Structural Optimization of 5Ton Hydraulic Press and Scrap Baling Press for Cost Reduction by Topology

Muni Prabaharan and V.Amarnath

***Abstract*—Structural optimization tools and computer simulations have gained the paramount importance in industrial applications as a result of innovative designs, reduced weight and cost effective products. Especially, in aircraft and automobile industries, topology optimization has become an integral part of the product design process. In this project, topology optimization has been applied on various components of scrap baling press and 5Ton hydraulic press using ANSYS WORKBENCH software. Suitable loads and constraints are applied on the initial design space of the components. An integrated approach has also been developed to verify the structural performance by using ANSYS software. At the end, shape optimized design model is compared with the actual part that is being manufactured for the press. It is inferred that topology optimization results in a better and innovative product design. In this project, we showed 26.26 percent cost reduction in scrap baling press. And we fabricated 5ton hydraulic press with cost reduction of 24.54 percent.**

***Index Terms*—Topology Optimization, Value Engineering, Scrap Baling Press, Hydraulic Press, Universal Testing Machine.**

I. Introduction

A. About shape optimization

Today, all the modern manufacturing enterprises are striving to develop best optimized reduced weight and cost effective products that meet the intended design functionality and reliability.

In this scenario, structural optimization tools like topology and shape optimization with manufacturing simulations are becoming attractive in product design processes. These tools also aid in reducing product development times [1].

In last few years, shape optimization has emerged as the valuable tool to develop new design proposals especially in automobile and aircraft industries [2].

This result in an innovative design proposal irrespective of dependency of the designer experience and conventional design approaches. In recent years aircraft industries have exploited the full benefits of optimization driven design.

B. About scrap baling press

Pneumatic scrap baling presses are designed for processing plastic, ferrous or non-ferrous scrap in all forms. These machines are capable of compressing various leftover, housing of junk, cab, metal structural, metallic chips into cuboids bales.

Fig.1. Scrap baling press

C. Components of the scrap baling press (Charging box assembly)

1) Pressing cylinder
2) Lid cylinder
3) revised July 6, 2011Trunion
4) Cylinder mounting plate
5) Cylinder and top door holding plate
6) Top door
7) Side door
8) Side wear plate
9) Base wear plate
10) Base plate
11) Front door
12) Front door stopper

D. Specification of the press

S.No	Specifications	Units
1	Over all dimension	cm
2	Charging box	cm
3	Bale dimension	cm
4	Bale weight	kg
5	Motor	hp
6	Lid ram thrust	tons
7	Main ram	tons
8	Idle cycle	sec
9	Operation	-

E. Charging box parts

1) Front door
2) Front door stopper
3) Base plate

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4) Pusher plate
5) Left door
6) Right door

F. Hydraulic press

A hydraulic press is a hydraulic mechanism for applying a large lifting or compressive force. It is the hydraulic equivalent of a mechanical lever, and is also known as a Bramah press after the inventor, Joseph Bramah, of England. He invented and was issued a patent on this press in 1795. As Bramah (who is also known for his development of the flush toilet) installed toilets, he studied the existing literature on the motion of fluids and put this knowledge into the development of the press. Hydraulic presses are the most commonly-used and efficient form of modern press.

G. Principle

The hydraulic press depends on Pascal's principle: the pressure throughout a closed system is constant. At one end of the system is a piston with a small cross-sectional area driven by a lever to increase the force. Small-diameter tubing leads to the other end of the system.

Pascal's law: Pressure on a confined fluid is transmitted undiminished and acts with equal force on equal areas and at 90 degrees to the container wall.

A fluid, such as oil, is displaced when either piston is pushed inward. The small piston, for a given distance of movement, displaces a smaller amount of volume than the large piston, which is proportional to the ratio of areas of the heads of the pistons. Therefore, the small piston must be moved a large distance to get the large piston to move significantly. The distance the large piston will move is the distance that the small piston is moved divided by the ratio of the areas of the heads of the pistons. This is how energy, in the form of work in this case, is conserved and the Law of Conservation of Energy is satisfied. Work is force times distance, and since the force is increased on the larger piston, the distance the force is applied over must be decreased.

II. Value Engineering

Value engineering (VE) is a systematic method to improve the "value" of goods or products and services by using an examination of function. Value, as defined, is the ratio of function to cost. Value can therefore be increased by either improving the function or reducing the cost. It is a primary tenet of value engineering that basic functions be preserved and not be reduced as a consequence of pursuing value improvements.

III. Universal Testing Machine

A universal testing machine, also known as a materials testing machine or materials test frame, is used to test the tensile stress and compressive stress of materials. It is named after the fact that it can perform many standard tensile and compression tests on materials, components, and structures.

