Study on Design and Optimization of vehicle crush box for reduced damageability and repair costs

Dr. Chandrashekhar Bendigeri[1], Supreeth Kalburgi[2]

[1]Professor Department of Mechanical Engineering, UVCE, Bangalore, India
[2]ME Department of Mechanical Engineering, UVCE, Bangalore, India

Abstract— *The Indian automotive buyer is very cost-conscious and the hence auto manufacturers are striving to bring in low cost of ownership with high fuel economy. Other than Initial cost and fuel consumption of the vehicle, damaged parts replacement and reparability of the vehicle is one of the major concerns of the customers. In cities, as the traffic density increases, low speed accidents are commonplace. Low speed impacts may cause significant vehicle damage and injuries to the occupants. In a low speed impact, the vehicle must withstand the crash with minimal damage so that repair costs remain low. Most of the vehicles on Indian road, mainly in entry and mid segment level cars don't have the rear bumper beam as well the crush boxes. Automakers eliminate the crush box and rear impact beam mainly to reduce the product cost, as rear impact safety norm is not a part of Indian automotive safety regulation. The purpose of the project is to make customer, manufacturer and regulation body aware the importance of having the crush box and rear impact beam in the vehicle, in India mainly in metropolitan cities lots of vehicle collisions occur at a low speed because of increase in traffic densityAs crashing of actual vehicle to design a crush box is not cost effective, CAE tools like Hypermesh, Primer, Ansa are used for FE modelling and model assembly. Ls Dyna Explicit solver is used to simulate the real time crash event.*

Keywords— Low speed impact, Crush box, FE Modelling, Implicit Solver

I. INTRODUCTION

Low speed rear impact is one of the commonly occurring events on Indian road. As the density of the passenger and commercial vehicles increasing on the road, vehicle commuting speed drastically reduced and occurrence of accidents increased.

In below paragraphs will elaborate the frequency of low speed rear impacts, its impact on the vehicle and occupants. How the use of simple crush box will reduce the damageability and reparability of the vehicle will be discussed in all upcoming chapters. Time allocated for design and optimization of the crush box is explained in detail in below sections.

1.1 Introduction to the area of work

In the recent years, the increasing number of vehicles on roads has led to an increase in road accidents – both at high and low speeds. In cities, as the traffic density increases, low speed accidents are commonplace. Low speed impacts may cause significant vehicle damage and injuries to the occupants. In a low speed impact, the vehicle must withstand the crash with minimal damage so that repair costs remain low. Low speed car crashes can be simulated to assess the damageability and reparability of the vehicles. Typically the bumper system which includes the crush box must absorb most crash energy so that the other safety critical components do not undergo extensive damage. As the name suggests, the crush box crushes during impact, thereby, absorbing energy in the form of internal energy. It connects bumper beam to the main motor compartment rails. This project involves the design of a crush box to maximize energy absorption and at the same time limiting damage to the components which are expensive to replace post-collision. A crush box also assists in progressive crush of the crumple zone during a high speed collision. This project aims to design a crush box and optimize the design to minimize its weight for improved crash performance and fuel economy.

1.2 Brief present day scenario with regard to the work area

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As per the different service stations of major car makers in India, 3 out of 10 low speed vehicle damages is due to damage at the rear of the vehicle. Whenever vehicle meets low speed impact the reparability and damaged part replacement cost will be on an average 20K to 30K for car price below 5 lakh, and 50 to 60K for the cars priced between 5 to 8 lakh.

1.3 Objective of the work

The objective of this project is to develop a vehicle crush box to reduce vehicle damageability, meet safety performance requirements and then optimize the design for mass savings for better fuel economy. This design will be tried on the readily available validated FE model on web. Multiple cost effective crush box design will be generated for the model, and a iterative study to find the optimal crush or reactive force that a crush box can and should take to achieve lowest possible reparability cost in case of low speed impacts.

