International Journal for Ignited Minds (IJIMIINDS)

Design and Development of 5 ton C-type press structure and Optimization through Finite Element Analysis

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ABSTRACT

In the present work, 5 tons of press structure is designed based on two conceptual designs. The analysis is done in two stages two find the effect of individual component analysis and assembly analysis. The results show small change in the deformation and stress conditions with both type of analysis. Since the stresses and deflections are well within the allowable limit, the conceptual design is safe for the given loading conditions. Further the second conceptual design is exported into Hypermesh and a good quality shell mesh is carried out due to regular and thin sections. The analysis results for the second conceptual model shows lesser deformation compared to the first configuration. Further design optimization is done to check the structural safety and weight reduction. Two sets of design variables with two sets of state variables are considered with one set of objective function (Weight) using sub problem approximation technique. Totally 11 sets of which 7 feasible sets are obtained and final set results are also presented.

Keywords *- Stresses, Deflections, Conceptual Design, Optimization, Hydraulic Press.*

1. INTRODUCTION

Hydraulic presses find wide usage in the engineering applications and works by moving hydraulic cylinder for compression of fluid to lift or perform the required operations. The hydraulic presses are also called as bramah press by the principal founder name Joseph Bramah. The hydraulic presses works on Pascal's principle that pressure inside a closed system is constant. In this work one small piston subjected to a moderate force will move a big piston moving with large area due to constant pressure inside the system.

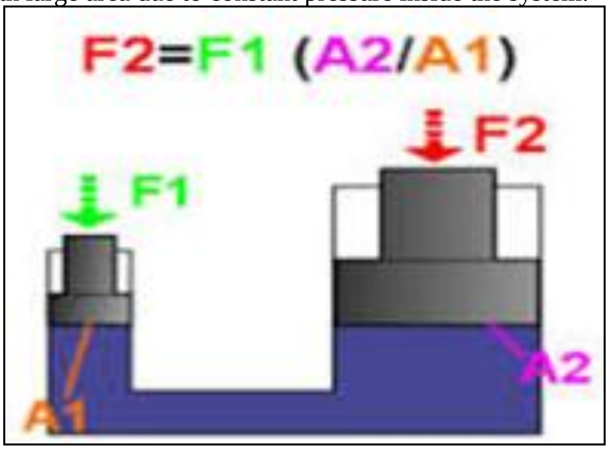


Fig 1: Bramah Press Principle.

When a piston is pressed down, the other piston will move due to incompressibility of the fluid. The amount of fluid displaced from the small piston should be equal to the volume of fluid displaced by the bigger piston. In this process for a small movement of larger piston, higher movement of smaller piston is required. During the process of movement work will be done on the system. Hydraulic presses are mainly used for forging, molding, blanking, punching, deep drawing and other metal forming process. Hydraulic presses based on the nature of working can be classified to many types. In certain presses, a ram will move against blanket sheet which is mainly used in the smaller C-Frame presses. C-Frame presses are very common application of engineering problems like, banking, straightening, drawing, forming, bending, and punching.

1.1 Design Considerations in the Hydraulic Press

Generally hydraulic presses are calculated for the following components.

Piston Rod dimensions: Piston rod is important and the design is based on simple axial stress and buckling load estimates.

Barrel Pressure: Hydraulic fluid pressure required need to be estimated for proper pressing operations.

Barrel Thickness: Minimum thickness required for safe working of the Barrel Structure need to be designed. The design is based on either thick cylinder concept or thin cylinder concept.

If D/t ratio is greater than 10 it is called thin cylinder or if it is less than 10 it is called thin cylinder.

Where, D=Internal diameter of the barrel,

t=Thickness of the barrel,

For the solution of thick cylinders, Lame's equations are used to solve the problem. To apply Lame's equation at least two boundary conditions should be known. Axial, Radial and hoop stresses are considered for deciding the safe design of the barrel. If the barrel is thin cylinder, analysis is simple and calculations are done for Hoop stress and axial stress neglecting radial stress due to very small thickness where radial stress is almost assumed to be constant.

Hoop Stress is calculated as σ_h=P*D/2t

Where, p is the operating pressure.

Axial stress is calculated as half the hoop stress. But our present work is the structural design of the support structure.

2. PROBLEM DEFINITION

In the design process, the variables or either maximized or minimized to obtain an optimized objective function through iterations which is shown in the figure. Lot of research is carried on the design optimization of the structures.

