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Research Article

Design and Development of Impact Attenuator for Racecar Safety

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Abstract

An impact attenuator is a structure used to "Decelerate impacting vehicles gradually to a stop" By gradually decelerating the racecar; the frame and driver are protected from significant deformation and injury. The bulk of impact energy is transferred into the deformation of the impact attenuator structure. Attenuators can be placed on vehicles or on road barriers to absorb large impacts to protect frames and people. FSAE specifies that each car in operation must have an attenuator that meets specifications and testing criteria Impact Attenuator when mounted on the Front Bulkhead, would give an average vehicle deceleration of less than 20g while hitting a non-yielding surface. The data requires the vehicle is traveling at 7 m/s during the impact with a total mass of 300 kg. The peak deceleration during the impact must be under 40g. Material testing of honeycomb, polyethylene foam and polyurethane foam is carried out. In that polyurethane foam is giving better energy absorption. By using polyurethane foam design and fabrication of impact attenuator is carried out. Drop testing result give deceleration of 13.37 g and simulation result on LS-DYNA give deceleration of 15 g. So it is safe to use polyurethane foam as an impact attenuator

Keywords: *Impact Attenuator, Polyurethane Foam, Stopping distance, Deceleration, Material Testing, Ls-Dyna, Simulation*

1.1 Introduction

The race car requires an impact attenuator that can protect the driver and the frame when mounted on the front bulkhead of the vehicle. This project includes the design, modeling fabrication and testing of impact attenuator.

The rules of competition explain that each car must be equipped with a crash protection device and it must absorb enough energy so that driver can walk away without sustaining serious injury and damage to the frame is minimized

The method of testing chosen was the drop test. A weight of 732 pounds was raised 7.5 feet into the air and released onto each prototype design. This height and weight were chosen to meet the requirement of the car reaching a velocity of 7 m/s at the point of impact. During the test a high speed camera recorded the test in slow motion so that the deformation patterns of each design could be analyzed.

1.2 Impact Attenuator

The Impact Attenuator must be

a) Installed forward of the Front Bulkhead.

b) The surface of the attenuator must be over 200mm long (fore/aft of the frame), 100mm high, and 200mm wide. This will allow the Impact Attenuator to be a minimum distance of 200mm from the Front Bulkhead.

c) An impact shall not cause the Impact Attenuator to penetrate the Front Bulkhead. It should be mounted directly to the Front Bulkhead and not be part of non-structural bodywork‖

d) The Impact Attenuator also must have 1.5 mm solid steel or 4.0mm aluminum Anti-Intrusion Plate built into the system.

1.3 Requirements

Impact Attenuator when mounted on the Front Bulkhead, would give an average vehicle deceleration of less than 20g while hitting a non-yielding surface. The data requires the vehicle is traveling at 7 m/s during the impact with a total mass of 300 kg. The peak deceleration during the impact must be under 40g**.**

1.4 Definition: Impact Attenuator

An impact attenuator is a structure used to ―decelerate impacting vehicles gradually to a stop‖ By gradually decelerating the racecar, the frame and driver are protected from significant deformation and injury. The bulk of impact energy is transferred into the deformation of the impact attenuator structure

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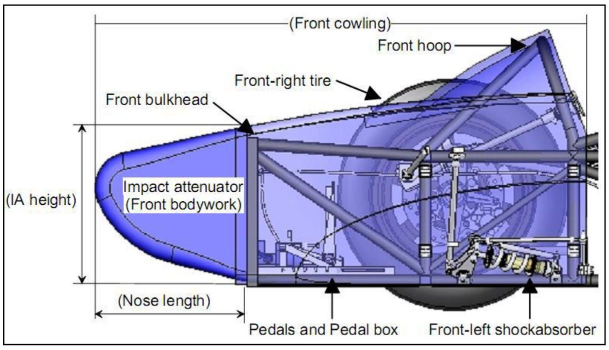


Fig. 1 Impact attenuator attachment to front bulkhead

Attenuators can be placed on vehicles or on road barriers to absorb large impacts to protect frames and people. FSAE specifies that each car in operation must have an attenuator that meets specifications and testing criteria.

The Impact Attenuator is an energy absorber device. Its purpose is to absorb as much energy as possible in case of collision. It provides a load path for transverse and vertical loads in the event of off-centered and off-axis impacts.

The design of this device requires consideration of the followings engineering metrics:

1. Low weight
2. Small size
3. Fire resistant
4. Cost
5. Energy absorption capability

1.5 Geometric Analysis

To perform any type of worthwhile analysis, the design team decided the geometrical limits of the impact attenuator should be determined. The FSAE rules require the impact attenuator have minimum dimensions of 150 mm by 200 mm by 100 mm or 5.9 in by 7.87 in by 3.94 in (depth by width by height, respectively). With impacts, however, if the collision distance is increased, the acceleration values will decrease.

