Design Optimization of Paver Finisher Chassis Using Topology Optimization

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Abstract— Chassis of an automobile or equipment is an important structure, which holds all the parts fitted on it and sustain all the static and dynamic loads imposed on it. So, it is necessary to design the chassis and its parts such that they are able to sustain all type of loads. Here, topology optimization method is applied to minimize the compliance of the chassis and solve the problem. Generally, Topology Optimization method is developed for compliance minimization. Solid Isotropic Material with Penalization (SIMP) using Optimality Criteria Algorithm is applied for Static response. Here, Topology Optimization is used to solve the static response problem of chassis. For achieving the best material distribution in the design domain we use the OPTISTRUCT for Topology Optimization problem. Validation is taken from the CAD model by using the reference of optimized model, and by analysing, it gives better results than earlier. The optimized model is verified by considering real load condition on the chassis.

Keywords: Topology Optimization, Compliance, Solid Isotropic Material with Penalization (SIMP), Chassis.

I. INTRODUCTION

Chassis of an automobile or equipment is an important structure, which holds all the parts fitted on it and sustain all the static and dynamic loads imposed on it. Here chassis is optimized for minimization of the minimization of the compliance viz. maximization of the global stiffness of the structure.

The objective of this project is, to minimization of the global compliance in static and dynamic response of loads applicable on the machine chassis and to minimize the deflection of the main side plate of the paver finisher chassis in static and dynamic response. Maximization of Stiffness of the structure is the important factor, which is covered in the project. In other words, the minimization of the global compliance of the structure.

Topology Optimization is an iterative process that determines the best arrangement of a limited volume of the structure material within a given spatial domain so as to obtain an optimal mechanical performance of the design. The method used to solve this problem is the topology optimization by Density method generally known as SIMP (Solid Isotropic Material with Penalization) Interpolation scheme.

II. LITERATURE SURVEY

Structural analysis and in mechanical product refers to different predictions in response to external loads. The geometry of the product is vital in consideration with applied static and dynamic loads. So, geometry parameterization determines the type of geometry. It can be classified as sizing, shape and topology parameterization [1, 2]. Here topology parameterization allows the change in topology in addition to its shape and product geometry. Topology Optimization has been applied to various problems such as stiffness problems, eigenfrequency problems, automobile crashworthiness problems and reliability optimization problems. Here, topology optimization is the part of structural optimization which is very useful at the concept design of the structures subjected to linear and nonlinear responses [1, 2, 3].

In our problem Topology Optimization is considered using SIMP interpolation scheme, which is also known as Density Method is used with Optimality Criteria (OC) Algorithm [2, 6]. Since SIMP approach has been applied to isotropic-solid or an empty finite element (ISE) therefore this method is applied to isotropic materials [5]. The basic idea of SIMP approach was proposed by Bendose [3, 7, 8]. The SIMP method introduces the concept of material density as a non-physical, independent variable. Topology optimization problem is virtually a combinatorial optimization problem with 0-1 variables for existence of members. The SIMP stands for Solid Isotropic Material with penalization for intermediate densities. This method provides the solution in the form of 0-1 material distribution, 0 means void part of the design domain and 1 represents the solid part of the design domain shown by the Rozvany [11]. Although, another method called Method of Moving Asymptotes (MMA) was also used by Savenberg [12] to solve the Topology Optimization problem.

In order to solve the problem by SIMP method there is an numerical instabilities like checker boarding which leads to insufficient results, and not useful for understanding the design. So, for improving the solution the filtering is employed to avoid the checker boarding problems. The different types of filtering techniques are reviewed by the Sigmund and Peterson [13]. Here, we are focused on the filtering of the sensitivities to remove the checker boarding.

The vehicle chassis is considered as a structure on which components are fitted and also static and dynamic forces are imposed on it. The construction equipment subjected to different loads such as static and dynamic loads. Non-linear problems have difficulties when solving with Topology Optimization because there is a complex calculations, which contains inertia and damping matrix with stiffness matrix [14]. Therefore, the equivalent loads for each time step is considered as the static loads and used for solution of the topology optimization problem. Park and Lee [15] propose the Equivalent Static Load method for structural optimization when considering non-linearity. Equivalent Static Loads (ESLs) are defined for linear analysis, which generate the same response field as those of non-linear static analysis. ESL is calculated by using the result of non-linear static analysis. Equivalent Static Loads can be calculated by transient analysis using ANSYS. Therefore, the ESL structural optimization can use conventional optimization technique which is very well developed. A nonlinear response optimization problem is converted to a linear response optimization with equivalent loads. The original loads are changed to as set of equivalent static loads according to the response [16]. In this method the original loads are changed to a set of equivalent static loads.