R.J. Duffin et al [1], has studied optimization through geometric programming techniques. Integral programming is used for optimizing the engineering problems. He has proved certain methodologies to improve the convergence of the iterative designs.

G.B.Dantzing [2], has worked on probabilistic studies which include variance, covariance, standard deviation and sigma values. He has working with multiple objectives for the design optimization which is generally for one objective function. So he was the starting person to coin the idea of multi-objective geometric programming.

Designing and analysis for structural safety of 5 ton press structure is the main definition of the problem. Design improvement and optimization for the best model is the objective. The other objective include

- Finding the best geometry for 5 ton press structure
- Optimizing the structure for to reduce weight

A. Requirement:

Press structures are very important in the manufacturing industry. Hydraulic presses, forging presses find wide application in the industry. Since the pressing process takes place gradually, the analysis is almost for static loads. But while forging, the members should not fail for the given loading conditions. The main objective for structural design is safety and optimization. In the project the same methodology is adopted to find the best structure through design optimization.

- **Material Used:**

  Material name: St42
  Yield Stress, E = 420Mpa
  Poison's ratio = 0.3
  Density = 7800kg/m^3
  Allowable stress = 140Mpa
  Factor of Safety = 4

3. METHODOLOGY

- Initial geometrical built up of two press designs
- Meshing and analysis of the press design
- Selection of the best design
- Design optimization of the press design
- Results interpretation

3.1 Design of Model-1

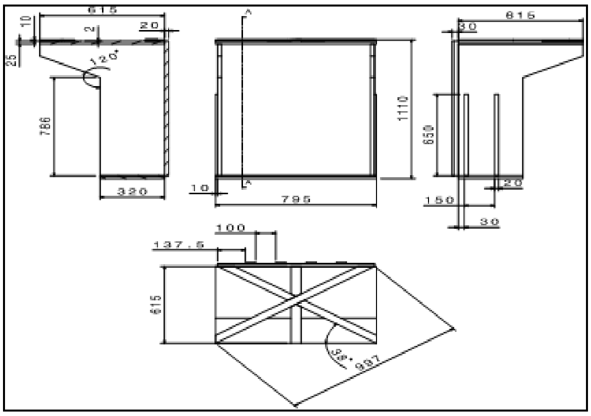


Fig 2: Dimensional Representation of the C-Press (Model 1).

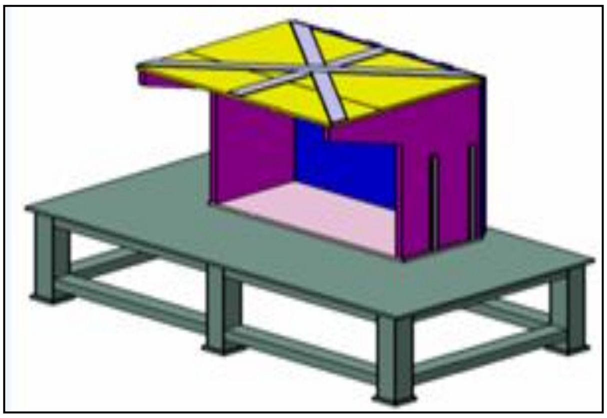


Fig 3: Geometry Model Built.

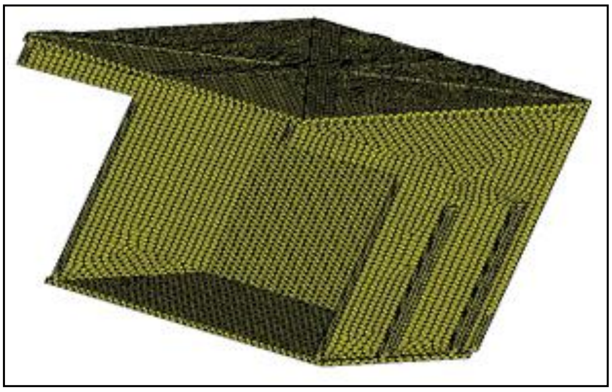


Fig 4: Mesh of the first configuration.

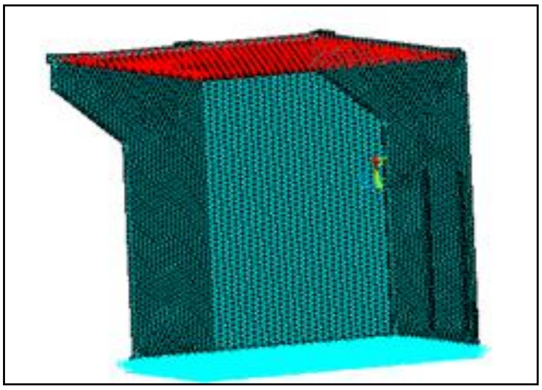


Fig 5: Boundary Conditions plot.

