Weight Optimization of Rear Bumper Fog Lamp Punching Machine

Prasad D. Rewade[1], Dipak N. Patil[2] and Prakash S. Dabeer[3]

Abstract— **Presently, plastics are widely used for car exterior and interior trims; however, with the growing importance of reducing vehicle weight, plastics application to body and chassis parts is ever on increase. In industries, previously not only interior and exterior trim was glued together but also, the fog lamp hole pierced by manual punching processes. These machines are huge and heavy since there are no predefined sets of loading, control over the design for structural parts. Due to these machines structural parts were designed on manufacturing trial and error basis. In this paper, Optimized design is done with the help of Bi directional Evolutionary Structural Optimization Technique (BESO). Components are analyzed in CATIA V5 software and restructured to meet structural, flexural requirements. Optimized design is targeted to fulfill the flexibility and huge change over requirements for various bumper models to assembly with reduction in weight of structural parts.**

***Index Terms*—BESO, Industries, Chassis**

I. INTRODUCTION

In the automotive area, Bumpers are also produced by injection molding process. Fog lamp holes, cooling grooves and mounting holes are features which requires huge tooling investment. So fog lamp punching machines are used for punching holes in molded bumper. These machines are very huge in construction since this are operated by means of hydraulic cylinders which carries die. These carries many components such as cylinders, bearing, support plates, bushes, guide rods, springs, wheels, safety grills, hoses, control panel. Machines are designed with trial and error function or past history of machines which results in overdesign of structural parts. Machines become very heavy due to use of heavy supports and plates with hydraulic cylinders acting upon die. Size & shape of parts becomes crucial which adds weight to assembly level also increases cost.

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Presently existence of Special purpose machines is widely distributed amongst the automotive components. One of the primary studies on the shaped holes has been conducted by Arun et al [1]. They found that machines are huge in construction and are designed based on iterative trial and error mountings. Success of these machines measured in terms of production rates and accuracy. Thorough studies of punching machine structural parts design have been carried out by Srinivasa et al [2]. They noted design can be made simple and robust with design calculation for structural parts. Satalkar et al performed numerical calculations on several structural parts which in turn reduce overall weight based on few assumptions on loading cases [3].

In the present study, the structural parts of machine are identified for weight optimization. Design requirements, transfer of hydraulic forces onto structural parts are investigated. Manual numerical calculations for structural parts are complex in today's design context. There is need of weight optimization in such machine structure parts to reduce weight which will save cost and to avoid overdesign. One of the analysis techniques is BESO i.e. Bi directional Evolutionary Structural Optimization Technique which gives good control over design of such parts.

II. METHODOLOGY

The design process is majorly classified into two stages as detail design and concept design. It has been observed & suggested that by use of the topology optimization techniques at concept design stage, we may obtain essential & better performance of structural components. The design of structural components and their layout may be obtained at the stage of concept where as the size and shape of the structure may be obtained at the stage of detail design.

Topology optimization is a technique that allows engineers to design appropriate structural layout for the particular performance of machine. This has evoked noticeable attention for last many decades. Further many techniques have been studied and investigated for topology optimization, taking as an example, the homogenization method [4, 5], solid isotropic material with penalization method [6–7] and the evolutionary structural optimization (ESO) method [8, 9]. The first method is homogenization where the results are generated in the form of perforated composite material. The resulting static structures cannot be developed directly as there is infinite scale of length is connected with the microstructures. Similar technique which uses properties of material is supposed to be constant within each of the element for SIMP method. Using these elements we can discretize the variables and the design domains which define element relative densities.

The ESO method was initially introduced by Steven and Xie [8] in the stages of early 1990s and they studied to use ESO method for a various number of shape, size and topology optimization problems [10–12]. ESO method is basically studying and gradually removing or adding material which is inefficient, these results in optimized structural design layout. Bi-directional evolutionary structural optimization (BESO) technique it can be expressed as advance technique to ESO which gives better option to add efficient materials to the structure as well as the inefficient ones to be restructured or removed [13].

