of machine tools in order to achieve reliable operation. On the machine table, the work item is held and supported. To produce a good completed and accurate work piece on a three axis CNC milling machine, the machine table must be sufficiently sturdy and have appropriate mechanical qualities. A finite element analysis (FEA) provides a methodical study of failure principles that aids in the advancement of 3 axis milling machine's tables to Foundation Bed. Static and Dynamic analysis is discussed in this paper. In this work, a static analysis is performed on a machine Foundation bed to determine the stresses values which is generated, as well as the Bed's deformation due to its weight and Cutting Forces. The finite element analysis is carried out using CREO software which is used to create 3D geometry and ANSYS software to analysis the results. The Result of Machine tool's Bed compares the Cast Iron, Carbon steel And UHM CFRP materials.**

Keywords* — *UHM CFRP, Foundation of milling machine tool, Hybrid milling machine bed

I. INTRODUCTION

The Fast-growing Manufacturing Industries needs High Accuracy with lesser Product Cycle time with Optimum Cost. In This Computational Situation Global markets push manufactures to reduce design cycle and manufacturing time without affecting cost of their products. To overcome this kind of Problem CNC Machine tool is a grate option. CNC (Computer Numerical Control) is dedicated and adaptable form of soft automation. CNC Machine tool Motion and Function Controlled by Pre-Prepared Code which have alphanumeric data (NC Code). In a Development of machine tool use of structure material and designed structural play a vibrant role in precision, productivity of parts and surface finish. During machining process Generated vibration get conveyed into machine tool. Manufacture structure with Modern material which has Higher Stiffness and good Damping abilities, help us to achieve faster cutting speeds. The Conventional material like Cast Iron use in Precision machine tool is Developed Positional error during High speed and transfer vibration into Foundation. To Handle This Problem, we Search for alternative material which have has Higher Stiffness and good Damping abilities and find Ultra High Modulus Carbon Fiber Reinforced Polymer (UHM CFRP). Design of CNC machine tool is Much Difficult to analyses by using analytical method.so; we carried out FEA analysis To Find deformation, Generated stress, natural frequency and displacement Static Structural and Modal analysis. Reduction of weight is also a Necessity so Changes in Design of Structural bed without declining its structural rigidity. 3D CAD model of Foundation bed is created through CREO 8.0 and Performing analysis and Changes In design by study Result of ANSYS. In this study our motto to increasing or maintaining the structural Index and reducing the structural weight.

The dynamics of the particular machining operation and nature of the forces applied, the effective design of machine tool structures needs an extensive knowledge of their forms designs and material properties. The Machine tools all component supports by the Foundation bed. A Machine bed must be sufficiently rigid and have strong mechanical qualities to produce a good finished on CNC milling machine. A finite element analysis (FEA) provides a systematic examination of the failure principle. The precision of machine tools is commonly assumed to be determined by their static and dynamic characteristics. Particularly in high-speed, precision machine tool structures, dynamic features play an important role,

 DOI : 10.35291/2454-9150.2022.0194

considering vibration during the machining process causes chatter marks on the machined surface, resulting in a noisy environment. New research has been published in the topic of enhancing the structural design of machine tools by increasing stiffness and reducing weight, which is particularly important for structural sections such as the base, machine table, saddle, knee, headstock, and column. Stiffening-rib prearrangement in machine tool systems is an important element for structural stiffness and material utilization. As a result, the stiffening-ribs' decreasing design is critical for machining performance and energy savings. High static rigidity, despite bending and twisting, and good dynamic properties, as seen by a high natural frequency and damping ratio. Engineers aim for strong long-term dimensional stability, a low coefficient of expansion, cheap cost, and minimal material requirements in machine tool structures when designing and producing them in production. Machine beds are presently built of grey cast iron, which causes a number of issues with machine tools. When the load spans ultimate loads, cast iron cannot withstand the unexpected loads and fails without warning

II. LITERATURE SURVEY

A. LITERATURE SURVEY

Sagar Pandit Mahajanet al. [1] conducted a study on an existing bed in which a conventional material was replaced with a composite material for increased strength, rigidity, and stiffness. Because of its high stiffness, composite deformation is minimal. The design life of the machine bed has improved, according to FEA analysis. Static analysis was carried out for the load applied, and the findings were compared in three ways: (1) both components constructed of grey cast iron (2) bed grey carbon fiber composite and Grey CI Work piece (3) bed grey CI and SS Work piece Due to its higher modulus of elasticity, the total deformation of the composite material is less than that of two materials. Finally, we can claim that the usage of carbon fiber composites is helpful to industry because different stress and deformation are kept to a minimum. (Deformation due to stress (MPa)) (mm). They used a 450 Newton pressure on the line of contact among the tool and the work piece.

Ch. Sridhar Yesaswi. [2] Have used a Nano material Graphene (monolayer of sp2-hybridized carbon molecules thickly stuffed like honeycomb) for machine tool and load is applied on bed without Nano coating on the material and with composite materials. Graphene is only used for coating on their strength and thermal properties. Modeling of the bed was done in Solid works and ANSYS is used for structural analysis. Hear applied tangential cutting force, radial force and feed force of total value of 717 N.in a worktable total 272N force considered by the tool at a working condition. Key parameters are Machine Tool, Machine Bed, Stiffness, Damping, SOLID WORKS, ANSYS in a paper they Comparison of Von-mises Stress (Pa), Total deformation (m) and Different frequency. The machine tool's bed's static properties have been improved. In the machine tool industry, nanomaterials give high specific modulus and specific strength while weighing less. Nano coated machine beds have less deformation and strain than traditional cast iron machine bed for their specific rigidity is higher than cast iron.