3.2 Design of Model-2

The fig 6 shows dimensional view of the 2nd conceptual design with specifications for dimensions and other details for fixing. All the major views, front, top view and side views are represented in the first angle projection. Maximum height of the structure is given as 1120mm with width of 750 and length of 862mm.

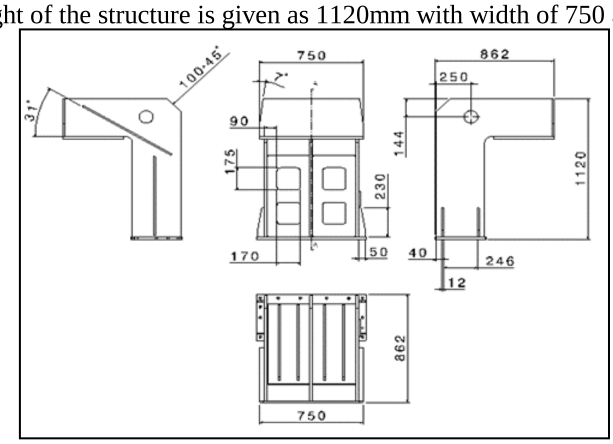
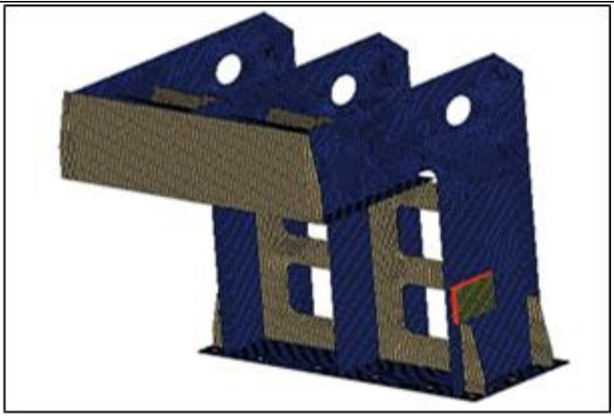


Fig 6: Dimensional Draft of the Second Model.

The shell mesh is shown in the figure3.10the mid surfaces are extracted and shell mesh is carried out to find the optimized for the structure for the given loading conditions. The members having similar thickness are grouped to separate components for structural analysis.

Total of 48248 elements with 54843 nodes are used for the problem. The members are split to ease quad meshing and quality criteria are checked for the acceptability of the mesh. The structure weight is around 405kg with all its structural components.



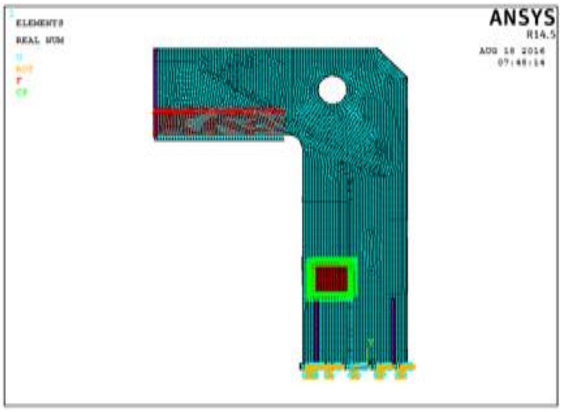


Fig 7: Mesh of the Second Conceptual Design. Fig 8: Boundary Conditions for the Second Configuration.

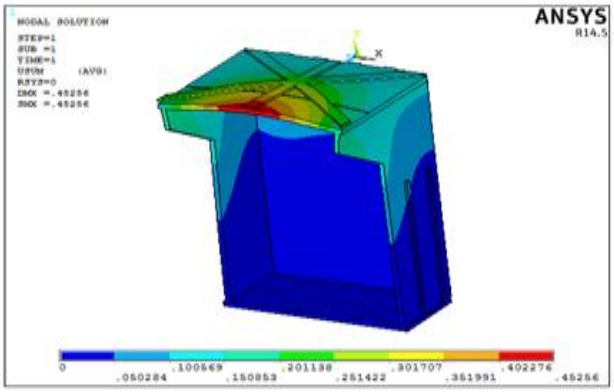
The fig 8 shows applied boundary conditions for the problem. Bottom of the structure is fixed and 15 ton load is applied as the pressure load on the top surface as shown with red color arrows.

