Design, Analysis and Weight Optimization of Rotary Table Pallet

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ABSTRACT:
Pallet is a work supporting and holding device used in rotary table and in automatic pallet changer to enhance the productivity of a CNC machining center. It is supported by a turn table with hydraulic clamp or bolted. Pallet supports and transmits all the forces to the base of the CNC machine. Hence pallet is the most critical component and has greater effect on machining accuracy. This work focuses on the design and weight optimization of pallet by changing the existing geometry of pallet .Further optimized pallet with is checked for resonance within the operating speed of the machine to improve the fatigue performance of pallet. Structural static analysis of the present and modified pallet will be carried out with finite element software and results will be compared for deflection and stresses.

Keywords: Rotary table, Machining centre, Finite element analysis, Design optimization.

[1] INTRODUCTION

An automatic movable table supports a work piece and slides or pivots inside and outside of the machining center. Multiple pallets allow an operator to set up a part while another is being machined. In the CNC machines, fixtures are still required to locate and hold the work pieces while machining. The work holding devices should have the following uniqueness:

(a) It must have required accuracy and must have matching reference surfaces with the reference system.
(b) It allowed performing a number of operations on different faces in a single setting.
(c) It must enable quick loading and unloading.
(d) It must be fool-proofing to avoid incorrect loading of the job.
(e) It must be sufficient rigidity to fully withstand the cutting forces.
(f) It must be safe in use and loading and unloading.
(g) It must have a sufficient of clamping force for use of full roughing cuts.
(h) It must be simple in construction maximum as possible.

Automatic pallet change over systems is used in modern CNC machines. These pallets simply move for interchanging their positions on the machine table. While machining is being done on a job kept on one pallet, the other pallets are accessible to the operator for clamping and unclamping raw material or finished product. This saves a lot of material handling and set up time, resulting in higher productivity.
The purpose of this work is to develop a Pallet to enhance the effectiveness of machining centers with multi-pallet automatic pallet changers. Rotary tables are provided with Pneumatic or Hydraulic Brake to support cutting forces. Some of the salient features of rotary tables comprises of the following:

- Hydraulic / Pneumatic clamping options.
- Dual lead worm and worm gear set for backlash elimination.
- Large module worm / worm wheel set for heavy duty application.
- Radial or axial roller bearings for high rigidity.

Rotary tables are used to index parts. Rotary tables containing the circular steel plate, spindles, a drive system, and pins that hold parts and components in place. Rotary tables have either fixed or adjustable indexing angles. After each revolution, the table stops for a specified period of time so that an operation can be performed at each station. The bearings that support rotary tables used to calculate both the load capacity and accuracy. Angular contact bearings are more expensive than re circulating ball bearings, but provide better load capacity and axial stiffness. Cross-roller bearings are also commonly available. For a large sized table with high load capacity, the practice of using hydrostatic bearings is now observed.