Amit Kumaret al. [3] used a configuration principle for redesign to improvement of static and dynamic performances of exciting structural bed. Analysis results show that the static and dynamic performances have been improved by the using vertical Stiffeners with hollow bed. Static and dynamic experiments expression that the deflection and mass are reduced by 8.08%% and 3.66% respectively and lower order natural frequencies are amplified. The traditional design of machine initial natural frequencies of vertical Stiffeners with muffled bed one was improved by around thirty one percent using structural vertical ribs with hollow bed one. The remaining frequencies, however, were far lower than the original type.

Jayachandra kambale [4] in a study suggests that Carbon Fiber Composite is most suited for CNC machine beds. Based on configuration principles, the previous bed material was switched to AISI1065 carbon steel material, which improved the static properties. The static characteristics of the machine bed have been improved, according to simulation results. These composite materials provide great precision and precession of the component generated in composite machine machines. Because the specific strength and specific stiffness of Carbon Fiber, AISI1065 carbon steel machine bed is more than grey cast iron, the induced deformation and strain in Carbon Fiber, AISI1065 carbon steel machine bed is smaller than traditional grey cast iron machine beds.

Sruthi Srinivasanet al. [5] MMCs are light weight, rigid, and have a low specific weight, according to researcher. As a result, we studied material weight reduction without sacrificing their qualities. Strength, thermal stability, fracture toughness and ductility, as well as increased high temperature performance, are all advantages of MMCs. According to the researcher, weight & cutting force of the work table and self-weight of the job are transmitted through the front end of the machine bed, resulting in a total load of 272 N being applied to the machine bed's guide-ways. The back end of the machine bed supports a vertical column as well as additional

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fixtures (such as servo motors and spindles). An entire load of 717N will be applied to the back end's two flat surfaces. And a comparison of the stressors Normal Stress versus Misses Stress Because of its high Young's Modulus, the total deformation of the Jute Composite machine bed is less than that of cast iron. Because generated stress is more released than material property, the stress imposed on all machine beds is roughly the same because no design changes are made. The optimum materials for CNC milling machine beds, according to this paper, are jute and glass fiber.

A.Merlo et al [6] The combination of modern materials (steel, Al honeycomb, CFRP,) and a concentrated use of laminates technology allows to improvement of damping while maintaining a steady mass decrease (up to 40%) without decreasing overall stiffness. Through a thermo-structural forecast model based on real-time sensor readings, the CFRP structure can compensate for geometrical aberrations. An assessment study of structural performance of a precision milling machine tool component created using various opposite material properties was also carried out.

B. *Objectives of work*

From the Literature review it has been observed that most of research work done to overcome, opposing and unwanted effects of these vibrations which contain decrease in tool life, inappropriate surface finish, unwelcome noise and unnecessary load on the machine tool. So, the machines are to be made structural Rigid by using of strong structured materials and Modification of Design concluded passive damping terminology to conquer the chatter vibrations and, in that way, increasing the manufacturing speed. The work's main goal is to investigate passive damping techniques in machine tool structures (foundation) using composite materials. With the goal of reducing vibrations in milling machines during cutting processes by using these materials as the work piece's base, which acts as a vibration-absorbing bed. Because of their inherent damping properties, composites can be employed in machine tool structures to lessen the negative impacts of vibrations. As above research they successively work on Cast iron, Steel, Aluminum alloys and HS/HM CFRP material but in a UHM CFRP have only little work available. Major research work only by change a material no one study geometry changes to improve rigidity so we work further on that by structural change on a machining bed with different available materials. To create optimal solution and try to increase structural rigidity of structure using structural changes the previous research papers of the machine bed the following defects are found: Increased weight, Vibration during process, cannot bear sudden loads, Casting defects of bed so we try to improve structural bed by using UHM CFRP composite material and Structural modifications. Machine mechanisms such as component vibration isolation, unique spring, rotating shafts designs that contain damping without the use of outmoded dashpots or shock absorbers, and structural supports have all benefited from passive damping technology. Reduce weight without sacrificing structure rigidity by studying structure design.[7]

C. *Methodology*

The machine bed played a crucial part in the strength and rigidity of the machining tool. All elements such as the base, machine table, saddle support, knee, headstock, column spindle hub, work table, and other accessories and controlling elements are supported by the machine bed. Cutting force is also easily shifted to the machine bed. As a result, its design of Machining Foundation bed is critical for machine performance and precision. Rotary and transitory pieces move or change Location as programming code in a machine tool. In this scenario, both static and dynamic forces are produced. So, in order to retain correct products, the bed must have superior damping capabilities and a greater structural index. To meet this demand, we combine structure design with appropriate material combinations.

Most Commonly Used a material for machine tool structure is cast iron. So, we Choose Alternative material which have Good Material Properties and Study them. Carbon steel and UHM CFRP best replacement of cast iron. Carbon steel has good stiffness and UHM CFRP Also Good dimpling and stiffness ratio to weight. So, In Study we Consider Following material and their properties as Material design input. Cast Iron and Carbon Steel have pre-defined Material properties in ANSYS Workbench. UHM CFRP Material Properties Define as Below Table.[8]

Tensile strength: 1607 MPa	Ultimate strain: 0.3-0.4%
Tensile modulus: 460-479 G pa	Fiber content: 0.71
4.4 Gpa1/3/(Mg/m3)	Mean failure strain: 0.163 %
Damping coefficient: 1.5×10-3¸3×10-3	

3D Model of CNC Structure Parts Modelled in CREO Software and Input in ANSYS as STEP File. Apply Load as Mention Is Design case.as below Figure We Perform analysis study each data and update design step by step. Study