4. RESULTS & DISCUSSION

Analysis is carried out for both the conceptual configurations to find the safety of the members along with minimum weight. Both the conceptual designs are modelled, meshed and analyzed for the best conditions. The analysis cases considered are as follows.

- First Conceptual design analysis.
- First Conceptual design assembly Analysis
- Second Conceptual design analysis.
- Second Conceptual design assembly analysis.

4.1 First Conceptual Design Analysis



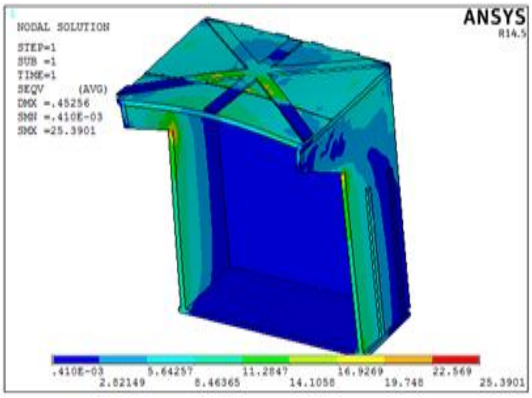


Fig 9: Displacement plot. Fig 10: von-Mises Stress Plot.

The figure4.1 shows displacement in the configuration for the given loads. Maximum displacement is around 0.45256mm as shown by red color region. The maximum displacement is taking place at the end region due to cantilever type arrangement of loading.

4.2 Modal Analysis for the First Configuration

Modal analysis is the most important analysis of structural design for dynamic considerations. Modal analysis gives the natural frequencies where possible resonance takes place in the structure. Resonance is the most undesirable feature of structures where the welds of the structure fail due to excessive deformations. Generally modal analysis is carried out with undamped conditions due to complication of solving the complex Eigen value problems. The analysis is called as Eigen value analysis and in Nastran it is called as either normal mode analysis or complex Eigen value analysis. Number of solvers is available out of which Block Lanczo's is the default solver for modal analysis.

Set No	Modal Frequency
1	94.245
2	119.56
3	232.31
4	239.17
5	253.99

Table 1: Modal Frequency Summary.

The table shows obtained natural frequencies for the system. The first frequency value is 94.245Hz. This frequency is sufficiently rigid for resonance conditions. So no possibility for resonance of the system. Higher natural frequencies are always desirable for a structure due to dynamic considerations. Higher natural frequency can be obtained better structural materials with good rib arrangement to prevent possible deformations.

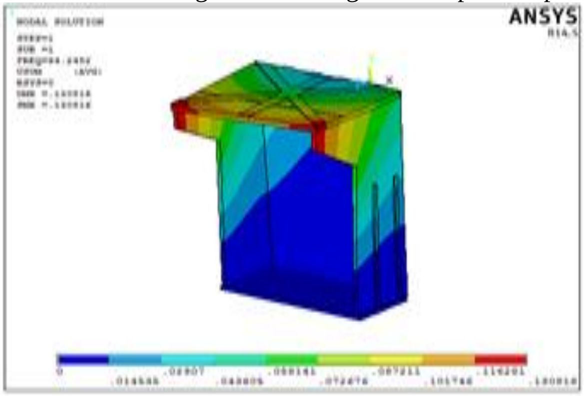


Fig 11: Mode Shape 1.

4.3 Assembly Analysis

To check the effect of constrain location on the deflection behavior of the problem, analysis is carried out for the assembly and for the same boundary conditions the results are obtained for displacements and stresses. The results are as follows.

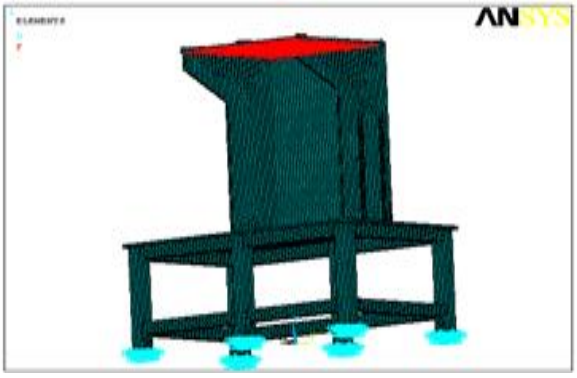


Fig 12: Boundary Conditions for the problem.