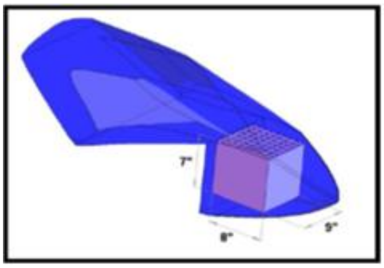


Fig. 2 Impact Attenuator Location

Therefore, the design team attempted to maximize the distance of the collision, or equivalently, maximize the depth of the impact attenuator. The only constraint for the maximum volume of the impact attenuator is the nose cone of the racecar. The impact attenuator must be completely enclosed by the nose cone. The maximum volume, for a rectangular prism, allowed within the nose cone of the car is 8 in by 9 in by 7 in (depth by width by height, respectively).

1.6 Requirement of Impact Attenuator as Per SAE Rules

Preliminary Calculations:

Initial Conditions:

V_{impact} = 7 m/s
Final = 0 m/s
G = 9.8 m/s^2
M = 300 kg
Ac =20xG =196 m/s^2
Kinetic Energy:
KE = 1/2 x M x (V_{impact}) ^{2} = 7.35 x 103 (kg* m^2/s^2)
= 7350 J
By Conservation of Energy, Kinetic Energy is equal to potential energy
KE = PE
Calculating the Desired Drop Height:
Pea = M x G x H
H =Pea / M x G
7350/M x G
HD =2.5m=8.2 ft
Time of Impact: t = V_{impact} /Ac
t = .036s
Impulse and Force: Im = M (Vimpact-Vfinal)
Im = 6.3x105 (kg)/s^2
F = Im/t
F = 58,800 N

1.7 PUF-Design Calculation

Depending upon the crush strength, density, velocity and maximum avg. decelerations we have decided dimensions of impact attenuator.

Fig. 3 Mass and Impact Attenuator

Given:
m=300 kg, f=1100x10^3 Pa, G=18, v=7 m/s, w=200 mm

First, the stopping distance is calculated and then the honeycomb length:

G = (V^2/2gs), (s =V^2/2gG), s = 50% T
s= (72/2 x 9.8 x 15) = 0.166 m
T= 0.166/0.5 = 0.332 m

Next, the kinetic energy is obtained, which will allow calculating the area and finally the honeycomb high:

KE = $mv^2/2$ = 300 * 72 / 2 = 7350 Nm
KE=f x A x S, A = w * H,
A=KE / f *s = (7350/1100 X10^3 X 0.166) = 0.04025 mm^2
H = A/w = (0.04025 / 0.220) = 220 mm
Mass calculation: mass=rho*A*T
126 X 0.200 X 0.200 X 0.330 =1.66 kg

2.1 Material Testing Set up at AML Lab of ARAI

Fig. 4 Universal Testing Machine

2.2 Material Testing Simulation

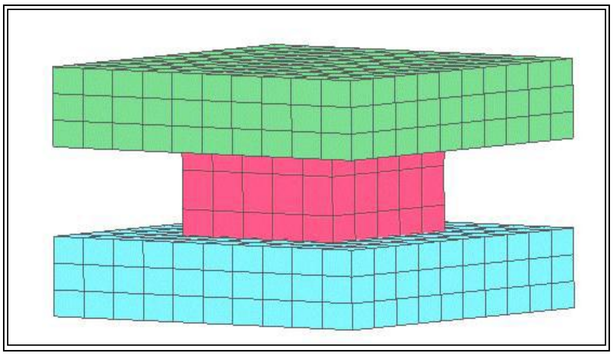
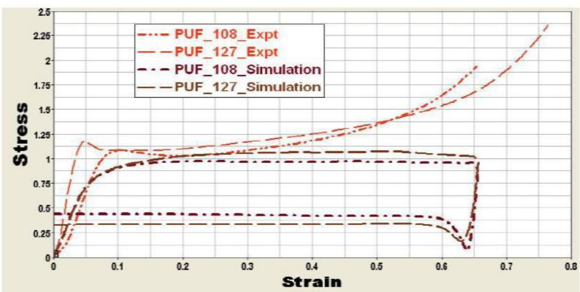