 DOI : 10.35291/2454-9150.2022.0194

ISSN : 2454-9150 Vol-08, Issue-02, MAY 2022

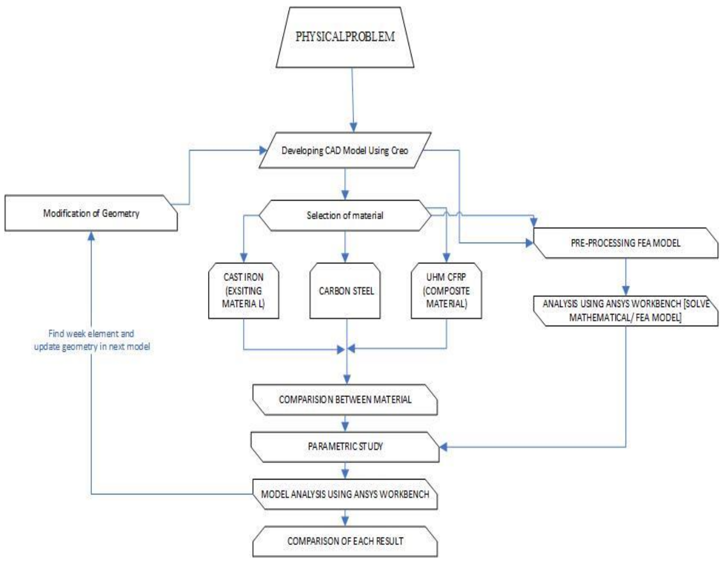


Fig : Steps of Parametric analysis

III. DESIGN CASES AND MODEL CONFIGURATIONS

First, we Import design Model Form CREO to ANSYS 2021 R2. Mesh Size is 8 mm and elements and nodes are 1245785 & 421547 respectively. Material is Carbon steel, cast iron and UHM CFRP. Result plot Deformation and Equivalent Stress. Design loading as describe below.

A parametric analysis method using FEA based static and dynamic analysis using ANSYS software, Choose a existing geometry and perform analysis and find critical parts and update each modified bed perform analysis at same loads and boundary conditions.

Primary Members Dead Load, Standard earth gravity, Cutting Forces and Moments and work piece weight as Input in This design case. At the conclusion of the simulation, the achieved response force is multiplied by the (1) Self-weight and live weight (2) Rotary equipment forces and moments (3) Cutting forces, thrust, and moment.

In this Case Forces and Displacement boundary condition applied as Follows forces rear end of the machine tool carries cutting forces, weight of the work table, saddle support and weight of workpiece. Worktable Carries Cutting Forces, thrust and Moment. Back end carries Spindle hub, Motor, and Column self-weight applied on two flat surfaces of Front end.[9]

- **Total weight of Machine** = 4100 Kg.
- **Load acting on rear end of Machine Bed** = 1200 Kg. =12000 N
- **Weight of the Work Table** = 300 Kg
- **Standard earth gravity**
- **Servo Motor assembly:** 500 N
- **Force on Spindle hub due to Servo motor** = 102 kg = 1000 N
- **Moment Due to Servo motor** = 71000 N.m
- **Diameter D =** 63 mm
- **Feed rate f =** 6mm/rev
- **Cutting speed v =** 23.75 m/min

Total forces and moment acting on guide ways = Torque and Moment on Spindle (carbide tool)

- **Cutting Force and Cutting thrust: Fz [10]**

  Fz = (-79 + 51.4D +1.22V -504F - 2.65*D*D-0.0102*V*V +2038*f*f + 0.128*D*V + 1 87*D*F + 0.07*Vf) N

  = 133896 N (addition of work piece weight)

  = 145668 N

- **Cutting Moment: Mz [10]**

  Mz = (1.51-0.309D + 0.00236V+1.06F + 0.016*D*D- 0.000037*V*V - 12.5*f*f +0 .000208D*V + 1.33D*F+0.0213V*F) (N*m)

  = 108.03 N*m

All above calculated loads applied on the machine bed during the further analysis.

IV. DESIGN MODELLING AND ANALYSIS OF MACHINE BED

CREO 8.0 was used to produce a 3D model of a CNC machine, which was then exported to STEP format for loading into ANSYS Workbench 2021 r2. The study looked at three different materials: carbon steel, cast iron, and UHM CFRP. We looked at Forces and Displacement Boundary Conditions in a separate scenario. Cutting Forces, trust and moments, work piece weight, and other successive bod's weight are carried by Following Forces in a front-end Machine tool bed so that force is placed on a Guide ways of machine tool bed. A Column, spindle hub, and other accessories such as servo motors, tool changers, and others are carried by the machine tool's back end. We explore the geometry below in the Design.

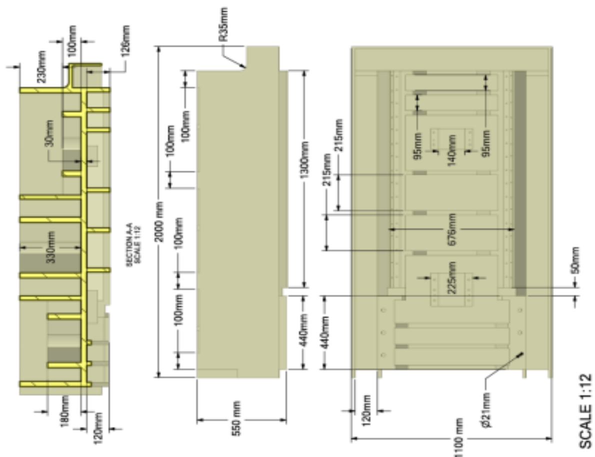


Fig. 2 Design Configuration 1-7

 DOI : 10.35291/2454-9150.2022.0194

International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-08, Issue-02, MAY 2022

Design Configuration 8 have made Frame Using structural material and Hollow section fill with RCC concrete in this case structural material reduce by 70%.as bellow fig we create structure frame and apply load of case 1.In using this configuration weight increase two times by ordinary but give significant result summery with grate reduction in material. In total mass only 15 % Weight is structural material.