Result of the technique is optimum topology which provides straight away profile of topology with no "green" area and thus it is easy & simple to design and manufacture. Hypothetically, it has been observed that the combination of approximate optimization method in connection with sequential linear programming and simplex algorithm is almost equal to ESO/BESO [14]. Consistent problem in the BESO method is that this method gives mesh-dependent solution number of times. The reason is behind that is different and variable types, mesh sizes, densities, and the introduction of more holes without changing the structural volume will generally increase the efficiency of a given design [4, 15]. This effect is observed and noted as a numerical instability where a larger number of holes appear when a finer finite element mesh is applied and it is termed as mesh dependency. However, prediction of the numerical value of the perimeter constraint for a new & complex design problem is a difficult task [17]. The BESO method is capable of obtaining mesh-independent solutions due to the more constraint on the topology optimization problem with perimeter control [16].

The optimization parameters in whole machine are identified such as plates, bushes, couplings, base frame, etc. there are many tools available in engineering technology of stress analysis. One of the techniques is BESO approach [18].

Steps for BESO approach are as follows:

Step 1: Discretization of the structural component using a fine mesh of finite elements.

Step 2: Carry out finite element analysis for the structure

Step 3: Remove elements which satisfy the following condition:

$$\frac{\boldsymbol{\sigma}_{\mathbf{e}}^{\mathbf{vm}}}{\boldsymbol{\sigma}_{\mathbf{max}}^{\mathbf{vm}}} < \mathbf{RR_i}$$

Where, RRi = Rejection ratio

Step 4: Increase the rejection ratio according to following equation:

$$\mathbf{RR_{i+1} = R_{Ri} + ER}$$

Step 5: Repeat steps 2 to 4 until a desired optimum is obtained

III. EXPERIMENTAL SETUP

Rear bumper fog lamp punching machine is operated on Hydraulic principle with fully automated system. As the forces required to punch the hole are of High magnitude the presence of hydraulics can be well identified.

The setup for the Machine will consist of following:

Base Frame
Base plate
Support plate
Mounting plates LH & RH
Cylinder mounting frame
Cylinder mounting plate
Guide bush
Hydraulic cylinder
Hydraulic Power pack (Pump, NRV, Level indicator)
Oil Reservoir
Hoses and clips
Electrical control Panel
PLC controller

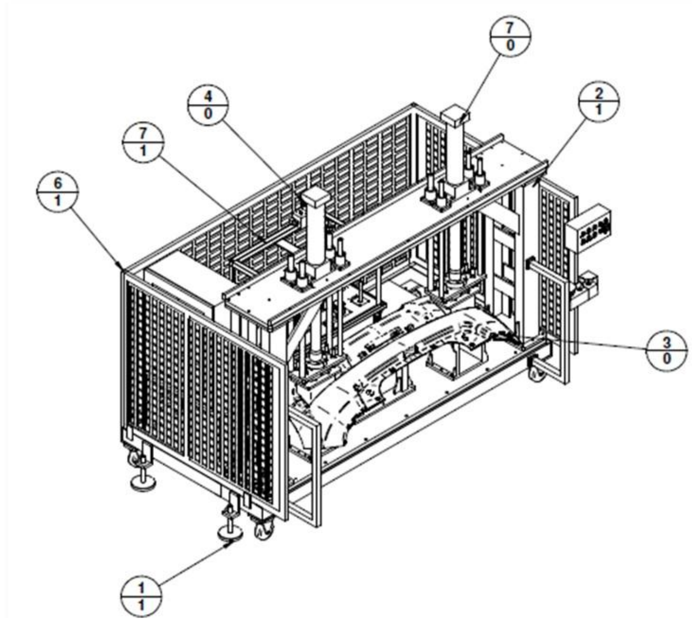

Figure 1. Machine Assembly

IV. FINITE ELEMENT ANALYSIS FOR TOPOLOGY OPTIMIZATION OF STRUCTURAL PARTS

BESO Approach for topology optimization technique applied for structural parts of machine using CATIA analysis tool. In this case, initially loads are applied to parts considering the thickness and parts checked in analysis. The topology of parts investigated on the basis of analysis results which gives highly stressed areas as well as low stress areas. These low stress areas are checked and optimized against the allowable stress of parts.

