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Cost Effective & Innovative Impact Attenuator for Formula SAE Car with Drop Test Analysis

Arpit Singhal, Vignesh S. Subramanium

Computational Fluid Dynamics, University of Petroleum and Energy Studies, Dehradun

Abstract- The impact attenuator [7] is an energy absorbing device installed forward of the front bulkhead of the car with the function to absorb energy and to protect the driver from a sudden change of momentum experienced during an event of a collision. It achieves that by deforming plastically and absorbing a part of the total energy involved during a collision. Aim of this paper is to provide innovation towards the usual and conventional Honeycomb Structured Attenuators for FSAE cars, and testing its effectiveness with drop weight test analysis providing average deceleration impact of vehicle to be less than 20g, which is required according to FSAE design rules.

Index Terms- Cost Effective Innovation, Drop weight Test Analysis, Formula SAE, Impact Attenuator

I. INTRODUCTION[4] [5] [6]

After researching over the internet it was found that honeycomb structure was mostly preferred for Impact attenuator, usually an Aluminium Honeycomb was used, with some teams using carbon Fibre Honeycomb. With the resources in hand Honeycomb was just out of league, as a result considering the need of an hour to think innovatively it was decided that empty beer cans, 600ml cold drink plastic bottles, and 330ml coca cola cans could make up a potential impact attenuator.

Also the FSAE design rules didn't mention of how the impact attenuator should be, it just mentioned it to be constrained within certain dimensions and providing experimental data to provide its effectiveness, so the focus was to design the attenuator in a way to comply with FSAE deceleration and size rules with minimum cost and maximum result.

II. DESIGN OF IMPACT ATTENUATOR [1] [2]

A shell of sheet metal was designed to accommodate the bottles/cans minding the minimum dimensions as required by the rules. The shell was made in the shape of a frustum of a pyramid with the upper cross-section of 240mm * 150mm and the lower cross section of 320mm * 230mm with the height of the shell as 215mm. With these dimensions the shell was designed using SolidWorks.

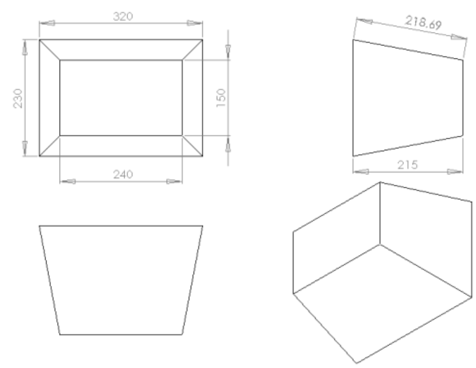

Figure 1: [1] [2]

To accommodate the bottles/cans in the shell was the next step; the bottles and cans were fixed to the shell using plaster of Paris. The maximum diameter and the length of the bottles/cans were:

- Beer can: Max Diameter = 60mm and length = 160mm
- 600mL Cold drink Bottle: Max Diameter = 69mm and length = 245mm

Orientations of bottles/cans were made in such a way that their axes were parallel to the axis of the frame. The length of the beer can is less than 215mm (length of the shell). Oasis foam (easily available from a florist) of thickness 55mm was added to fill the gap, while the length of 600mL Cold drink bottle is more than the length of the shell so the bottle was cut from its end to the length of the 215mm. Using SolidWorks simulation it was found that each shell could accommodate about 6 bottles or cans.

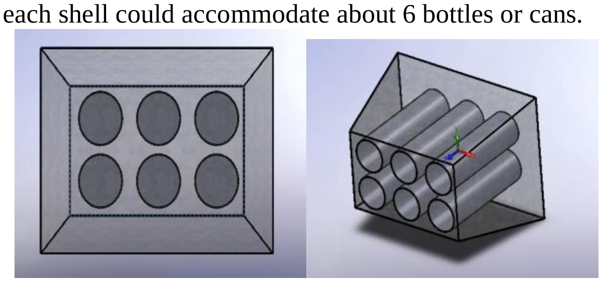

Figure 2: [1][2]

After the bottles/cans with the shell are assembled, the lower cross section of the shell (320mm * 230mm) was welded along its edges to the center of a base plate (390mm X 290mm). The base plate made of sheet metal was bolted to the anti-intrusion plate [8]

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Figure 3: Different setups for can/bottles in the first shell.

III. MODIFICATION: [1] [2] [3]

A two-stage impact attenuator was made:

- The first shell was a frustum of pyramid with upper cross-section of 240mm*150mm and lower cross-section of 270mm*180mm. The height of the first shell was 110mm. This shell accommodated six 330mL Coca Cola Cans (length = 110mm and diameter = 66mm).

- The second shell (again, a frustum of pyramid) was made with upper cross-section of 290mm*200mm and lower cross-section of 320mm*230mm. The height of this shell was 110mm and accommodated eleven 330mL Coca Cola cans (length = 110mm and diameter = 66mm).

  First shell was placed on top of second shell and then spot welded along the edges of the lower cross-section of the first shell.