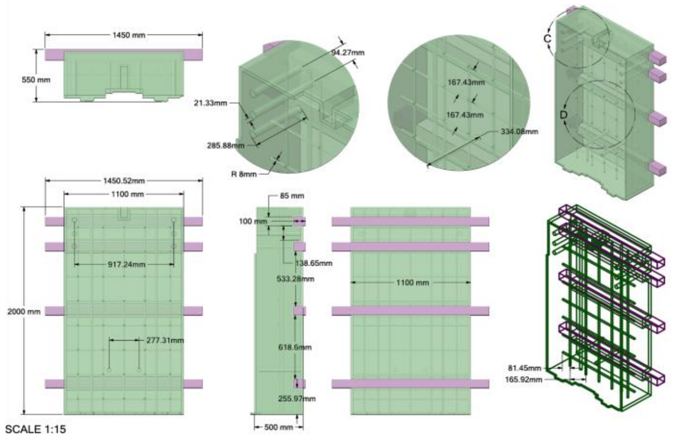


Fig. 3 Design Configuration 8

Design modeling basic frame is same for all configuration but Rib design differ from each other.as bellow fig all design is similar but bottom rib changed in all configuration as below fig: A to C

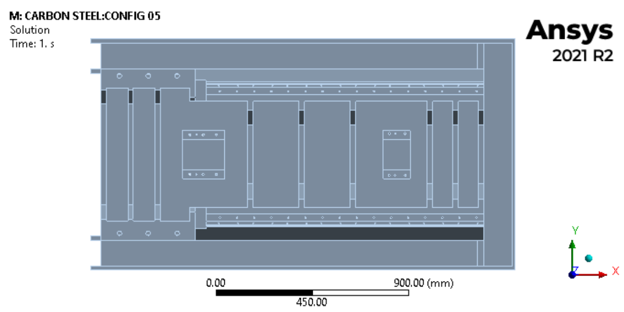


Fig A: 3D Model of Stuructural bed (top)

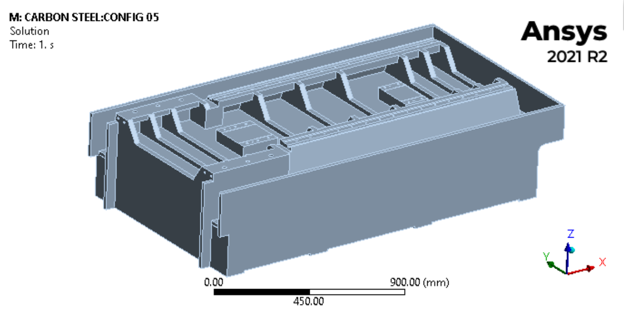


Fig B : 3D Model of Stuructural bed

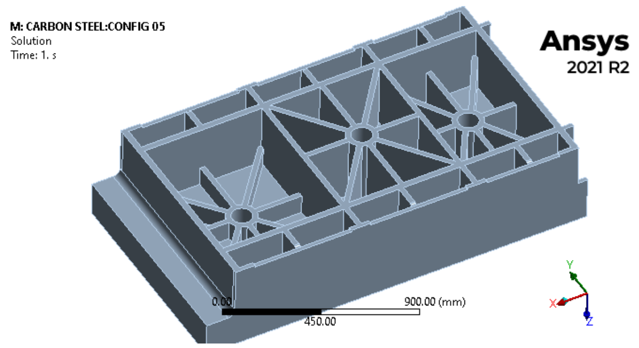
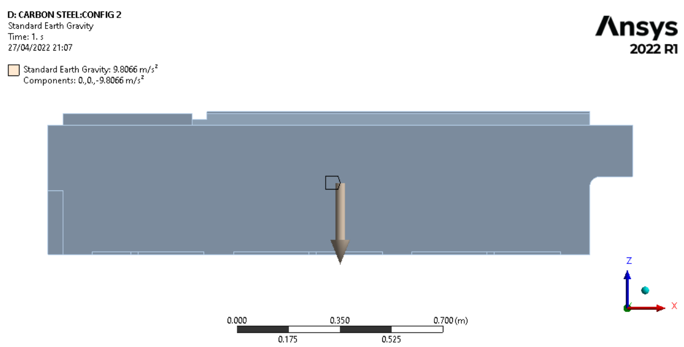
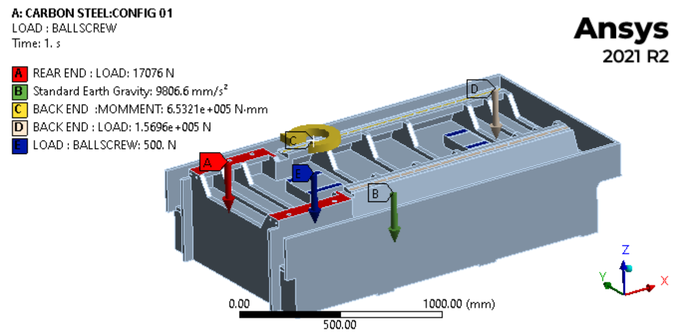


Fig C : 3D Model of Stuructural bed

A parametric analysis method using FEA based static and dynamic analysis using ANSYS software, Choose a existing geometry and perform analysis and find critical parts and update each modified bed perform analysis at same loads and boundary conditions. Static analysis loading condition: all loading and boundary conditions for all as bellow Fig: design case.



[A] Standerd Earth Gravity



[B] Input of loding Condition

Static analysis design configuration: multiple geometry configurations As Configuration fig (1) to (8), due to size limitation we can't provide graphical plot each case result in this paper so we provide comparison result bellow result summery. Configuration 1 to 5 Have all plate thickness 25 mm.in a Configuration 6 to 7 plate thickness reductions to 20 mm. And Configuration 8 has Frame Thickness 25 mm and core fill with concrete.