From the review of research papers, the Topology Optimization is used here to carry out the optimization. The Topology Optimization uses the Density Method to solve the problem. Here, Hyper Mesh [17] is used for meshing and setup the optimization problem, and OPTISTRUCT [18] is employed to perform the Topology Optimization.

III. TOPOLOGY OPTIMIZATION

Topology Optimization is an iterative process that determines the best arrangement of a limited volume of the structure material within a given spatial domain so as to obtain an optimal mechanical performance of the design. From a given design domain the purpose is to find the optimum distribution of material and voids. To solve this problem it is discretized by using the finite element method (FEM) and dividing the design domain into discrete elements (mesh) [4]. The resulting problem is then solved using optimization methods to find which elements that are material and which are not. This result in a so called 0-1 problem, the elements either exists or not, which is an integer problem with two different states for each element, a so called ISE topology (Isotropic Solid or Empty elements). The two main solution strategies for solving the optimization problem with an ISE topology are the density method (SIMP) and the homogenization method [5].

In designing the topology of a structure we determine which points of space should be material and which points should be void 1 (i.e. no material). However, it is well known that an optimum result of topology optimization consists in a structure with intermediate (or composite) material. So, continuous values between 0 and 1 replace the discrete 0/1 numbers to represent the relative densities of the elements, while some form of penalization is used to steer the solution back to discrete 0/1 values [7]. The objective function is the compliance and there is a volume constraint. This is the basic set-up of a topology optimization problem.

The solid isotropic material with penalization (SIMP) method [3, 5] uses one design variable to represent the density in each element. Since the focus of this paper is the linear solver in the finite element analysis (FEA), we use the SIMP method as a simple set-up. There are various optimization algorithms that can be used for topology optimization. For instance, an optimality criterion (OC) is a simple approach based on a set of intuitive criteria.

IV. THE SIMP METHOD

The solid isotropic material penalization (SIMP) method borrows principles from the homogenization method, but greatly simplifies the process. The SIMP method introduces the concept of material density as a non-physical, independent variable. The SIMP method also omits the rotation angle as a design variable and therefore assumes isotropic material properties at the macro-scale.

Under this assumption, the effective material stiffness E_e, of a given cell or finite element can be expressed as the product of the Young's modulus of the solid material, E_0 and some interpolating function of the material density, $\rho_e \in (0, 1]$.

$$E_e = \emptyset(\rho_e)E_0 \qquad \text{....(1)}$$

where the function Φ must be chosen such that during the optimization process each cell is forced toward either the solid or void phase, by penalizing intermediate densities. Although intermediate density material could, in theory, be manufactured by introducing an infinite number of holes into the microstructure, this process would be impractical and the cost would be prohibitive.

Based on the SIMP penalization function, the element stiffness matrix k_e, can also be expressed as a function of ρ_e using,

$$k_e = \rho_e^p k_0 \qquad \text{........(2)}$$

Where k_0 is the stiffness matrix of the element in the solid phase (ρ = 1). Note that one must enforce a bound such that $\rho \geq \rho_{min} > 0$. Typically, ρ_{min} is chosen as 10^{-3} to avoid singularities in the global stiffness matrix.

V. PROBLEM FORMULATION

The objective is to minimize the compliance of the structure. The problem formulation of Topology Optimization using SIMP material interpolation scheme and FEM form of the Compliance Minimization problem is written as follows:

Minimize $\quad C(\rho) = f^T u\{\rho\}$ ....(3)

Subject to $\quad : \frac{V(\rho)}{V_0} \leq f_V$ ....(4)

$:K\{\rho\}\, u\{\rho\} = f$ ....(5)

$: 0 \leq \rho_{min} \leq \rho \leq \rho_{max} \leq 1$ ....(6)

where $C(\rho)$ is the objective function representing the compliance of the structure, $u\{\rho\}$ and f are the global displacement and force vectors, respectively, $u_e\{\rho\}$ and f_e are the element displacement and force vectors, respectively, $K(\rho)$ is the global stiffness matrix, ρ is the vector of design variables representing the generalized density of the mesh, V_o is the design domain volume and f_V is the prescribed volume fraction constraint.