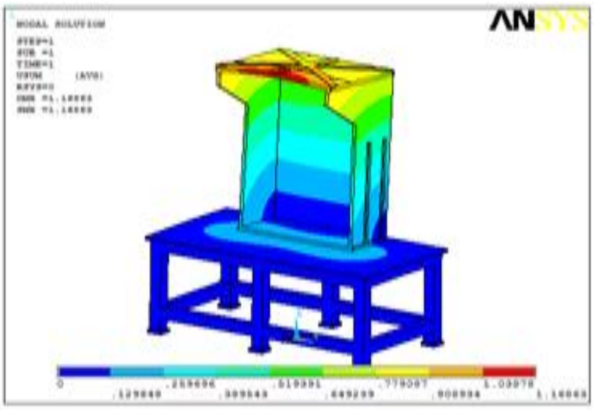


Fig 13: Displacement plot.

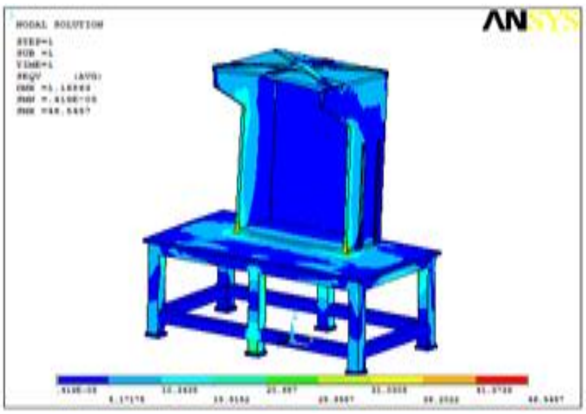


Fig 14: von-Mises Stress Plot.

4.4 Shell Analysis

Second conceptual model is analyzed with shell element due to regularity of the geometry. In the assembly, elements are used which are having regular cross section. So the geometry is exported to Hypermesh for meshing through mid-surface extraction and quality meshing satisfying aspect ratio, warpage, skew angle, minimum and maximum angle quad, number of tria's etc. The mesh is carried out to minimize the compound quality index of the problem.

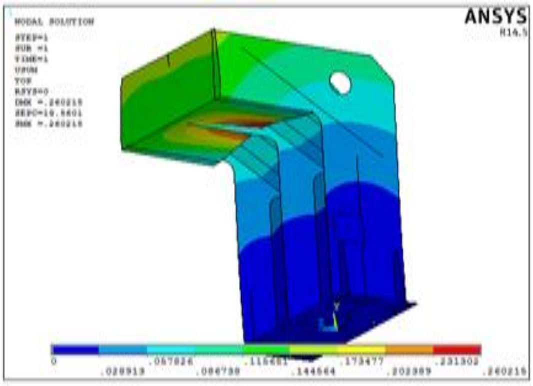


Fig 15: Displacement plot.

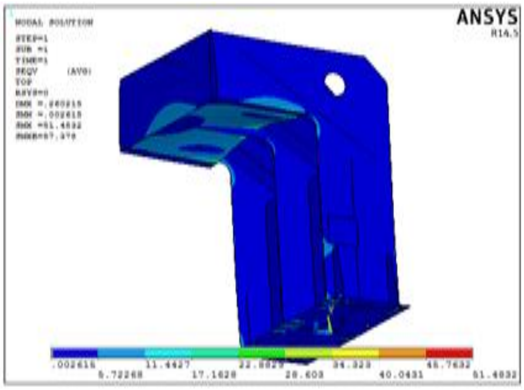


Fig 16: von-Mises Stress Plot.

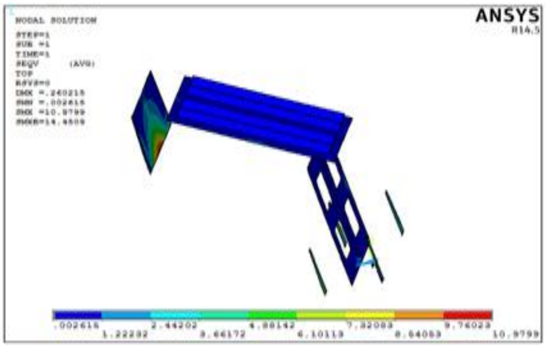


Fig 17: von-Mises Stress in 12mm sections.