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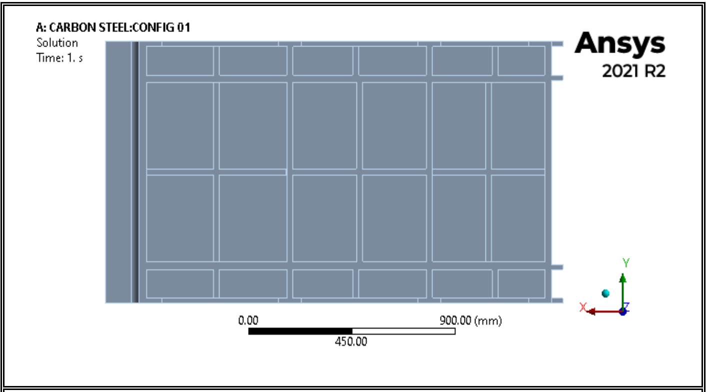
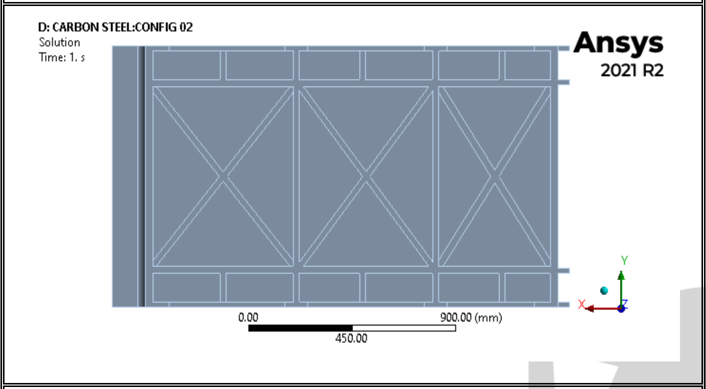
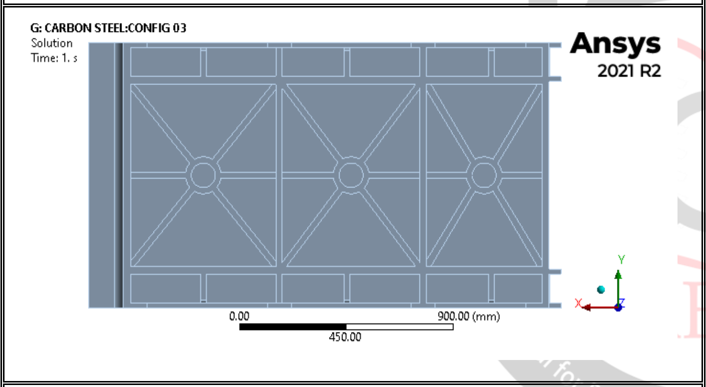


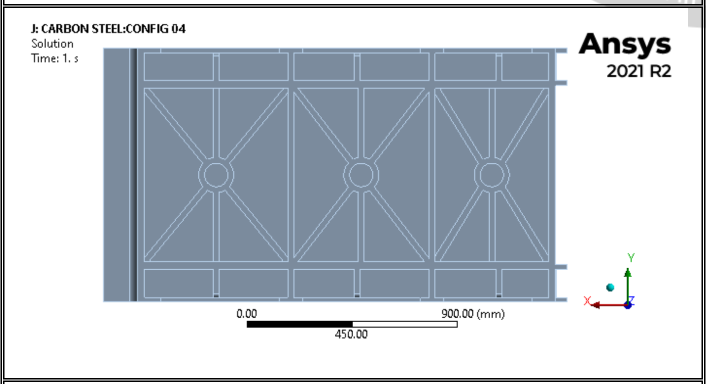
Configuration [1]



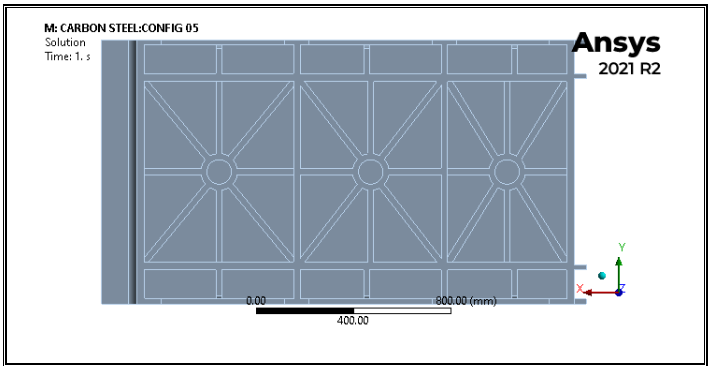
Configuration [2]



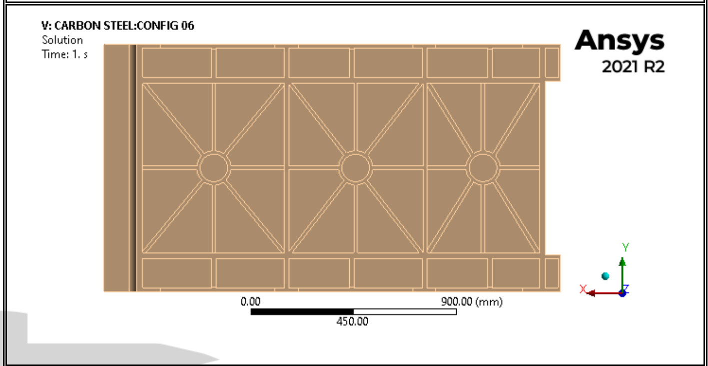
Configuration [3]