Thickness, Width, Length of structural parts are varied in order to meet strength requirements as well as optimized design of components using CATIA V5 analysis tool.

40 mm thk 30 mm thk

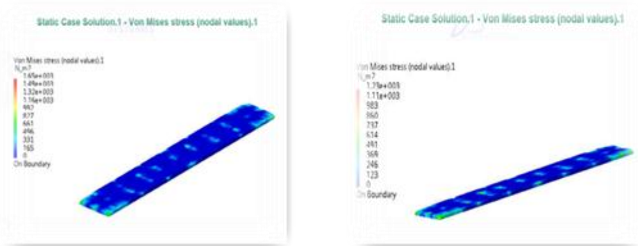

Figure 2. Optimization of Bottom Base plate

The current BESO method can be easily applied to three dimensions structural components. Although, it is most significant to consider that most time is spent on solving the iterative equilibrium equations which consumes most part of the optimization. It becomes crucial for large and complex structural problems substantially in three dimension problems to get better efficiency of the optimization method [4]. It has been observed, optimal solution can be obtained if large area is taken out for Discretization and analysis which will provide improved design very quickly with its better performance.

Bottom plate is iterated at various thickness and weight, max stresses are evaluated to observe the results against yield strength of material of plate. Table 1 shows evaluated results:

Bottom Base Plate			
Thickness (mm)	Weight (kgs)	Allowable Yiled Strenth(N/m2)	Evaluated Max. Stress (N/m2)
40	324	2.05E+08	1.71E+04
39	315.9	2.05E+08	1.77E+04
38	307.8	2.05E+08	1.82E+04
37	299.7	2.05E+08	1.88E+04
36	291.6	2.05E+08	1.17E+05
35	283.5	2.05E+08	1.14E+05
34	275.4	2.05E+08	1.10E+05
33	267.3	2.05E+08	1.69E+06
32	259.2	2.05E+08	1.74E+06
31	251.1	2.05E+08	1.78E+06
30	243	2.05E+08	1.83E+06