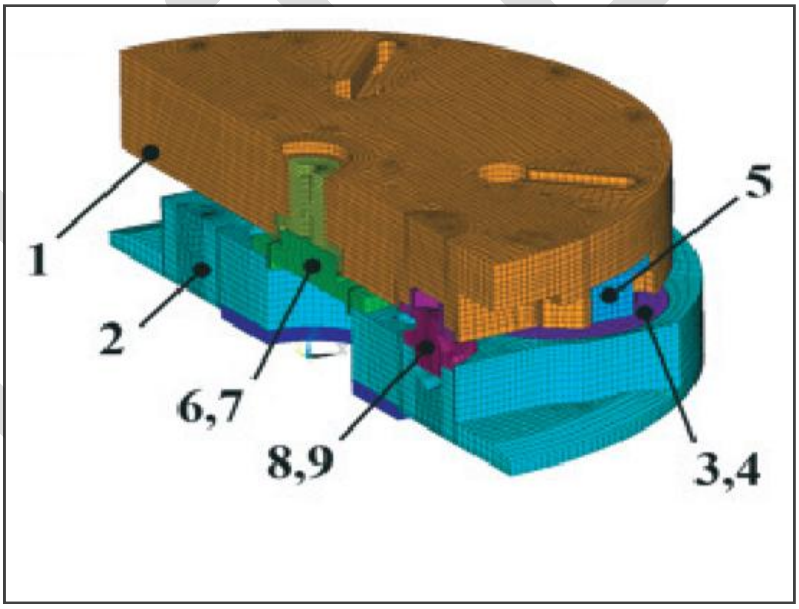


Fig 1: Rotary pallet
1 – Pallet, 2 – clamping base, 3 and 4 – cylinder and piston, 5 – Clamping strip, 6 and 7 – centering pin and sleeve, 8 and 9 carrying pin and sleeve.

Pallet is the most critical component in the rotary table assembly. Design of the pallet should take care of several aspects like work holding space, less deflection, fixture mounting facilities, T – slots for rigid fastening, specific load carrying capacity, and required elevation, less weight.

[2] RELEVANCE

Rotary tables are mostly used for index parts in defined, angular increments. They can be machined, worked in multiple operations. It consists of a circular steel plate, spindles, a drive system, and pins that hold parts in proper place. Rotary tables have fixed or adjustable indexing angles. The table stops for a specified period of time so that an operation can be performed at each station during every revolution. The supporting bearings of rotary tables determine both the load capacity and accuracy. Re circulating ball bearings are cheaper than Angular contact bearings. But angular contact bearings provide better load capacity and axial stiffness. Cross-roller bearings are also used. For a large sized table with high load capacity, the hydrostatic bearings are also tables are mostly used for index parts in defined, used. Selection of rotary tables requires an analysis of specifications and features. It contains maximum indexing increment, rotational speed, torque obtained at the table top, maximum axial load, maximum applicable machining force, maximum radial load, work table diameter. A variety of features are available. Some table surfaces can be raised or lowered at a controlled angle. Others have more than one rotating work surface. Computer numerically controlled (CNC) devices provide greater accuracy and repeatability. Position encoders are often used to relay the position of the table surface.

Rotary Table is also called as rotary indexing table is used in machine tool as an aggregate for machining of components on multi faces. A component can be clamped in fixture assembly mounted on round table can be milled, drilled, boring, tapping, etc operations can be perform. Rotary Table are available in market with different indexing positions like 180°, 90°, 1° and continuous rotation Incremental angle of 0.001°. Rotary axis is essential for machining the complex jobs where the machining forces are not at 90 or 180 degree to each other. Even if the jobs are rectangular, these can be machined in one setup using rotary table to improve the accuracy and productivity. Rotary table is designed with heavy duty axial radial roller bearing to take heavy loads. Rotary tables with dual lead worm and worm wheel with from correction are widely used for longer life and sustained accuracy.

[3] LITERATURE REVIEW

The automatic pallet changer mechanism presented in this paper can be attached to almost any conventional machine tool along its travel axis. This mechanism is hydraulically driven, being supplied from the machining center’s main hydraulic unit, can be used in handling weights up to 800 kg. The main advantage of an automatic pallet changer is the small setup time of the workpiece to follow in the machining chamber, the automatic pallet changer presented in this paper binds together the drives of the two main movements into one double hydraulic piston. This solution reduces the space occupied by an extra motor used to perform one of the main movements, and also the manufacturing cost of the automatic pallet changer mechanism is reduced [1]. Equipping the numerically controlled machine tools with automatic tool changers and automatic pallet changers has lead to the development of multi-axis machining centers, which include linear and rotary feed axes in their structure. The main advantage of the presented technical solution is that it reduces the non cutting time from the manufacturing process, thus leading to a high productivity. Together with the automatic pallet changer, this solution significantly reduces the auxiliary time and also the errors caused by setting the workpiece on the machine tool table [2]. We establish the computational complexity of the problem of minimizing make span in a flow shop, where each jobs requires a pallet the entire time, from the start of its first operation until the completion of the last operation. We prove that the problem is NP-hard in the strong sense for $m > 2$ and $K > 3$, and for $m > 3$ and $K > 2$, where m is the number of machines and K is the number of pallets in the system.[3] In