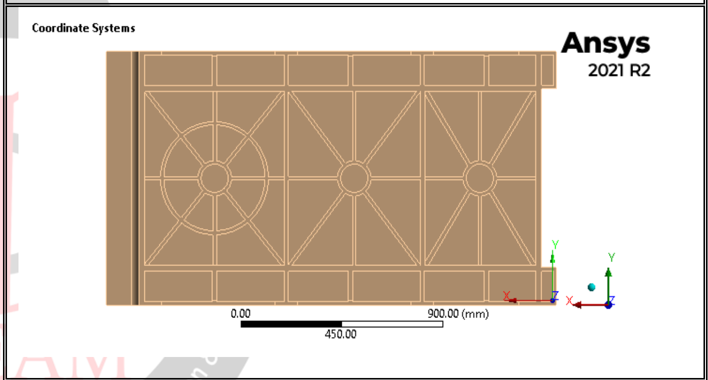
Configuration [4]



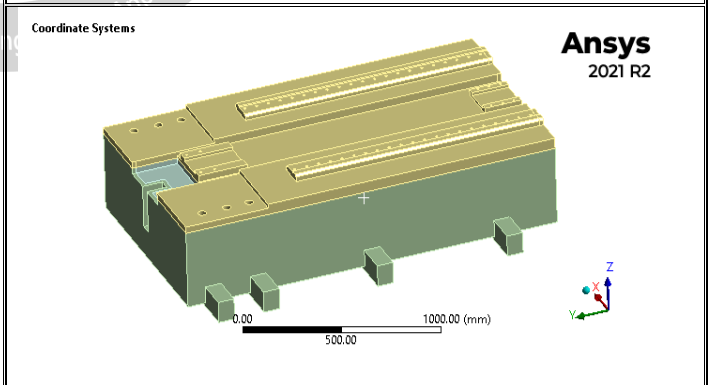
Configuration [5]



Configuration [6]



Configuration [7]



Configuration [8]

V. RESULT SUMMARY AND DISCUSSION OF STATIC ANALYSIS

A. Result summary:

Comparison of the result obtain from analysis under static load is given in bellow Configuration 1 to 8 compared in

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table. Allowable deformation for machine tool 0.5 mm. which is large scale milling machine accuracy or tolerance.

i. Result summary and discussion Static Result analysis (Static structural analysis)

	CARBON STEEL	CAST IRON	UHM CFRP
BED GEOMETRY 1	2.81E-02	6.89E-02	2.13E-01
BED GEOMETRY 2	2.49E-02	5.88E-02	1.97E-01
BED GEOMETRY 3	2.39E-02	5.66E-02	1.91E-01
BED GEOMETRY 4	2.39E-02	5.64E-02	1.89E-01
BED GEOMETRY 5	2.29E-02	5.40E-02	1.82E-01
BED GEOMETRY 6	4.93E-02	1.17E-01	3.01E-01
BED GEOMETRY 7	3.65E-02	8.71E-02	2.33E-01
BED GEOMETRY 8	4.40E-03	5.80E-03	2.28E-02

Table 1: Comparison of Deformation result of different design configurations (millimeter-mm)

	CARBON STEEL	CAST IRON	UHM CFRP
BED GEOMETRY 1	1.22E+01	1.24E+01	3.71E+01
BED GEOMETRY 2	1.09E+01	1.10E+01	4.05 E+01
BED GEOMETRY 3	1.06E+01	1.08E+01	4.38E+01
BED GEOMETRY 4	1.15E+01	1.18E+01	4.04E+01
BED GEOMETRY 5	1.15E+01	1.18E+01	3.80E+01
BED GEOMETRY 6	1.92E+01	1.91E+01	9.32E+01
BED GEOMETRY 7	1.52E+01	1.50E+01	7.59E+01
BED GEOMETRY 8	2.37E+00	1.64E+00	9.14E+00

Table 2: Comparison of EQ Von-misses stress result of different design configurations (mega Pascal-Mpa)

	CARBON STEEL	CAST IRON	UHM CFRP
BED GEOMETRY 1	1.69E+03	1.53E+03	4.92E+02
BED GEOMETRY 2	1.77E+03	1.60E+03	5.15E+02
BED GEOMETRY 3	1.81E+03	1.63E+03	5.24E+02
BED GEOMETRY 4	1.83E+03	1.65E+03	5.31E+02
BED GEOMETRY 5	1.88E+03	1.70E+03	5.45E+02
BED GEOMETRY 6	1.49E+03	1.35E+03	4.32E+02
BED GEOMETRY 7	1.50E+03	1.35E+03	4.35E+02
BED GEOMETRY 8	3.80E+03	3.61E+03	2.35E+03

Table 3: Weight Summery of different design configurations (Kilogram-Kg)

	CARBON STEEL	CAST IRON	UHM CFRP
BED GEOMETRY 1	3748.236	1138.336	4389.481
BED GEOMETRY 2	4038.754	1275.51	4534.03
BED GEOMETRY 3	4114.751	1300.7	4596.139
BED GEOMETRY 4	4069.781	1289.491	4583.545
BED GEOMETRY 5	4134.535	1307.19	4637.564
BED GEOMETRY 6	2423.186	759.7341	3537.591
BED GEOMETRY 7	3251.142	1020.538	4538.503
BED GEOMETRY 8	7645.93	5731.206	8585.293

Table 4: Specific stiffness of different design configurations

Configuration 7 result plot: final result summery fig a & b shows carbon steel deformation and von misses stress. Fig c & d shows cast iron deformation and von misses stress. Fig e & f shows UHM CFRP deformation and von misses stress.