Table 1. Bottom Base Plate Results

35 mm thk 20 mm thk

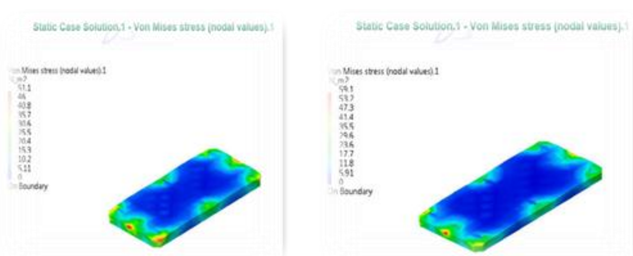

Figure 3. Optimization of Pillar bottom base plate

30 mm thk 16 mm thk

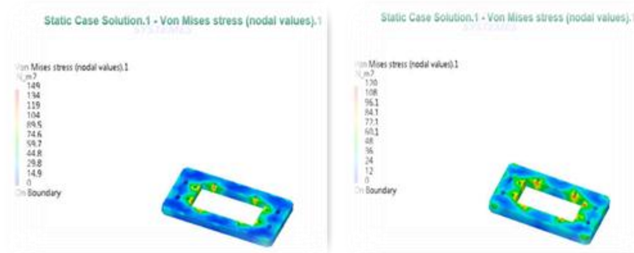

Figure 4. Optimization of Pillar top base plate

40 mm thk 30 mm thk

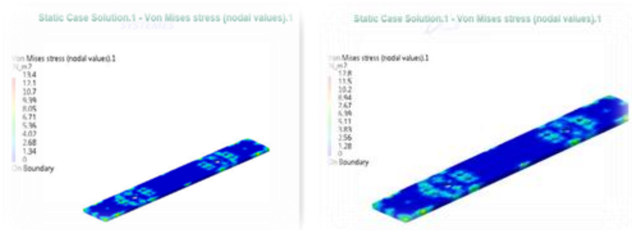

Figure 5. Optimization of Tool mounting plate

The above figures illustrates that the BESO technique gives a restructuring of full structural components and analyze an optimal solution considering the required load cases. This is an iterative approach which allows thickness of material or the size and shape can be varied according to basic steps of BESO method i.e. discretize, add or remove inefficient area and again check against required loads. BESO starts from the initial guess design which may give optimal solution or may deviate to the controversial solution which leads much number of solutions to be operated. This method must start from initial full design guess which will eliminate or remove chances of further failures at the components. Components checked against each loading case and then the materials to be added or deleted from the structure.

This method is time consuming sometimes since there is no prediction about the guesses and results. For getting an optimal solution many number of iterations are needed for evolving a guesses and design to an optimal one especially when the guess design is closer to the optimal topology. The results may be studied and guesses can be made precise so as to save time while performing iterations in optimizing component. Iterations are many times dependent upon complexity of component and load cases. Optimal solution may be close to the predicted solution.

In optimization of plates or components we have used the CATIA Analysis tool for analyzing the load cases. The loads are applied in the direction of cylinder piston i.e. downward which creates stresses on plates and structural member. Here we have analyzed the components and iterated to get optimized result.

30 mm thk 20 mm thk

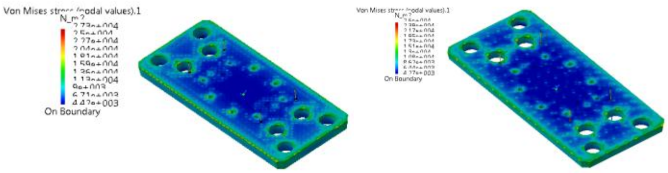

Figure 6. Optimization of Block supports

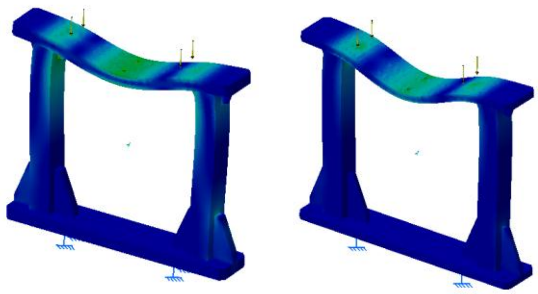

Figure 7. Optimization of Block supports

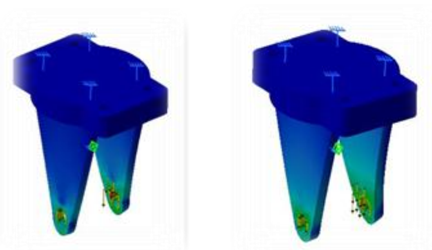

Figure 8. Optimization of support

Supports holds wheels which carries whole weight of machine gives flexibility towards movement of machine. Supports are checked against static condition when the cylinders are in operation i.e. worst case situation as design must satisfy worst case.