FEM analysis, it was possible to eliminate successfully some possible undesirable effects after the manufacture and assembly of the pallet exchange system. Moreover, it was also possible to optimize technologically the pallet shape as well as the clamping base shape. Some increased values of stress or forces in the contact surfaces are caused by the fact that the surfaces transfer centrifugal load from the particular components in the slipping way, i. e. by means of the Pallet. The design and the strength check of the screw were made simultaneously with the calculations mentioned here. It is possible to see these main critical points on the calculation results: sharp corners and edges in the T-slots on the inside pallet diameter; end of the T-slots on the outside pallet diameter.[4]. Existing geometry such as housing and pallet supporting components are modified with weldment structure for housing component and ribbed structure for pallet. Structural static analysis of these components carried out with ANSYS 12 finite element software. Pallet is build with ribs and patterns with this there will be reduction in the weight of the pallet compared to the solid pallet. Housing of the rotary table is developed by Weldment using a structural steel plates, hence there will no any extra cost of mould and machining operations [5].

[4] METHODOLOGY

The first step is to calculate the parameters by using the given specification. Based on the geometric dimension obtained cad Pallet of the rotary pallet and casing is generated using appropriate modeling software. The generated Pallet model is discretized using meshing software Ansys. The discretized Pallets are solved with appropriate boundary condition. The obtained results are analyzed and required modification to geometric Pallet is carried out and the process is repeated once rotary pallet geometry is optimized.

Initially the pallet is designed for dimensions specified by the customer and it is easily suit the HMC machines for various operations but was not having any considerable deflection. The pallet of size 200 mm diameter is designed for deflection and stresses. The analysis has been carried out on the existing Pallet by FEA to check the stresses and deflection. The process flow chart to carry out finite element analysis of the rotary pallet is shown in figure2.

Technical details of pallet:

- The diameter of the structure 200 mm.
- Force acting on the table is weight of work piece and Jigs and fixtures
- work piece weight=70kg
- Jigs and fixtures weight=20kg
- machining force of 15000 N

Table 1: Mechanical properties of fg300

Sr. No.	*Property*	*Unit*	*Value*
1.	Density[ρ]	Kg/m³	7160
2.	Modulus of Elasticity[E]	GPa	116
3.	Poisson’s ratio[γ]	NA	0.29
4.	Ultimate Tensile Strength[σu]	MPa	298
5.	Compressive yield strength	MPa	972
6.	Hardness	HRc	18
7.	Shear modulus[G]	GPa	47.6
8.	Specific Heat	J/kg°C	10^{-3}