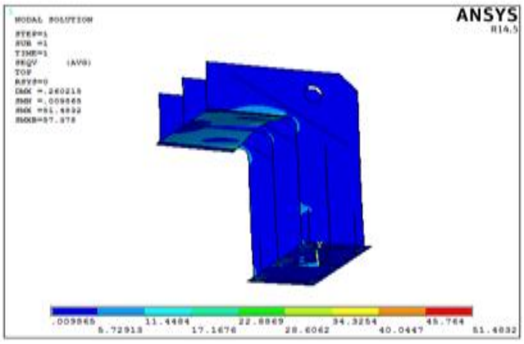


Fig 18: von-Mises Stress in 20mm Sections.

4.5 Modal Analysis for Second Configuration

Set No	Modal Frequency(Hz)
1	68.468
2	84.249
3	95.689
4	141.03
5	157.91

Table 2: Modal Analysis for the Second Configuration.

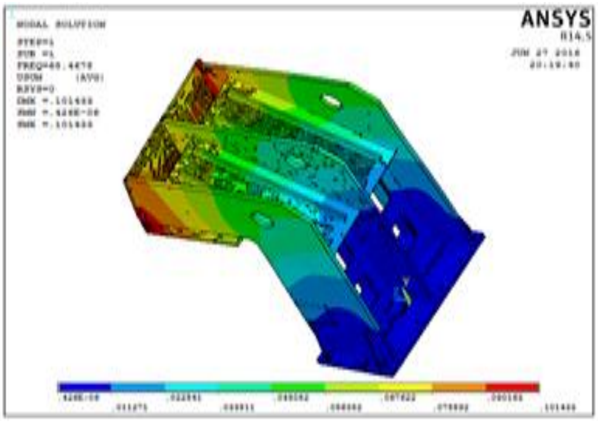


Fig 19: Mode Shape for the Conceptual design 2.

4.6 Design Optimization

Design optimization is carried out for the second structure as it has less deformation compared to the first configuration. Generally the press structures are mainly designed for deformation compared to stress to obtain required accuracy of pressing or blanking or forging etc.

		SET 1	SET 2	SET 3	SET 4
		(FEASIBLE)	**(FEASIBLE)**	**(INFEASIBLE)**	**(INFEASIBLE)**
MAXD	**(SV)**	0.26021	0.37108	> 1.3814	> 0.83358
MAXS	**(SV)**	51.483	69.427	> 176.54	> 124.64
T1	**(DV)**	20	17.708	10.82	13.063
T2	**(DV)**	12	7.1147	9.2313	8.5613
WT	**(OBJ)**	459.31	373.33	275.65	307.65
		SET 5	**SET 6**	**SET 7**	**SET 8**
		(INFEASIBLE)	**(INFEASIBLE)**	**(FEASIBLE)**	**(FEASIBLE)**
MAXD	**(SV)**	0.4065	0.36765	0.36856	0.35686
MAXS	**(SV)**	> 76.808	> 71.197	69.579	69.782
T1	**(DV)**	17.246	17.901	17.794	18.109
T2	**(DV)**	3.8388	3.8583	6.1746	3.6717
WT	**(OBJ)**	334.09	345.49	365.81	347.27
		SET 9	**SET 10**	***SET 11***	
		(FEASIBLE)	**(FEASIBLE)**	**(FEASIBLE)**	
MAXD	**(SV)**	0.3555	0.35453	0.35411	
MAXS	**(SV)**	70.089	70.043	70.013	
T1	**(DV)**	18.159	18.182	18.192	
T2	**(DV)**	3.1562	3.0594	3.027	
WT	**(OBJ)**	343.19	342.66	342.52	

Table 3: All Design Sets from the Design Optimization Process.

In the table

MAXD: Maximum displacement in the structure
MAXS: Maximum Stress in the structure
WT: Weight of the structure
T_1: Design parameter 1(DV)
T_2: Design Parameter 2(DV)
SV: State Variable

4.7 Final Set Results

After design optimization, results are represented for the final best set for the given loading specifications. Again the results are represented for the structural safety parameters of stress and deflection.