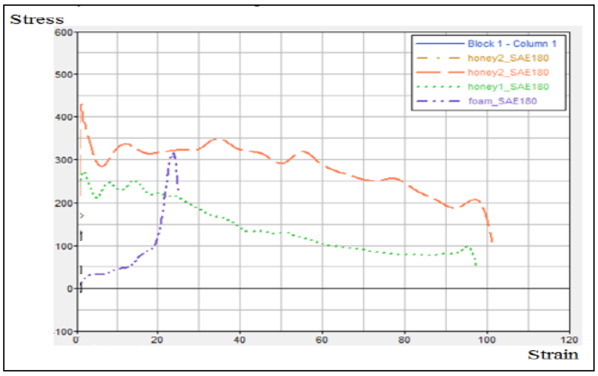
Fig. 5 Material Testing

2.3 PUF-Material Testing Result



Graph 1 PUF Material Testing

2.4 Honeycomb Material Testing Result



Graph 2 Honeycomb material testing

Material Testing Result

Requirement of impact attenuator:

M=300 kg, g= 9.81 m/s^2, h= 2.5 m
Pea = m x g x h
Pea = 300 x 9.81 x 2.5
= 7357.5 J

Energy abrortion by PUF Foam:

From load vs. deflection graph, specific energy absorbed by material
=744 x 10^3 J/ mm^3 (Density= 108 kg/m^3)
= 795 x 10^3 J/ mm^3 (Density= 127 kg/ m^3)
Dimension of impact attenuator =0.33 m x 0.20 m x 0.20m
Total energy absorbed = specific energy absorbed x volume
= 0.33 x 0.20 x 0.20 x 795 x 10^3
= 10494 J

2.5 Dynamic Testing

Once a specimen is obtained and cut to size, whether aluminum foam or expanded polypropylene, we recommend performing dynamic testing so the energy absorption capabilities of the materials can be experimentally validated. This is especially important if the expanded polypropylene is selected, because we were unable to find literature regarding its strain rate dependency during compression. If a proper facility can be located, the design team recommends performing a full scale dynamic test, i.e. releasing a 300 kg mass from a drop height, h_{drop}, of 2.5 m. The drop height was calculated using the kinematics equation shown in equation:

$$V^2_{final} - V^2_{initial} = 2.a.h_{drop}$$

$$h_{drop} = \frac{v_{final}^2 - v_{initial}^2}{2 \cdot a}$$

Where f_{inal} = impact velocity, i_{nitial} = initial velocity, a = gravitational acceleration
Given f_{inal} = 7 m/s, i_{nitial} = 0 m/s, a = 9.81 m/s^2
h_{drop} = 2.5 m

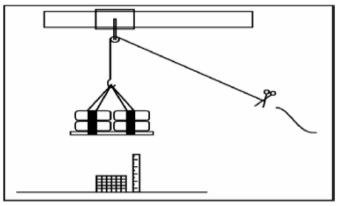
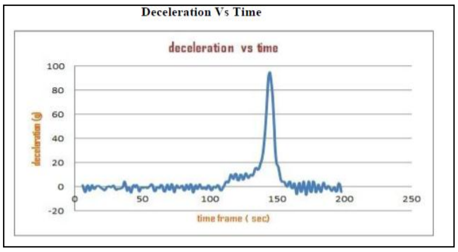


Fig. 6 Dynamic Test Set-up

2.6 Preliminary Test Set up and Result

Fig. 7 Test Set up



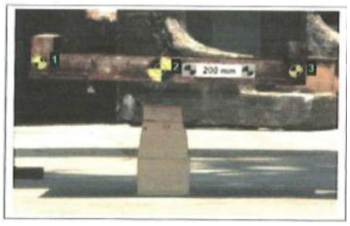
Graph 3 Deceleration Vs Time

Conclusion

Average deceleration during impact testing is 43g and maximum deceleration is 93 g. So it is not meeting the average deceleration of 20g and maximum deceleration of 40g.

2.7 Final Dynamic Testing Result

a) Test Set up, b) Impact Attentuor before and after drop test

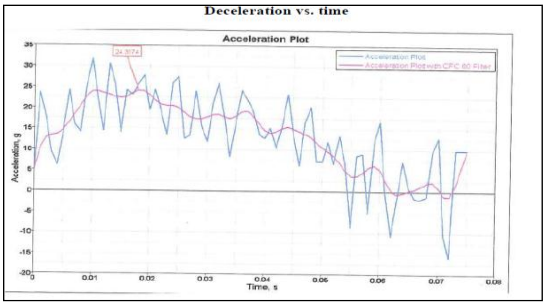


c) Marker location for drop test

Figure 8 Final drop testing set up

2.8 Results and Discussions

1) The impact attenuator before and after drop test and marker location for the drop test is shown in figure.
3) The average deceleration from raw data for marker 2 is **13.37 g** which is within the limit of 20 g and meets the requirement.
4) The peak deceleration after using CFC 60 filter for marker 2 is **23.31 g** which is within limit of 40 g and meets the requirement.