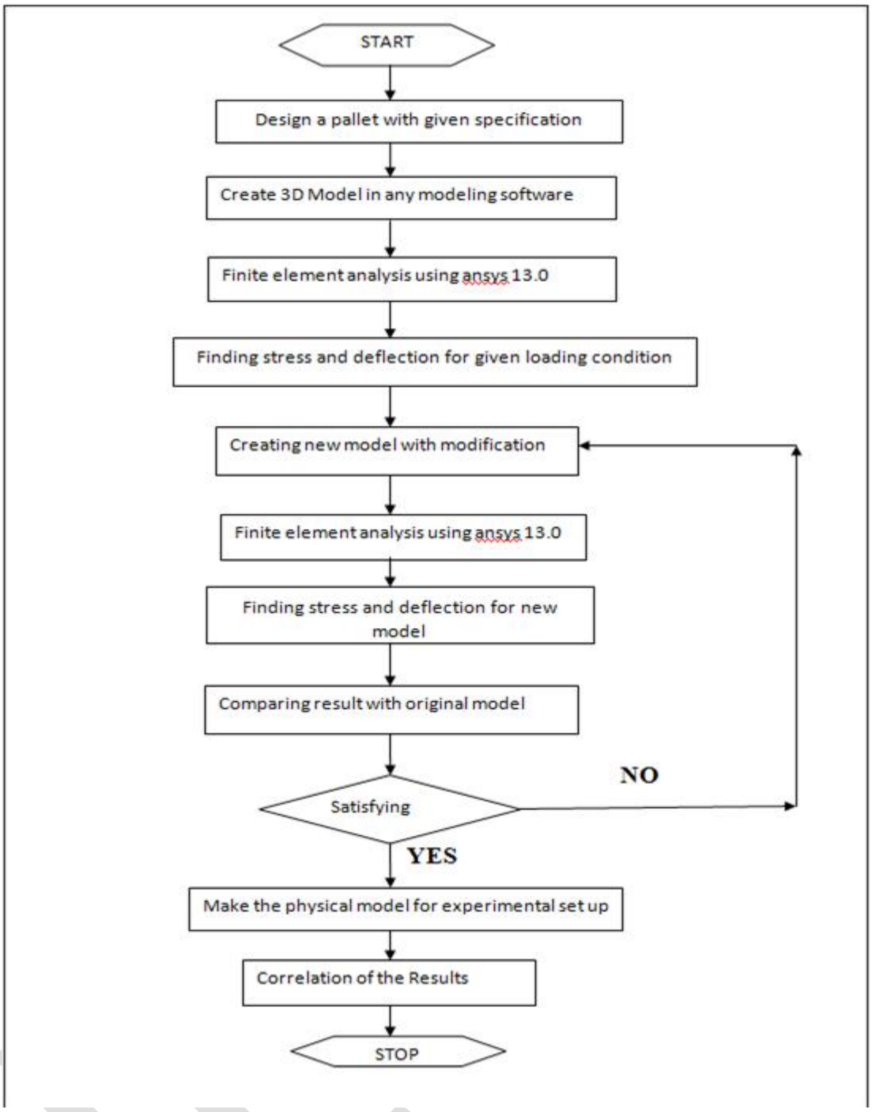
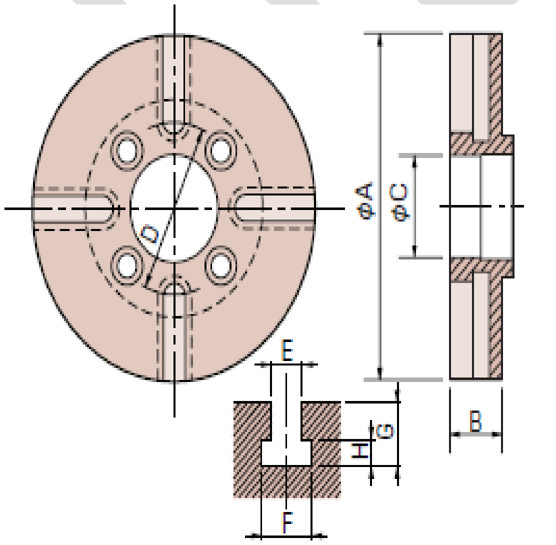


Fig 2: Process flowchart



Unit : mm

	A (Faceplate outer dia.)	B	C	D	E	F	G	H
RNA-160	160	30	φ50H7	φ75	12H8	19^{+2}_{0}	19	8^{+1}_{0}
	200							
RNA-200	200	30	φ60H7	φ90				
	250							
RNA-250	250	30	φ75H7	φ110				
RNA-320	320	40	φ110H7	φ140	14H8	23^{+2}_{0}	23	9^{+1}_{0}

Fig 3: Details of Rotary Pallet from catalogue of the standard of precision test: Japan jis