The steps for the Topology Optimization is as follows:

A. Pre-processing of geometry and loading

1) Choose a suitable reference domain (ground structure)
2) Choose the part to be designed (the solid domain and voids)
3) Construct FE mesh for the ground structure
4) Construct FE spaces for displacements and ρ (design variables)

B. Optimization

1) Compute the optimal distribution over the reference domain of
2) the design variable ρ
3) Displacement base FE method analysis
4) Optimality update criteria scheme for the density

C. Post-processing of results

1) CAD representation

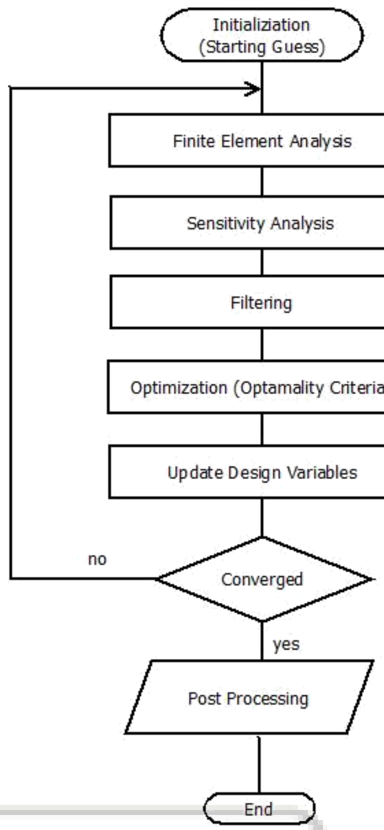

Fig. 1: Flow of Computations Topology Optimization using Optimality Criteria [3]

VI. CAD MODELS AND SOLUTION

The model and the design of the chassis is obtained from the AMMANN APOLLO (I) PVT. LTD. The model AP550 of Hydrostatic Sensor Paver Finisher's chassis is used here for application of the topology optimization method. The model consists of two side plates, front plate and auger support is welded at the rear side. The model is supported by ten C-channel between two plates and four angles are welded at specified shown locations. Additionally, two C channels are provided for supporting the plates at top side. The Geometry and the dimensions are shown in the figure 2. Different supporting channels, angles and plates are provided for fitting of different equipment.

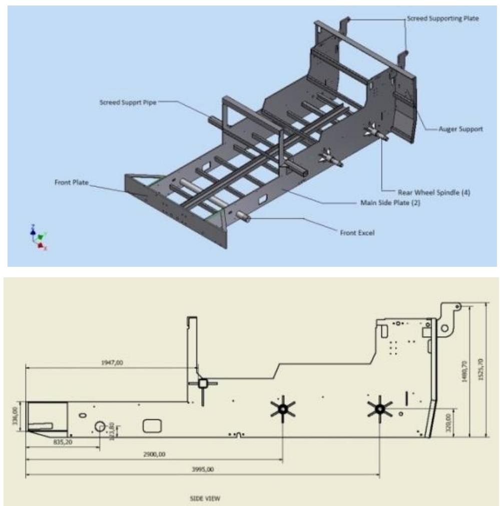

Fig. 2:Chassis CAD Model – AP550 and Side View of Chassis

In order to simplify the problem limited part of the chassis is used. In solving the problem of topology optimization, the model of the chassis is limited to the CAD model as shown in fig. 3 & 4. This is simplified because the forces which acting on the chassis is transferred through this channel and to the main side plate of chassis. It is not possible to change the design of the side plates, so here, chassis replacement plate is taken for obtaining the sustainable design of the chassis.