A. Mild steel

Mild steel is the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications. Mild steel contains 0.16–0.29% carbon. Mild steel has a relatively low tensile strength, but it is cheap and malleable; surface hardness can be increased through carburizing. It is often used when large quantities of steel are needed, for example as structural steel.

Since we don't know whether our mild steel which is used in various components of scrap baling press and hydraulic press is standard one or not. If it is standard one, then we can get its properties from PSG Design Data book. Otherwise, we should go for testing. For confusion, we are testing our mild steel material in Universal Testing Machine.

IV. Problem Statement

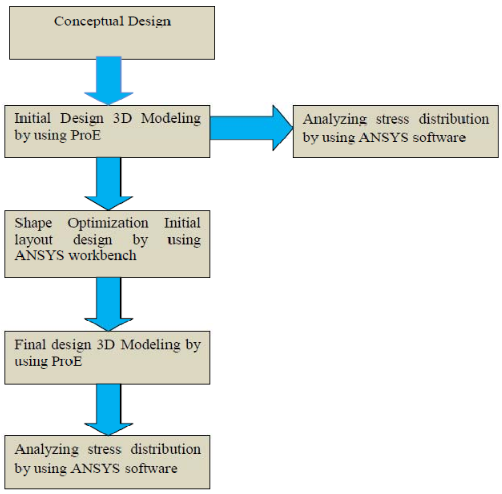
A. Problem statement

We are design and analyze a scrap baling press. The company needs, cost reduction in the baling press. The charging box assembly is one of the parts of the press. The weight of the box is above 1000kg. Approximate cost is Rs. 3 lakhs. Saving is very important in their future projects. Design upgrading is also their need to meet global competition. Our work is to analyze the need of the company. We are analyzing only the charging box structures.

B. Problem statement

The project needs reduction in thickness of the hydraulic press frame. The thickness of the frame is 10mm. We have analyzed that whether it is possible to reduce the thickness of the frame or not.

V. Design Approach



VI. Design

A. Density of material

Material: MS

- Diameter =16mm
- Length=56.2mm

- Weight=90gms

Volume=3.14*r^2*h=11299.68mm^3=11.2997cm^3

Weight=volume*density

Density=weight/volume=90/11.29=7.9648gm/cc

B. Readings

S.No	Load(P) kgf	Extensometer reading	Extension(Δl) mm	Stress, N/mm^2	Strain
1	000	0	0.00	00.00	0.00000000
2	200	1	0.01	17.98	0.00004545
3	400	2	0.02	35.96	0.0000909
4	600	3	0.03	53.95	0.0001363
5	800	3	0.03	71.93	0.0001363
6	1000	3	0.03	89.91	0.0001363
7	1200	3	0.03	107.89	0.0001363
8	1400	3	0.03	125.88	0.0001363
9	1600	3	0.03	143.86	0.0001363
10	1800	3	0.03	161.84	0.0001363
11	2000	3	0.03	179.82	0.0001363
12	2200	3	0.03	197.81	0.0001363
13	2400	3	0.03	215.79	0.0001363
14	2600	3	0.03	233.77	0.0001363
15	2800	3	0.03	251.75	0.0001363
16	3000	4	0.04	269.73	0.0001818
17	3200	4	0.04	287.72	0.0001818
18	3400	4	0.04	305.70	0.0001818
19	3650	4	0.04	328.18	0.0001818
20	3900	4	0.04	350.66	0.0001818
21	4150	4	0.04	373.13	0.0001818
22	4400	4	0.04	395.60	0.0001818
23	4650	5	0.05	418.09	0.0002270
24	4900	5	0.05	440.57	0.0002270
25	5150	5	0.05	463.65	0.0002270
26	5400	5	0.05	485.50	0.0002270
27	5650	5	0.05	508.02	0.0002270
28	5900	5	0.05	530.48	0.0002270
29	6150	5	0.05	552.96	0.0002270
30	6400	5	0.05	575.44	0.0002270
31	6650	5	0.05	597.91	0.0002270
32	6900	5	0.05	620.39	0.0002270
33	7150	5	0.05	642.87	0.0002270
34	7400	5	0.05	665.35	0.0002270

C. Tension test on mild steel rod

- Original diameter=11.9mm
- Neck diameter=7.5mm
- Extension length=235mm
- Gauge length=220mm
- Least count=0.01
- Area=3.14*5.95^2 =111.22mm^2