[5] DESIGN CALCULATIONS OF EXISTING PALLET

Table 2: Design calculations of existing pallet

Sr. No.	*Required parameter*	*Given value*	*Formula*	*Output parameter*
1	Outer surface area (a1)	A=200mm	$\pi(A/2)^2$	31415.92 mm^2
2	Inner hole surface area (a2)	C=60mm	$\pi(C/2)^2$	2827.43 mm^2
3	Inner bolt hole surface area (a3)	I=15mm	$4 * \pi(I/2)^2$	706.85 mm^2
4	Rectangular slot area with hemi circular section (a4)	F=19mm H=08mm G=11mm E=12mm	4*[(F*H)+(E*(G-H))+ (π*(E/2)2)]	1249.04 mm^2
5	Total surface area(a)		A= A1-A2-A3-A4	26632.6 mm^2
6	Volume of outer hole (v1)	A1=31415.92mm2 T=30mm	$A1 * T$	942477.6 mm^3
7	Volume of inner hole (v2)	A2=2827.43mm2 T=30mm	A2*T	84822.9 mm^3
8	Volume of inner bolt hole (V3)	A3=706.85 mm2 T=30mm	A3*T	21205.5 mm^3
9	Volume of inner rectangular slot hole (V4)	A4=1249.04mm2 T=30mm	[6] A4*T	37471.2 mm^3
10	Total volume of pallet (v)		V=V1-V2-V3-V4	817203.91mm^3
11	Total force on pallet (f)	Machining force =15000N Mass of jig & fixture=70 Kg Mass of workpiece= 20Kg	15000+(9.81*(70+ 20))	**15900N**
12	Mass of pallet	DENSITY=7160Kg /m3 Volume= 817203.91	Mass=(Density* Volume)	**5.8511Kg**
13	Pressure (p)	F=15900N A=26632.6mm2	$\frac{F}{A}$	**6 bar**

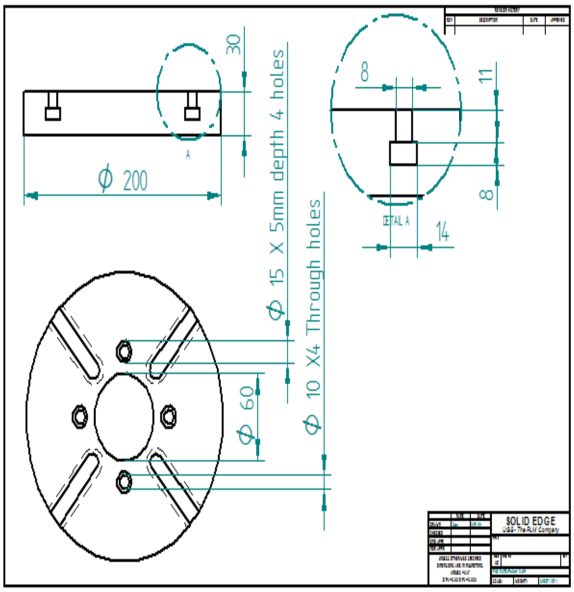


Fig 4: Details of pallet (RNA-200)

After modifying the existing pallet design, the total volume and the mass of the pallet is calculated as follows:

- Outer diameter of pallet=200 mm
- Inner diameter of pallet=65 mm
- Step thickness of pallet=06 mm
- Thickness of pallet =24 mm

Total volume of final Pallet is = π*(100)2*24 - [π*(65/2)2*30] + [π*((150-65)/2)2*6]
- [4* π*(25/2)2*6]-(4*Volume of rectangular slot)
= 753982.23 – 99549.21 + 34047.01 – 2945.24 – 19245.16
= 666289.63 mm^3

Therefore, mass of the modified pallet is = density*modified volume
= 7160*10-9*666289.63
= **4.7706kg**.

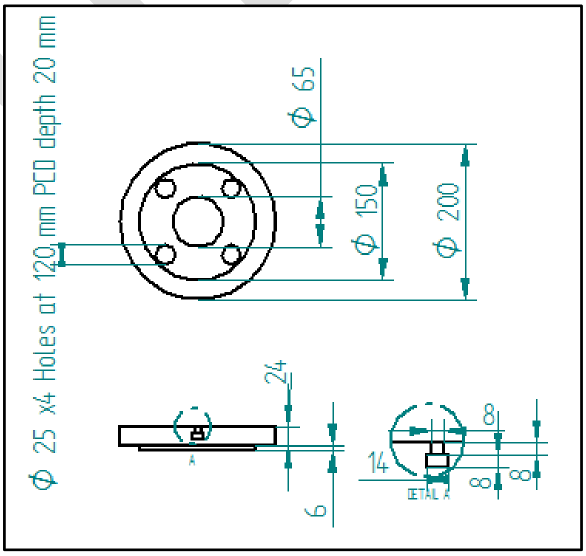


Fig 5: Details of Modified pallet (RNA-200)