Graph 4 Deceleration vs Time

Conclusions

Impact attenuator design meets both the requirement of average deceleration not to exceed 20 g's and peak deceleration less than or equal to 40 g's.

3. 1 Simulation of Impact Testing

Introduction to LS-DYNA

1) LS-DYNA is an advanced general-purpose multiphasic simulation software package developed by the Livermore Software Technology Corporation (LSTC).
2) While the package continues to contain more and more possibilities for the calculation of many complex, real world problems, its origins and core-competency lie in highly nonlinear transient dynamic finite element analysis (FEA) using explicit time integration.
3) LS-DYNA is being used by the automobile, aerospace, construction, military, manufacturing, and bioengineering industries.
4) LS-DYNA can predict how a prototype will respond to real-world events, thus minimizing the time spent in design and money spent on experimental testing.

5) Metal forming applications for LS-DYNA include:
1) Metal stamping 2) Hydroforming 3) Forging4) Deep drawing 5) Multi-stage processes

3.2 Finite Element Analysis Using Ls-Dyna

A) Introduction

1. Pre Processing: Preprocessing Involves Following important things
Preparing the CAD data
2. Solving:
3. Post Processing

Post processing involves processing and analyzing the results which have been created by the solver like the deformation plots, stress contours, acceleration history, studying the reaction forces at contact, global energy balance monitoring etc. It also included filtering the noise in both input and output response curves to view the realistic results to assure accuracy and presenting the results obtained... Post processing was done using three Post processors:

- Hyperveiw 10.0
- HyperGraph.
- LS-PrePost

3.3 Catia Model of Impact Attenuator

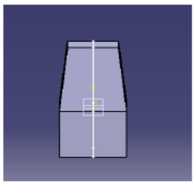
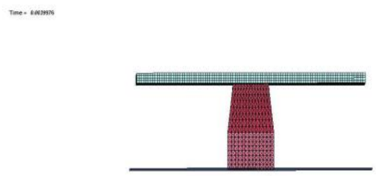


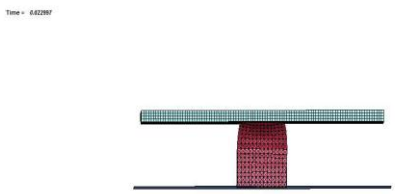
Figure 9 Catia model – Impact Attenuator

3.4 Deformation of Impact Attenuator in LS-DYNA

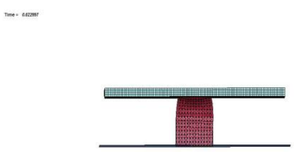
Stage-I



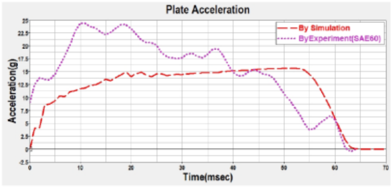
Stage 2



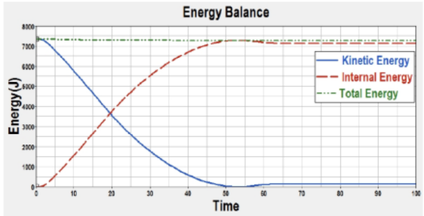
Stage 3



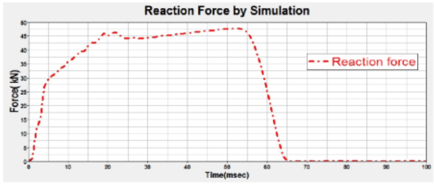
3.5 Graphical Result



Graph 5 Deceleration vs Time



Graph 6 Energy Absorbed



Graph 7 Reaction Force Applied

Conclusion

1) Impact attenuator design meets both the requirement of average deceleration not to exceed 20 g's and peak deceleration less than or equal to 40 g's .
2) Average deceleration of plate as per the simulation and experimental result is within 20g which is meeting the requirement of FSAE rules
3) Average deceleration as per the physical testing is 15g and by simulation it is 13.37.So there is difference of about 1.5 g or (10%) between physical testing and simulation
4) Energy absorbed by the impact attenuator as per the simulation result is near about 7.5 kJ which is meeting the requirement
5) Reaction force acting on impact attenuator as per the simulation is 45 KN which is near 58.8 KN as per the requirement
6) Polyurethane foam that we have selected as an impact attenuator is meeting the requirement Of FSAE. It is completely safe to use polyurethane foam as impact attenuator

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