During experiment, the following readings are also taken

Ultimate load= 7130kg

Breaking load=5500kg

Yield load=3750kg

Change in length of the rod=235mm

Original length of the rod=220mm

D. Calculations of the MS material properties

- Ultimate stress

= ultimate load/original area

= (7130*9.81)/ (π*5.95^2)=628.89N/mm^2

- Breaking stress

=breaking load/original area

= (5500*9.81)/ (π*5.95^2)=485.12N/mm^2

- Yield stress

=yield load/original area

= (3750*9.81)/ (π*5.95^2)=330.762N/mm^2

- Percentage of elongation

= (change in length/original length)*100

= (235-220)/220*100=6.82%

- Percentage of reduction in area of cross section

= (original area-neck area)/original area*100 =60.28%

Neck area= π*3.75^2=44.179mm^2

Original area= π*5.95^2=111.22mm^2

- Actual breaking stress

=breaking load/neck area

= (5500*9.81)/ (π*3.75^2)=1221.29N/mm^2

- Young's modulus, E=2.2*10^5N/mm^2

E. Calculations of stress acts on various parts of the Scrap Baling Press

a) *Determining stress acts on base plate*

Pressure from lid cylinder = 300bar =30N/mm^2

Diameter of the lid cylinder = 160mm

We know that,

Pressure = (Force/Area)

Force = (Pressure*Area)

=30*(3.14*160^2/4)

=603.18KN

Area of the base plate= (1450*548) =794600mm^2

Stress acts on base plate= (Force/Area)

= (603.18*10^3/794600)

=0.759 N/mm^2

=7.59 bar

b) *Determining stress acts on front door*

Pressure from pressing cylinder= 300bar

=30N/mm^2

Diameter of the pressing cylinder= 250mm

We know that,

Pressure= (Force/Area)

Force = (Pressure*Area)

=30*(3.14*250^2/4)

=1472.62KN

Area of the front door= (400*364) =145600mm^2

Stress acts on front door= (Force/Area)

= (1472.62*10^3/145600)

=10.11 N/mm

=101.11 bar

c) *Determining stress acts on right side door and left side door*

Maximum force acts on the door =1472.62KN

Area of the door = (1450*360)

=522000mm2

Stress acts on front door = (Force/Area)

= (1472.62*103/522000)

=2.82 N/mm2

=28.2 bar

d) *Determining force acts on the MS plate of 5Ton Hydraulic Press*

Force acting on the cylinder = 5Ton=5000N

Number of nodes chosen on the MS plate = 24

Therefore, force acting on the MS plate = (5000/24)

= 208.33 N

e) *Determining Von Mises stresses from various components of Scrap Baling Press for new design*

TABLE1: VON MISES STRESSES

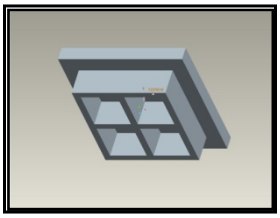
S.No	Component	Obtained stress (N/mm^2)
1	Front door	250.722
2	Front door stopper	145.769
3	Pusher plate	17.0880
4	Base plate	205.290
5	Right door	63.3010
6	Left door	67.3810
7	Frame	68.1100

We know that, the yield stress obtained in UTM testing is 330.762N/mm^2. From the above tabular column, the obtained stresses are less than the yield stress.

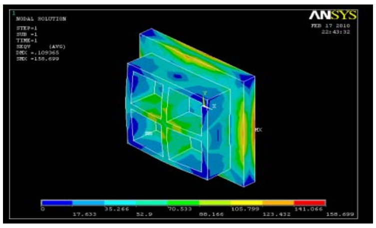
Therefore, our new design is safe.

VII. PROCEDURE FOR TOPOLOGY OPTIMIZATION ANALYSIS

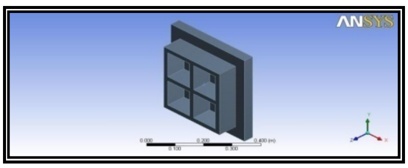
1) First, the front door part (component) is created in ProE software.



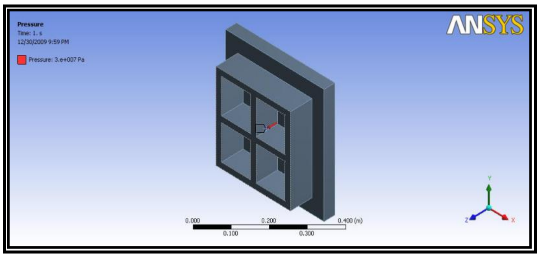
2) The model is saved by using .igs extension in ProE.
3) Now, the model is opened in ANSYS for analyzing stress distribution.