As the low speed impacts increasing in developing countries like India, plan is to make consumer, manufacturer and Govt regulatory body, to make aware the importance having safety features in entry level and mid segment vehicle. Making such regulation mandatory not only make vehicle safer, it also save huge money consumer spends in vehicle reparability and how this helps in gaining no claim bonus while renewing the vehicle insurance.

II. FE MODEL BUILDING

Below document provides FE (Finite Element) modelling requirements for modelling of components to be used in RCAR (Research Council for Automobile Repairs) simulations. Below Flowchart explains part modelling, Assembly and analysis specific requirements.

Basically in any vehicle development process, if the its new car development then 3D math data will generated 1st using any of the modelling packages as per engineering and styling requirements. If the developments are happening on existing vehicle then available FE model of the vehicle is used. As we are developing crush box to the existing vehicle to improve its repair-ability cost and reduce vehicle damage during low speed impact. Either its new vehicle or continuous improvement to existing model, model building will follow below flowchart as per requirement of respective load cases.

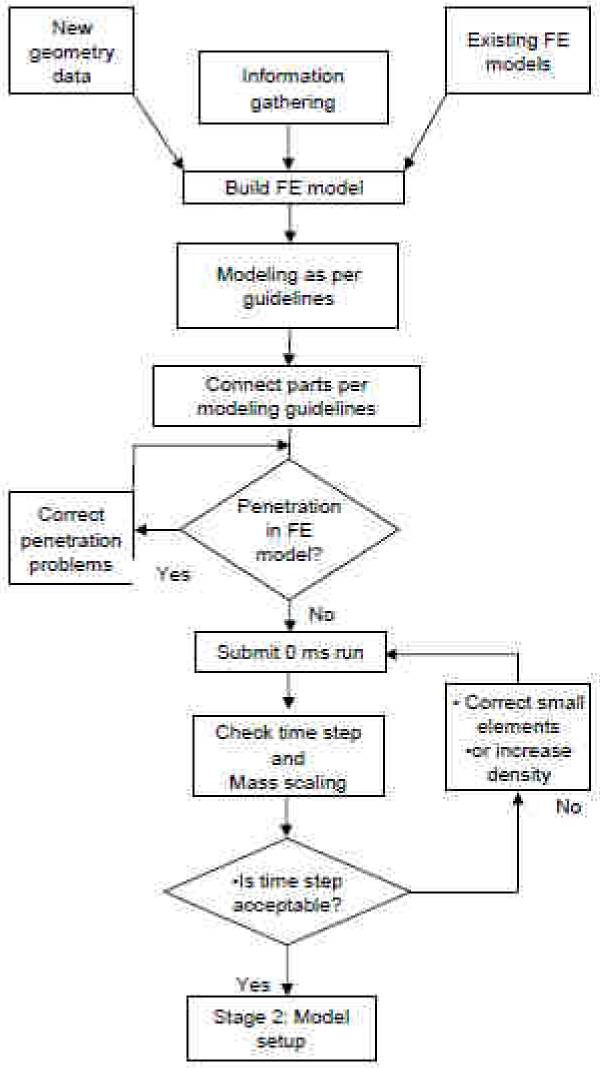

Fig.2.1: FE Modelling Flow Chart For Crash Analysis

2.1 FE Barrier model setup

Standard barrier model which is exact FE replica of real test barrier is obtained from RCAR website. The barrier is positioned as per RCAR barrier setup guidelines, with 40% overlap at 10° inclination as shown in the figure 2.4. Appropriate velocity is assigned to the barrier to simulate the low speed rear impact scenario. Barrier and impact vehicle should be in same plane.

2.2 The Rear RCAR Barrier shall be re positioned to the vehicle as follows

 The bottom of the barrier is 200 mm above the ground plane (see Figure 2.3).

 40% of the width of the vehicle (excluding side mirrors) overlaps the barrier (see Figure 2.4) Note: The RCAR protocol usually requires that the barrier must strike the passenger side of the vehicle. However, an impact on the driver side may be requested if the exhaust or tow hook (or other component) may negatively alter the performance on that side.

 The barrier is within 2mm of contact with the vehicle.