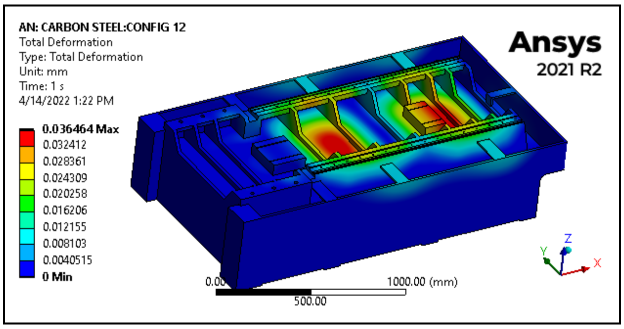


Fig a: Total deformation: carbon steel

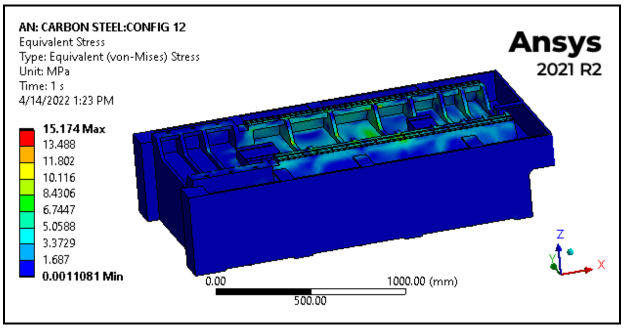


Fig b: Equivalent (Von-Mises) stress: carbon steel

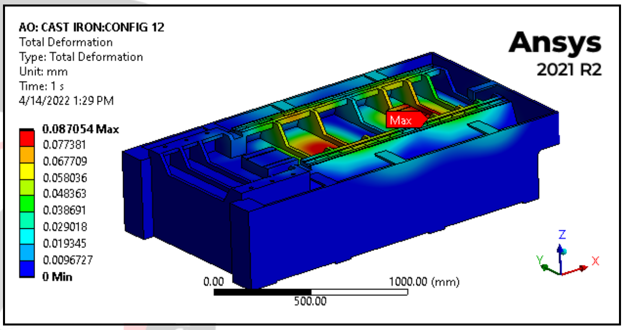


Fig c: total deformation: cast iron

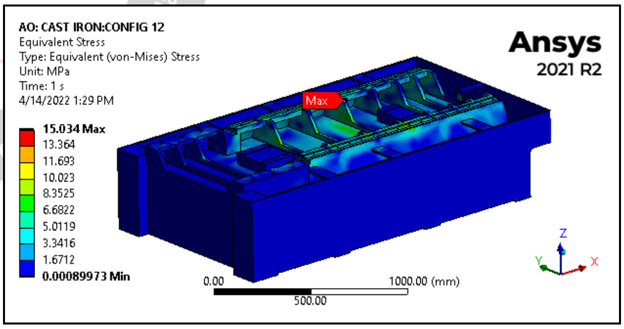


Fig d: Equivalent (Von-Mises) stress: cast iron

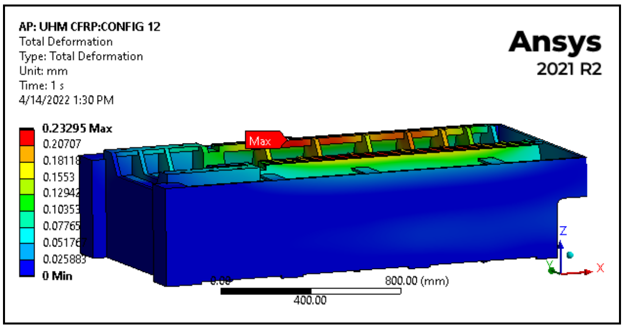


Fig e: Total deformation: UHM CFRP

 DOI : 10.35291/2454-9150.2022.0194

ISSN : 2454-9150 Vol-08, Issue-02, MAY 2022

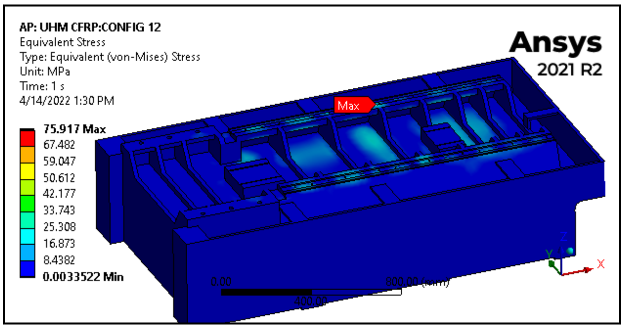


Fig f: Equivalent (Von-Mises) stress: UHM CFRP

ii. Result summary and discussion Dynamic analysis (Model analysis)

Model analysis performs for all Configuration and Plot result of Final Configuration 7 and 8. Configuration 01/06 For Analysis for Find Critical Portion and Fix them. Final result summery mention as per below table.

	CARBON STEEL	CAST IRON	UHM CFRP
mode 1: configuration 7	405	276	223
mode 2: configuration 7	431	295	229
mode 3: configuration 7	431	295	231
mode 4: configuration 7	438	298	240
mode 5: configuration 7	455	309	244
mode 6: configuration 7	515	352	248

Table 4: Modal frequency (Hz) result of configurations 7

	CARBON STEEL	CAST IRON	UHM CFRP
mode 1: configuration 7	1.43E+01	1.50E+01	4.17E+01
mode 2: configuration 7	2.19E+01	2.48E+01	4.31E+01
mode 3: configuration 7	2.78E+01	2.47E+01	2.29E+01
mode 4: configuration 7	8.18E+00	8.58E+00	1.73E+01
mode 5: configuration 7	4.90E+00	5.14E+00	1.42E+01
mode 6: configuration 7	1.89E+01	1.98E+01	3.05E+01

Table 5: Deformation (MM) result of configurations 7

	CARBON STEEL	CAST IRON	UHM CFRP
mode 1: configuration 8	700	580	317
mode 2: configuration 8	701	594	387
mode 3: configuration 8	849	694	438
mode 4: configuration 8	957	803	470
mode 5: configuration 8	1012	826	492
mode 6: configuration 8	1038	836	509