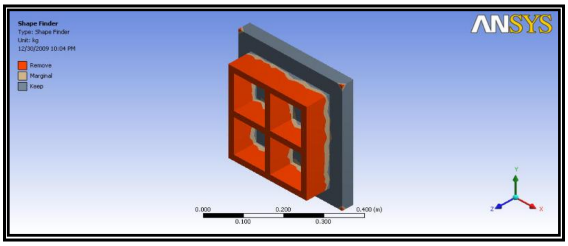
4) Open the model in Simulation, establish units, and set up a shape optimization analysis



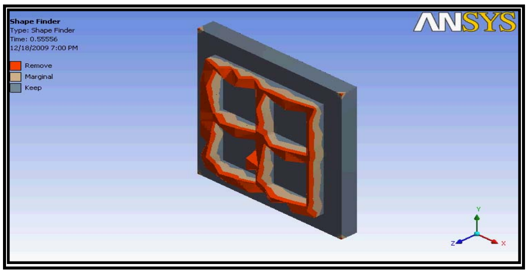
5) From the main menu, choose Units> U. S. Customary (in, lbm, lbf, ºF, s, V, A).
6) Choose New Analysis> Shape Optimization from the toolbar.
7) Specify boundary conditions and loads. The shape optimization analysis will show where material can be removed from the structure with minimal impact for the given load condition. Apply fixed support by selecting the face shown and choosing Supports> Fixed Support and also Load from the toolbar.



8) Specify the target volume reduction as a percentage of the original volume. The analysis removes material while maximizing the stiffness, that is, removes material that contributes least to the stiffness of the structure under the given loading conditions. Highlight the Solution folder and choose Shape from the toolbar. Set Target Reduction.
9) Solve the analysis. Choose Solve from the toolbar.
10) Review the results of the shape optimization analysis. Highlight the Shape Finder object. The results show suggested areas of material removal.



11) Simulation of front door is done in ANSYS WORKBENCH.

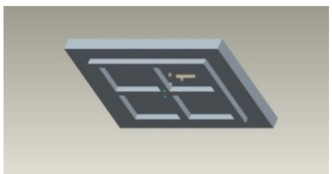


12) Result from ANSYS WORKBENCH report.

Model > Shape Optimization > Solution > Results

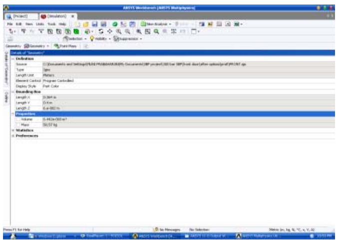
Object Name	Shape Finder
State	Solved
Scope	
Geometry	All Bodies
Definition	
Target Reduction	90. %
Results	
Original Mass	65.124 kg
Optimized Mass	45.646 kg
Marginal Mass	0. kg

13) From the step 10, we should mark where the materials can be removed.
14) Now, optimized model should be drawn in ProE software.



15) The optimized model should be analyzed by ANSYS software.

16) The weight of the optimized component can be found by using ANSYS WORKBENCH software.

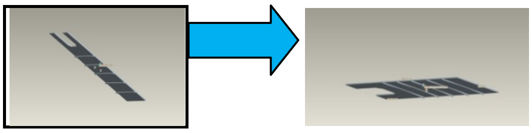


17) Similarly, the other components can also be optimized.

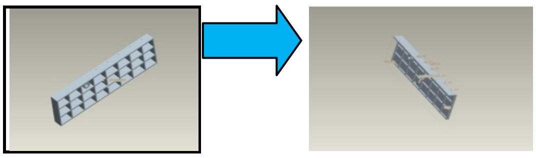
A. Inputs and Outputs of Other Components

1) Front door stopper

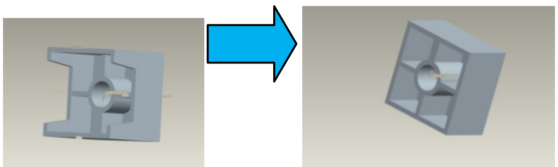
2) Base plate



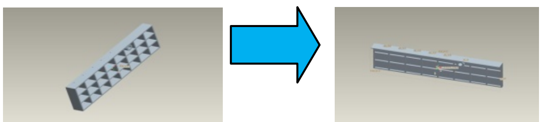
3) Left door



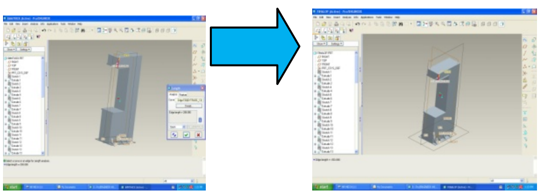
4) Pusher plate



5) Right door



6) .Hydraulic Press



VIII. Cost Analysis

A. Shape optimization results for Scrap Baling Press

B. Percentage of weight reduction

= (Weight reduction/ Current design weight) *100
= (177.504/ 673.237)*100
=26.36%