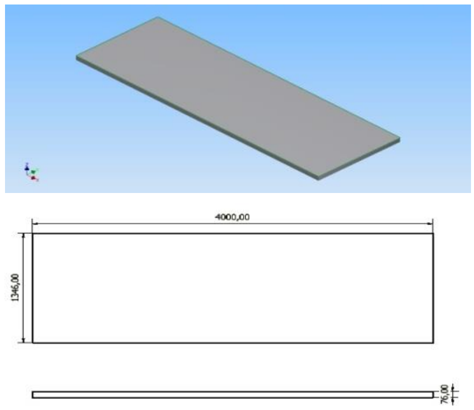

Fig. 3: Channel Replacement Plate and Dimensions of Channel Replacement Part

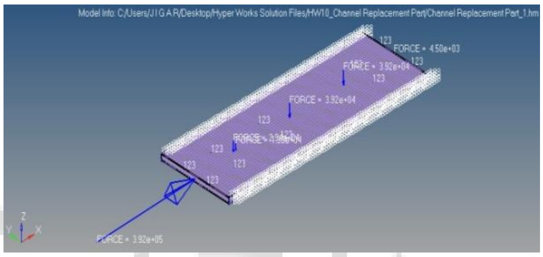

Fig. 4: Model Setup and Meshing in hypermesh

The forces are applied on chassis are described as follows:

– On front Side = 392.4 kN
– From Top Side = 98.1 kN Force distributed over three points as shown in Fig. 4

Optimization Problem Parameters are as Follows:

Objective Function : Minimize Compliance

Response Summary :

Number of volume fraction responses : 1

Number of compliance responses : 1

Total Mass of Design Material : 3216.2 kg

Solid Design Elements : PSOLID

Optimization Parameters Summary :

Initial Material Fraction [0,1] : 0.3000

Minimum Element Volume Fraction : 0.0100

Discreteness Parameter : 1.0000

Topology Optimization

Method : Density Method

Run Type : Topology Optimization

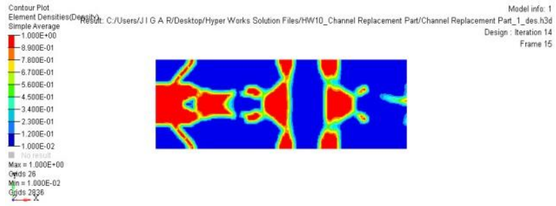

Fig. 5: Material Distribution of plate according to given load condition

By solving the problem using OPTISTRUCT, the optimization has converged and total 14 iteration are performed to obtain the desired design. Fig. 5 shows the material distribution of plate according to give load case. The red part in the design domain shows, that in which part material distribution is very important and blue coloured part shows which have less importance in designing the chassis. Maximum material density in the plate is 1 shown by red colour and minimum density of material is 0 shown by blue colour. All the intermediate colours are shows the importance of the material distribution in the design domain, they can be used as per requirement of the design.

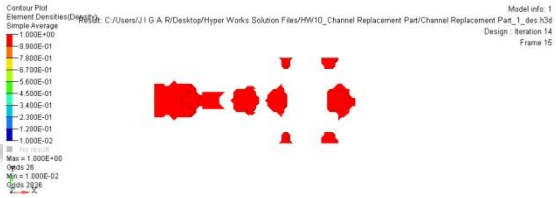

Fig. 6: Maximum Density of Material Distribution

Fig. 6 shows the maximum density of 1 is shows where the material distribution is important. From where it can sustain maximum loads exerted by the components external loads of raw material and load exerted by the truck. So, this updated design concept can be used in new design of chassis.

VII. MODIFICATION, SOLUTION & RESULTS

A. Modification Based On Optimized Model:

From the results of topology optimization the Frame Structure is modified as shown in fig. 7. In this structure flat bars, C-channel, tube and support stiffeners are attached which are same that of material distribution of optimized model. The stiffeners are attached at the place where material density is 1 in the optimized model – Fig. 5 & 6.

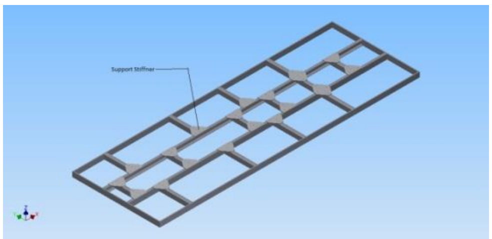

Fig. 7: Modified Frame Structure of Chassis

1) Material Data:

- Material : Structural Steel
- Young's Modulus: 2.1×10^5 MPa
- Poisson's Ratio: 0.3
- Density of Material (ρ) : 7850 kg/m^3