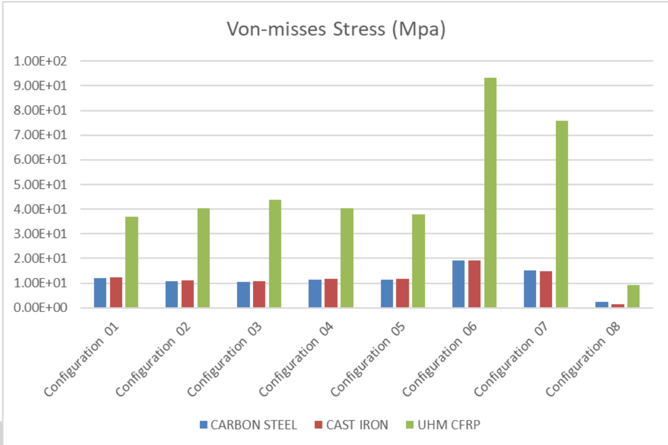
Table 4: Modal frequency (Hz) result of configurations 8

	CARBON STEEL	CAST IRON	UHM CFRP
mode 1: configuration 8	1.40	1.45	1.25
mode 2: configuration 8	1.07	1.06	1.32
mode 3: configuration 8	1.19	1.29	1.11
mode 4: configuration 8	1.30	1.45	1.55
mode 5: configuration 8	1.21	1.12	1.32
mode 6: configuration 8	1.83	2.06	1.85

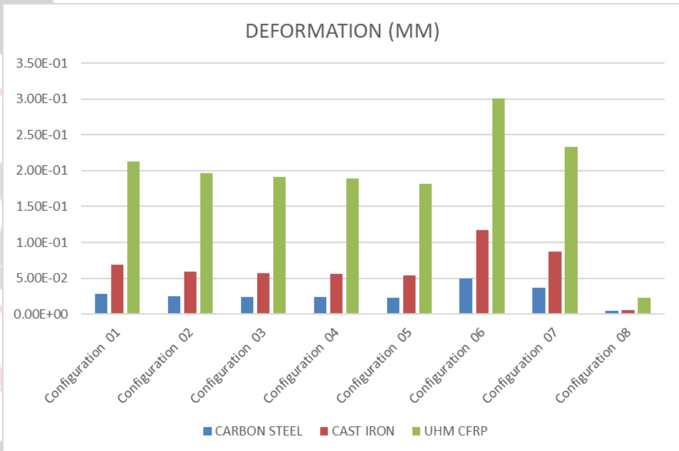
Table 5: Deformation (MM) result of configurations 8

B. Result summery graph

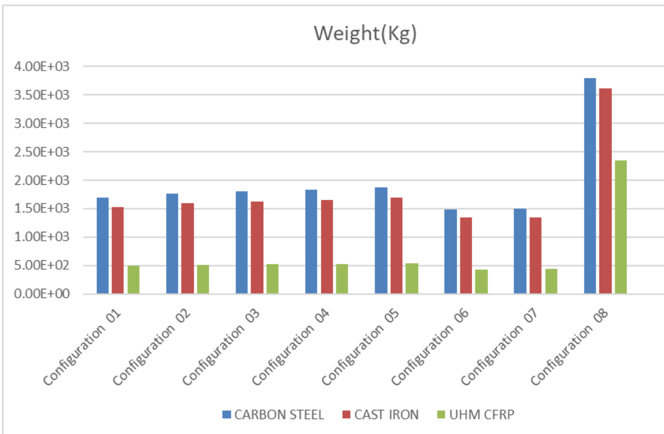
Graphical result summery as below figures generated von Mises stress plot in graph 1, total deformation in graph 2 and weight summery in graph 3.



Graph : 1 Equivalent stress of the different design configuration (Mpa)



Graph : 2 total deformation of the different design configuration (mm)



Graph : 3 Weight of the different design configuration (Kg)

VI. RESULT DISSECTION

Finite element analysis performs as same loading and boundary condition. In a Configuration 1 have simple

DOI : 10.35291/2454-9150.2022.0194

modeled as conventional geometry and perform analysis. And study result than update different ribs and supports successively.in this study model analysis play grate role to find out critical point in body.in a configuration 1-6 we only change rib and study result summery and find out configuration 6 rib works good.so we choose that patent in configuration 7 analysis with reduction of plate by 5 mm and perform static and dynamic analysis. Configuration 7 in dynamic analysis has some issue in first rib structure so we modify and finalize configuration 8.

UHM CFRP has higher structural stiffness value than conventional material as table 4.all generated stress & deformation with I allowable limit.

VII. Conclusion

Based on parametric study, the existing bed material was replaced by UHM CFRP and compare with Convention materials and found that improvement in static characteristics. As per design rules structural index in critical point improved and gives higher structural index to weight to deformation ratio. Analysis result shows that the static characteristics of structural bed have been improved.in a general case composite material has higher specific strength and young modulus. In a physical machine tool need accuracy and precision which is deliver by composite material.by study all result we justify the induced deformation and generated stress is higher but compare with weight to deformation ratio than they give significant improvement. In a configuration 8 gives grate alternative which have higher weight but reduce structure material usage by 70 percentages. Configuration 7 has improved static and dynamic performance.by proper design updating and material selection we improve structural index. From Our study we understand that by using UHM CFRP is grate solution to reduction of weight but losses of some rigidity due to their ductile properties but weight to deformation ratio of critical part is improved than conventional material. UHM CFRP gives weight reduction by three times.

Acknowledgment

A special thanks is offered to Dr. C P Patel (HOD, UVPCE Ganpat University-Kherva), for her encouragement, helpful guidance and kindly advise throughout the preparation of this research.

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