C. Calculation of cost reduction for Scrap Baling Press

1) Total cost before topology optimization

Material cost per kg =Rs.50
Material cost for 673.23 kg = (673.23*50)
=Rs.33661.50
Fabrication cost per kg =Rs.25
Fabrication cost for 673.23 kg = (673.23*25)

=Rs.16830.75
Total cost = (33661+16830.75)

=Rs.50492.25

2) Total cost after topology optimization

Material cost for 495.73kg= (495.73*50) =Rs.24786.50
Fabrication cost for 495.73kg = (495.73*25) =Rs.12393.25
Total cost = (24786.5+12393.25)
=Rs.37179.75

3) Cost reduction of Scrap Baling Press

Percentage of cost reduction
= (50492.25-37179.75)/50492.25 *100
= 26.26%

D. Shape optimization results for 5Ton Hydraulic Press

TABLE 2: Comparison of Current Design and New Design Weight for SBP

Components	Current design weight (kg)	New design weight (kg)	Weight reduction (kg)
Front door	65.000	50.570	14.43
Base plate	92.000	91.430	0.570
Front door stopper	109.00	98.210	10.79
Right door	182.70	110.81	71.89
Left door	182.70	110.81	71.89
Pusher plate	41.837	33.903	7.934
Total	**673.23**	**495.73**	**177.5**

TABLE 3: Comparison Of Current Design And New Design Weight

Components	Current design weight (kg)	New design weight (kg)	Weight reduction (kg)
Frame	432.8	326.59	106.21

E. Percentage of weight reduction

= (Weight reduction/ Current design weight) *100

= (106.21/326.59)*100
=24.54%

F. Calculation of cost reduction for 5Ton Hydraulic Press

1) Total cost before topology optimization

Material cost per kg =Rs.50
Material cost for 432.8 kg = (432.8*50)
=Rs.21640
Fabrication cost per kg =Rs.25
Fabrication cost for 432.8 kg = (432.8*25)
=Rs.10820
Total cost = (21640+10820)
=Rs.32460

2) Total cost after topology optimization

Material cost for 326.59 kg = (326.59 *50)
=Rs. 16329.5
Fabrication cost for 326.59 kg = (326.59*25)
=Rs.8164.75
Total cost = (16329.5 +8164.75)
=Rs.24494.25

3) Cost reduction

Percentage of cost reduction
= (32460-24494.25)/32460
= **24.54%**

IX. Photograph Of 5Ton Hydraulic Press

X. Conclusions

Optimization design is compared to the actual part design that is being manufactured for the scrap baling press and hydraulic press. It is inferred that under the same loading conditions, constraints and intended design purposes, shape optimization results in better and more reliable design. A designer can produce the best optimized design without much dependency of his experience and previous design options and practices.

Shape optimization is a promising tool to explore optimal solutions to engineering products. Benefits are numerous, including: load path visualization, weight savings, systems design space, ballistic protection, and improved fatigue resistance.

These benefits offer a compelling incentive to employ this technology into the current design process to increase the performance of our products, adding value for our customers.

In this project, we have shown 26.36 percent volume reduction for scrap baling press and 24.54 percent for hydraulic press. We have also fabricated 5Ton hydraulic press by employing topology optimization.

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Prof. V.Amarnath has obtained his Bachelor of Engineering (Mechanical Engineering) and Master of Engineering (Production Engineering) from Bharathiar University, Coimbatore, Tamilnadu, India in the years 1991 and 1992 respectively. He had also received his Master of Business Administration (MBA in Production Management) from Bharathiar University in the year 1997. He has worked in Industries like Lakshmi Machines Works Ltd. and K.G.Denim Ltd. at various capacities. From 2001 onwards he has been working in the Department of Mechanical Engineering of Sri Ramakrishna Engineering College, Coimbatore, Tamilnadu.

His research areas include Metal Joining, Materials Engineering and Industrial Engineering. The projects guided by him had received "Innovative students projects award" instituted by National Academy of Engineering, New Delhi for five times in the years 2002,2004,2006,2007 and 2009. He has undergone several training programmes in the areas of Metal Joining and Materials Engineering. He is the life member of American Welding Society (AWS) and Indian Welding Society (IWS).