[7] STRUCTURAL ANALYSIS

A static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time. Static analysis calculates the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time-varying loads

6.1 Boundary Conditions

All degrees of freedom on the nodes of four holes of the pallet were arrested; load is applied at the top face. Fig. 6 show the boundary conditions and applied pressure on the mesh model of rotary pallet.

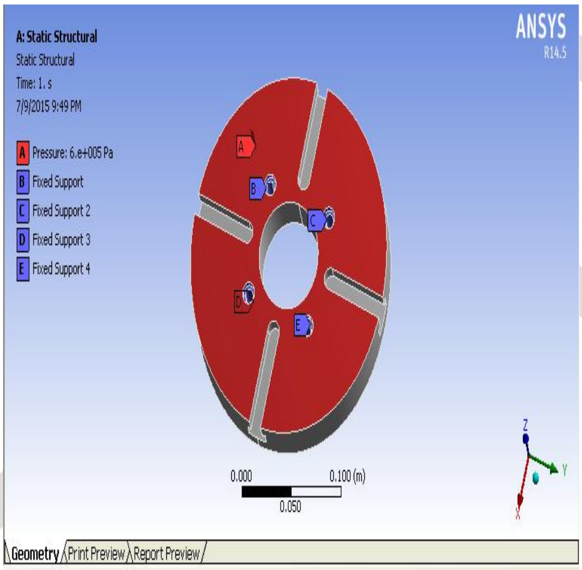


Figure 6: Boundary Condition.

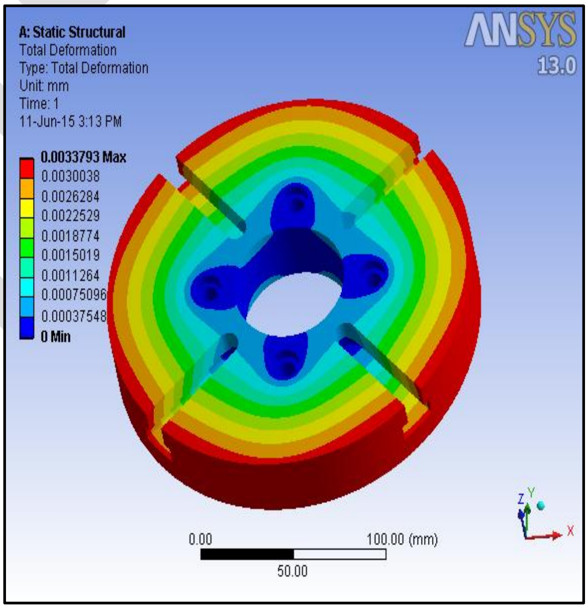


Fig 7: Deformed Pallet

From fig.7, it is observed that the maximum deflection in existing solid pallet under given conditions is 3.37 micron.