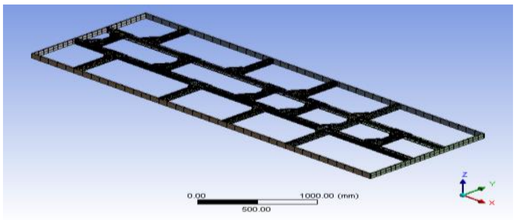

Fig. 8: Meshing of Frame Structure

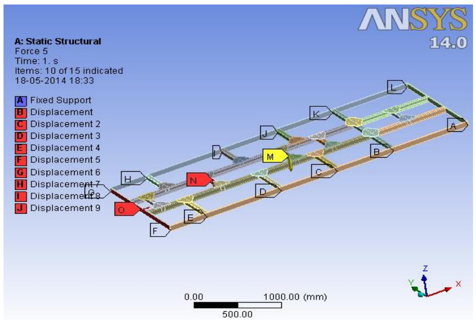

Fig. 9: Constraints applied on Frame Structure

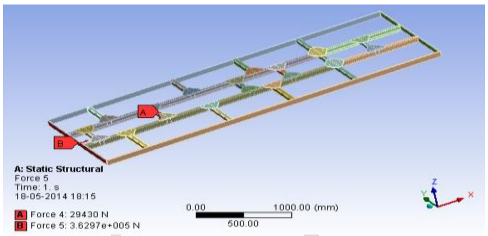

Fig. 10: Constraints applied on Frame Structure

2) Magnitude of Applied Force are given below:

Force A:

Force Applied by the Raw Material = 29.43 kN

Force B:

Reaction Force Against Truck = 362.97 kN

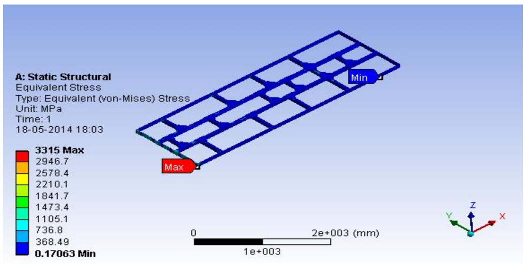

Fig. 11: Result Von-Mises Stresses

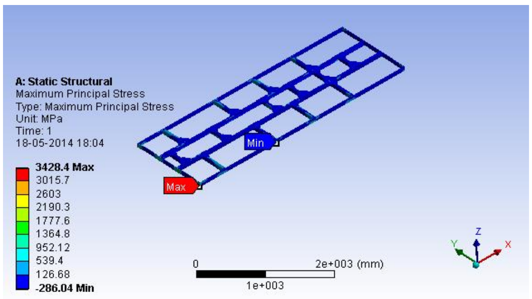

Fig. 12: Result: Maximum Principal Stress

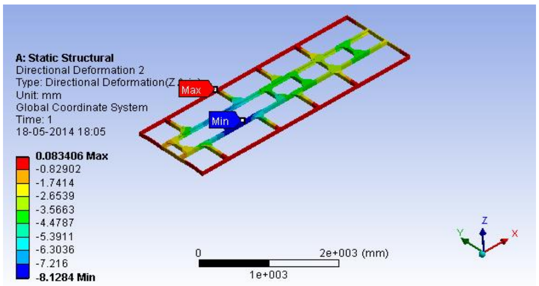

Fig. 13: Result: Directional Deformation (Z=Axis)

VIII. DISCUSSION ON RESULTS

Force A defined as the force applied by the raw material dumped in to the hopper of machine and Force is defined as the reaction force against truck which continuously supply, the raw material in to hopper. So, the force A is increases when the truck is gradually unload and the reaction force against truck because the load in the truck is decreases.

A. Result of the Analysis

- Force A = 29430 N
- Force B = 362970 N
- Von-Mises Stress = 3315 MPa
- Max. Principal Stress = 3428.4 MPA
- Max. Directional
- Deformation (Z – Axis) = 0.083406 mm

The directional deformation in Z direction is very important. It is shows that the deformation is minimum when the Force B is larger and the stresses are maximum. Hence, from the above discussion it is safe for the highest load acting on it.

IX. CONCLUSION

In the present work, the topology optimization using the Hyperworks OPTISTRUCT is performed for Paver Finisher Chassis. The topology optimization procedure is performed to obtain the optimum material distribution over the prescribed constraints and load condition.

Optimization has been carried out for new design concept for the chassis. The topology optimization has primarily gives the compliance minimization under the given load condition. It is also observed that topology optimization gives the best concept design for optimum material distribution over the design domain. Through the optimization and analysis procedure it is concluded that the modified model of chassis is better than the earlier design of the chassis. This frame structure is attached with the two main side plates of the chassis gives better output to sustain larger loads.

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