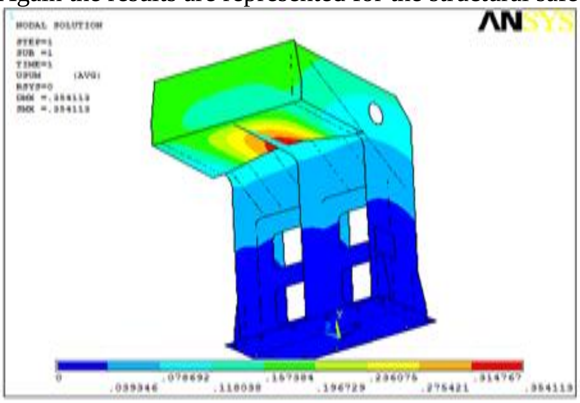


Fig 20: Deflection for the final optimized set.

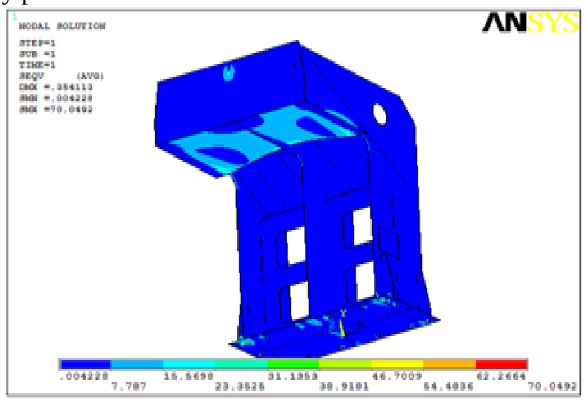


Fig 21: Von-mises Stress plot for the final optimized set.

4.8 Discussion

Two conceptual designs for 5 tons pressure structure is analyzed and the best configuration is design optimized. Initially analysis is carried out only for the C-Frame without the base support. The results shows deformation 0.45mm and stress value equal to 25Mpa. But when analysis is done in assembly, the deformations are varied to 1.1mm and stress to 46.54Mpa. This shows increased values for deformation and stress. So it is better to go for full analysis for the engineering components to avoid error in the problem. Further analysis is carried out on the second configuration for the same loading conditions. The results shows the displacement value of 0.26mm and stress value of 51.468Mpa. So second configuration less deflection compared to the first configuration. But the natural frequency values are reducing from 94.25Hz to 68.46Hz. This reduction can be attributed to reduced stiffness of the structure. But both stress, deformation and modal frequencies are above the safe levels. The individual component results are also presented to estimate factor of safety in the individual components which helps in proper optimizations of the structure. Since the component stresses are well below the allowable stresses, design optimizations is carried out based on 2 design variables, 2 state variables and one objective function. Sub problem approximation technique is applied which shows 11 feasible sets for the problem. The iteration summary shows effect of design optimizations on reducing the weight of the structure. So finite element analysis can be used to find the best set for the problem and any number design alterations can be carried out for better product design.

5. CONCLUSION

Two conceptual designs of 5ton press structure is analyzed using finite element analysis and design optimizations is carried out for the selected structure. The overall summary is as follows.

- Initially two structures are modelled for the specified dimensions using a three dimensional modelling software Catia with its effective features for modelling like sketcher, part modeler, assembler and drafting.
- The built models are exported to Hypermesh for good quality meshing. The first conceptual design is meshed with three dimensional elements due to irregularity. Sold45 element is used for meshing attributed of the first design.
- Analysis is done in two stages to find the effect of assembly analysis.
- Initially only frame structure is analyzed and checked for structural safety conditions. The results show development of 0.4mm displacement along with 25MPa stress.
- Further assembly analysis is carried out to check the safety conditions. The result shows both stress and deflection values are increasing with the complete assembly analysis.
- The results indicates, the flexibility of the structure plays important role in the increase of stress and deflection. But still structure is safe for the given loading conditions due to the allowable limits.
- Deflection is the critical design parameter for press structures. So second conceptual design is considered and design optimizations is carried out reduce the weight by redistributing the stresses.
- Totally 2 design parameters in scalar format with 2 state variables (deflection and stress) with convergence for weight is analyzed with the Ansys design optimizer using sub problem approximation.
- Total of 11 sets (7 feasible + 4 Infeasible) sets are obtained through design optimizer with weight convergence. The initial structure weight of 459kgs is reduced 342kg. So a weight reduction of 117kgs can be observed (25.5% reduction of weight).
- Further modal analysis is carried out and results are obtained for the modal nature of both conceptual designs. The results shows first configuration has better natural frequency compared to the second for dynamic stability. But with the deflection as the critical parameter, the second conceptual design is considered for further improvement.

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