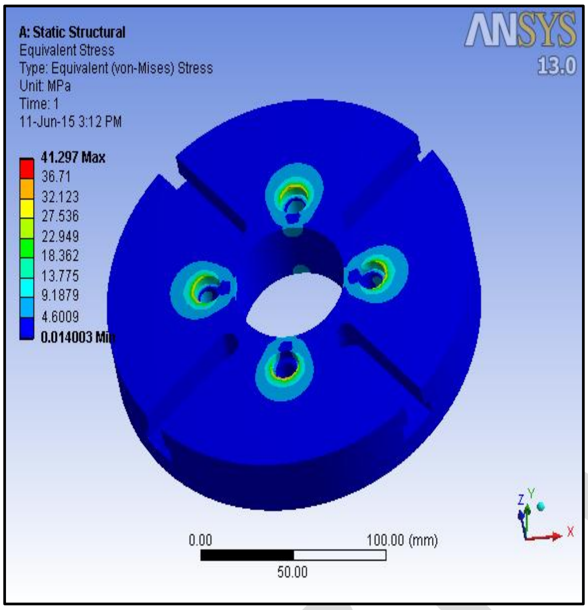


Fig 8: Maximum Von-Mises Stress

From fig.8 it is observed that the maximum von mises stress in existing solid pallet under given conditions is 41.297 Mpa.

[8] GEOMETRY & MATERIAL OPTIMIZATION

This chapter discusses the optimization options, their combination under a set of defined constraints and a comparison between the original pallet and the final optimized pallet component. The main objective of this analysis was to optimize the weight thus manufacturing cost of the pallet, which not only reduces the final production cost of the component, but also results in a lighter weight pallet. Optimization carried out on this component is not the typical mathematical sense of optimization, because variables such as manufacturing and material parameters could not be organized in a mathematical function according to the set of constraints such that the maximum or minimum could be obtained. As the main objective of this analysis, it was attempted to reduce the weight and final cost of the component.

7.1 Objective Function

Objective function is defined as the parameters that are attempted to be optimized. In this study the weight and fatigue performance of the component were the main objectives. Optimization attempt was to reduce the weight, while improving the fatigue performance and maintaining the bending stiffness within permissible limits.

7.2 Design Variables

Parameters that could be changed during the optimization process are design variables. Considering the functions of the pallet and its constraints, the following design variables were considered in the optimization study:

- Thickness of pallet
- Geometry of pallet
- Increasing inner hole diameters and depths
- Changes in fillet radii

In modified pallet the inner hole diameter increases up to 65mm and the fixed support hole move to pitch circle diameter of 120mm for getting the optimum design shape by performing various trial modification in geometry of existing pallet.

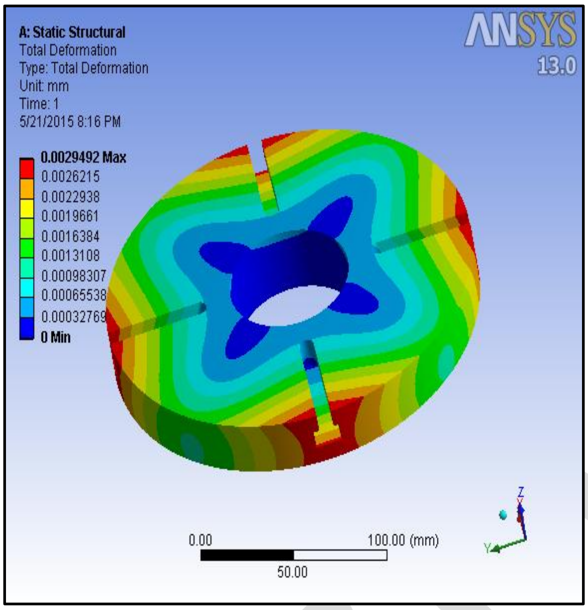


Fig 9: Deformed Pallet

From fig.9 it is observed that the maximum deflection in modified pallet under same given conditions is 2.94 micron which is less than the deflection in existing solid pallet.