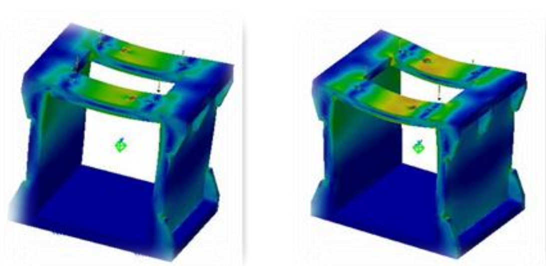

Figure 9. Optimization of Fixture

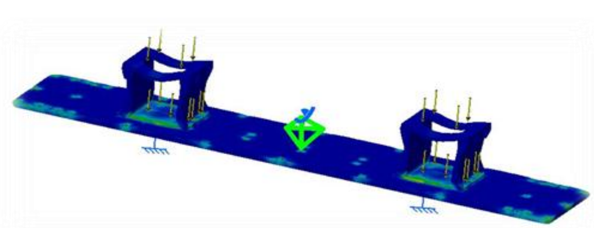

Figure 10. Overall Weight reduction from 44 kg to 38 kg

V. RESULT & DISCUSSION

Optimization of various components is performed using CATIA V analysis tool. The components are checked against various geometrical shapes and thickness. Results are obtained using this technique which allows addition and deletion of efficient and inefficient areas which can be identified using stress values at the parts. Table 2 shows weight saving against each component

Sr. No.	Component	Old Weight (kgs)	Optimized Weight (kgs)	Weight Saving (kgs)
1	Bottom Base Plate	365	243	122
2	Top Base Plate	365	233	132
3	Pillar LH & RH	298	136	162
4	Die Mounting Supports LH & RH	98	76	22
5	Nylon Block Supports LH & RH	82	60	22
6	Support Plate LH & RH	9.6	7.2	2.4
7	Pillar Base Plate LH & RH	43	29	14
8	Pillar Top Plate LH & RH	31.2	18.6	12.6
9	Punch Bottom Plate LH & RH	15.2	8	7.2
10	Guide Shaft x 8	47.2	39.2	8
Total Weight saving achieved in strutural parts >= 0.5 Tons				504.2

Table 2. Weight Saving results

This is a new approach which is introduced in such structural components gives solution towards compliance minimization problems of continuous structural components. Discretization becomes of critical in determination of the adding elements and to remove or eliminate inefficient or unnecessary structural elements.

In earlier studies as we noted, the techniques like SIMP method, homogenization method are used to optimize the components using numerical methods, linear programming, simple algorithms which were time consuming and provides instable values of numerical results. These techniques are very complicated to be applied onto complex and irregular shaped components. Drawbacks of this techniques applied limitations to implementation of this techniques in optimization.

In this paper, using BSEO Technique an appreciable weight reduction of structural parts is achieved as compared to the earlier machines which were not at all checked for target stresses and failures or overdesign. Weight is not of prime importance in earlier scenario. In this technique it gives more exposure towards weight saving with prediction of failures.

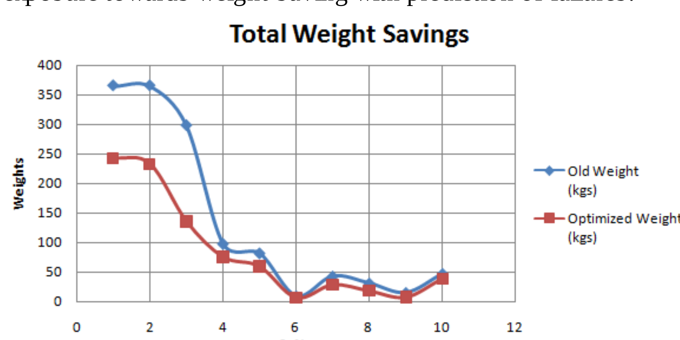

Figure 11. Weight saving Comparison

VI. CONCLUSION

This paper presents the optimized design is achieved using topology optimization technique i.e. BESO technique which gives better control over size & shape of structural parts. This avoids overdesign and also provides strength results which predicts highly stressed & failure areas at various components which helps to minimize probability of machine failures. Components optimized will provide control over overall dimensions of parts resulting into weight and cost saving. Almost half ton weight saving is achieved using BESO topology optimization technique for machine structural parts.

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