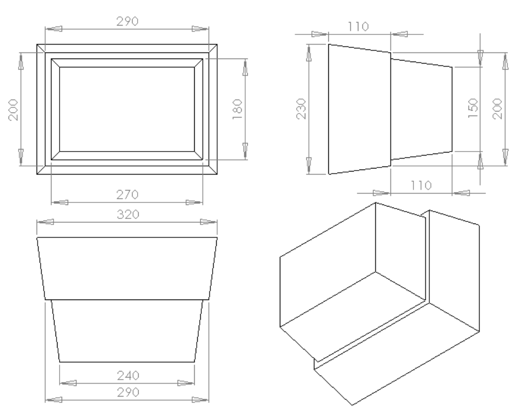

Figure 4:

Figure 5: Second Shell with Cans

IV. TEST SCHEMATIC [1][2]

According to the FSAE design rule: [3]

“The team must submit test data to show that their Impact Attenuator, when mounted on the front of a vehicle with a total mass of 300 kg (661 lbs) and run into a solid, non-yielding impact barrier with a velocity of impact of 7.0 m/s (23.0 ft/sec), would give an average deceleration of the vehicle not to exceed 20 g, with a peak deceleration less than or equal to 40 g.

The kinetic energy for which the impact attenuator is designed is given by:

K.E. = (1/2)*m*v2

K.E = (1/2)*300*72

K.E = 7,350 J

To simulate the given scenario, a drop weigh test was conducted. The mass (m) was dropped on the impact attenuator, which was kept on the ground from a known height (h). The velocity (v) of the mass (m) dropped from a height (h) can be given by the relation:

v = √ (2*g*h)

Where, g (acceleration due to gravity) =9.8 m/s2; and for velocity of 7 m/s, the required height is 2.497 m.

But, we were available with a drop height of 5m. So, the velocity, for a drop height of 5m can be approximated as:

v = 9.9m/s [By Conservation of Energy]

The impact attenuator is designed for an energy of 7350J, therefore, the mass required for the same energy, when impact velocity is 9.9m/s can be approximated as:

7350 = (1/2)*m*(9.9)2

m = 149.98kg

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Thus, the specifications of the drop weight test were:

Height (h) = 5m, Mass (m) = 150kg, Velocity of impact (v) = 9.9m/s&Energy (E) = 7350J.

The drop test was recorded with help of a high speed camera, capable of capturing 10,000 fps. A scale was kept along the impact attenuator and such that the readings on the scale were clearly visible as a part of the video and it wasn't crushed under test weight. The drop test was accurately done, taking care that was no one near the test site. Then to determine the peak deceleration, video of the test was analyzed and the whole process of deformation was divided into number of small steps. The amount of deformation in each step was obtained through the scale. This time period of each step and the initial velocity of impact for the first step were known, and were used to calculate for each subsequent step:

For the first step of deformation:

Velocity of impact (u) = 9.9m/s

Deformation = s (known)

Time period of deformation = t (known)

Deceleration during the step = a (unknown)

Final velocity (at the end of the step) = v (unknown)

According to motion Equations:

s = u*t + (1/2)*a*t**2

Thus, 'a' was calculated.

v = u + a*t

Thus, 'v' was also calculated.

For the deformationof second step, the final velocity of first step becomes the initial velocity of the second step with rest of the procedure remaining same. The amount of deformation is noted from the scale and the time is noted from the video. So, the deceleration and final velocity of the second step are calculated using the equations of motion.

Thus, the final velocity of second step becomes the initial velocity of third step and so on. The whole deformation is analyzed by dividing it into a number of small steps. The maximum value of deceleration amongst all the steps gives the peak deceleration.

The average deceleration is calculated by considering the initial condition, just before the impact, and the final condition, just when the deformation is complete.

The initial velocity (u) = 9.9m/s

Total deformation = s (known)

Time period of deformation = t (known)

Let the average deceleration = a (unknown)

From the equations of motion:

s = u*t + (1/2)*a*t**2

Thus average value of deceleration is calculated.

Figure 6: Set up

V. TEST DATA

During the test, an empty shell was also tested to see how it behaves and the difference that the bottles/cans create. The calculations for average decelerations are shown below.

- Empty Shell

Deformation Start Time = 1.6s
Deformation End Time = 3.2s
Total Deformation Time, t = 1.6s
Average Deceleration, a = (v-u)/t
a = (9.9 – 0)/1.6
a = 6.18m/s2 = 0.63g

- Beer Can

Deformation Start Time = 1.6s
Deformation End Time = 4s
Total Deformation Time, t = 2.4s
Average Deceleration, a = (v-u)/t
a = (9.9 – 0)/2.4
a = 4.12m/s2 = 0.42g

- 600mL cold drink Bottle
  Deformation Start Time = 2.0s
  Deformation End Time = 4.0s
  Total Deformation Time, t = 2.0s
  Average Deceleration, a = (v-u)/t
  a = (9.9 – 0)/2.0
  a = 4.95m/s2 = 0.50g

- 2 Step Shell with 330mL Coca Cola Can
  Deformation Start Time = 1.88s
  Deformation End Time = 4.5s
  Total Deformation Time, t = 2.62s

Average Deceleration, a = (v-u)/t

a = (9.9 – 0)/2.62

a = 3.78m/s2 = 0.38g

VI. RESULTS

From the above data, it can be seen that the deceleration is minimum in the case of the two step shell with 330mL Coca Cola cans. Thus, this was chosen as the final Impact Attenuator.

During the testing, it was realized that the sheet metal shell was creating problems in deformation. Thus, holes were made in the side faces of the shell of the final design.

Figure 7: Impact Attenuator before test

Figure 8: After Test

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AUTHORS

First Author – Arpit Singhal, M.Tech (CFD), University of Petroleum and Energy Studies, singhal.arpit89@gmail.com
Second Author – Vignesh S. Subramanium, M.Tech (CFD), University of Petroleum and Energy Studies, vignesh.er@gmail.com
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Correspondence Author –Arpit Singhal, singhal.arpit89@gmail.com, +91-9045732589