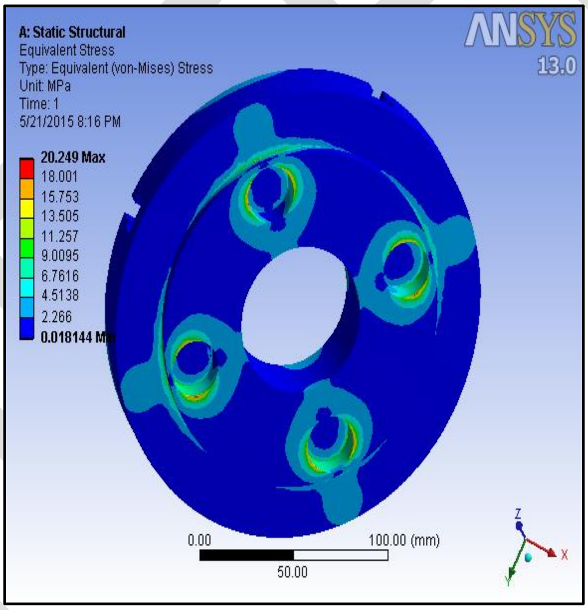


Fig 10: Maximum Von mises stress

From fig.10 it is observed that the maximum von mises stress in modified pallet under same given conditions is 20.249 Mpa which is less than the existing solid pallet.

Table 3: ansys results for mass modified pallet

Properties	
Volume	6.7369e-004 m³
Mass	4.8236 kg
Centroid X	-4.2482e-018 m
Centroid Y	6.8864e-016 m
Centroid Z	1.3815e-002 m
Moment of Inertia Ip1	1.3099e-002 kg·m²
Moment of Inertia Ip2	1.31e-002 kg·m²

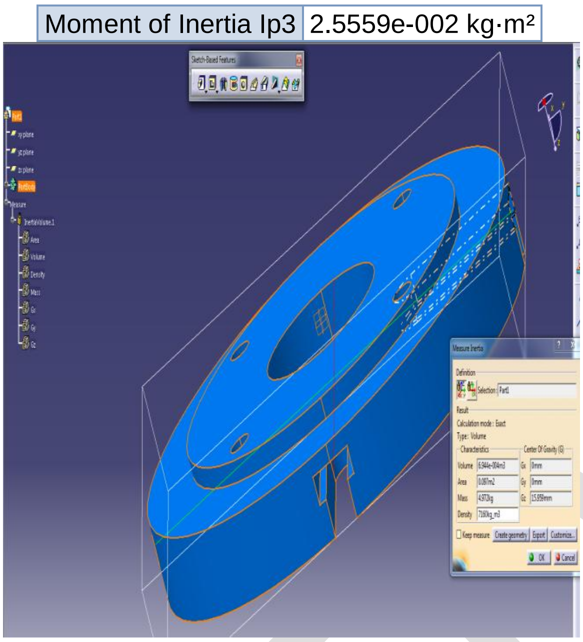


Fig 11: Weight of Modified Rotary Pallet

Fig.11 shows the mass of the modified rotary pallet is 4.824 Kg by using CATIA V5 Software.

[9] Results and discussion

Static structural analysis of the present and modified pallet is carried out with finite element analysis software Ansys. Comparison of the results of existing and modified pallet for deflection and stresses are shown in Table 4.

Table 4: Comparison on the basis of ansys results

Parameter	Existing Pallet	Modified Pallet
Deflection	3.37 Micron	2.94 Micron
Stress	41.297 Mpa	20.249 Mpa

From Table3, it is observed that for the same boundary conditions the modified pallet case IV gives the values of stress and deflection as .00294 mm and 20.249MPa respectively, which is less than the original one.

Table 5: Comparison on the basis of ansys results

Parameter	Analytical Weight in Kg	CATIA V5 Software Weight in Kg.	Ansys Software Weight in Kg.
Existing Pallet	5.858	5.942	6.1308
Modified Pallet	4.776	4.824	4.8236

Table 5 shows the comparison between the analytical and software results of the existing and modified Pallet for weight optimization. It is observed that the modified design of pallet shows the minimum weight as compared to existing pallet for the same boundary conditions.

[10] CONCLUSION

From the proposed modified pallet design, it is concluded that

- The weight of the existing pallet is reduced up to 18.57% by analytical results and as per the software analysis; weight of the existing pallet is reduced up to 18.81%.

- It is observed that there is negligible difference of 1% between the weight obtained by analytical and software results. Hence, the optimized weight of the rotary pallet is 4.77kg.

The Stress and deflection in modified model is reduced to 20.249MPa and 0.00294mm respectively. Thus, it improves the fatigue life of the rotary pallet.

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