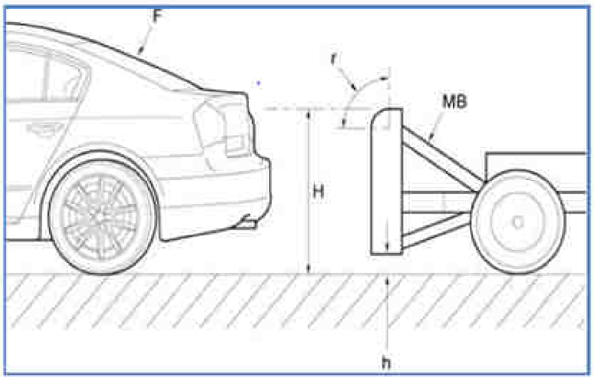

Fig. 2.3: Barrier setup Front view

The barrier will usually be oriented to impact the side opposite that of the steering column (as illustrated in Figure 2.4 for left hand drive vehicle), however, the RCAR test procedure requires the impact on the steering column side if "*there is evidence to show that the opposite side is more appropriate*". This should be interpreted to mean that the "worst case" side should be impacted (i.e. exhaust is only on steering column side).

III. ANALYSIS REQUIREMENTS

3.1 Analysis Duration

The simulation must be run until the barrier begins to separate from the vehicle which can be determined when the force between the barrier face and vehicle returns to 0.0. A typical Rear RCAR impact simulation will be run to 100 ms. Analysis duration may be shorter or longer depending on vehicle length and stiffness.

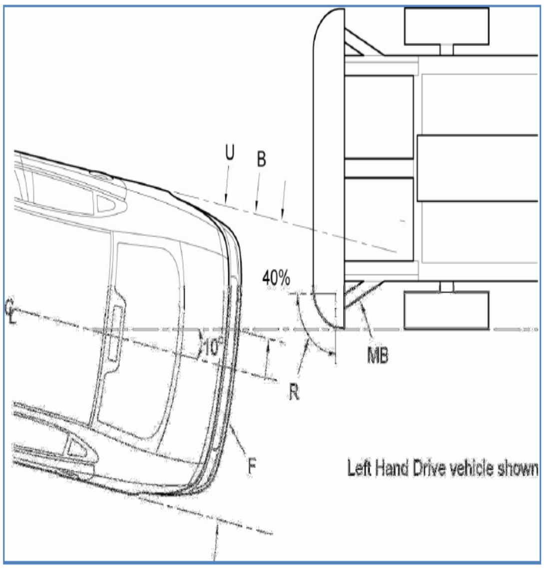

Fig. 2.4: Barrier setup Top view

3.2 Simulation Quality Checks

The analyst should perform analysis quality checks on the results generated. Plots of kinetic energy, internal energy, and hourglass energy should be inspected to ensure that there are no spikes or abnormalities. The following should be evaluated in each 10 degree rear impact simulation:

Initial penetrations in the sliding interfaces should be avoided.

The smallest time step should be approximately 0.7 microsecond (0.007 ms). Normally, the time step is computed internally by LS-DYNA based on the element characteristic length, Young's modulus and density. Care should be taken to ensure that the time step does not fall much below the initial time step during the simulation.

Location and amount of mass added for mass scaling must be checked and may not be more than 1% of the total mass.

Total energy should remain nearly constant. Total energy divided by initial energy should be between 0.98 and 1.02.

Hourglass energy should be less than 5% of the total energy.

There should not be any discontinuous jumps or spikes in any of the energy calculations. Sliding interface problems can cause these occasionally.

3.3 Simulation Reality Checks

The analyst should also check animation for irregularities in the model. The following should be monitored in each low speed rear impact simulation

- Crush pattern of bumper system, rails, and underbody structure
- Stack up of components to barrier face and to other components
- Penetration of one part into another
- Penetration of any node through the rigid walls
- Forces in discrete elements.

3.4 Damage Evaluation

Damage is evaluated by 2 methods using simulation results:

3.4.1 Plastic Strain

Plastic strain greater than 3% is generally considered damaged requiring repair.

3.4.2 Permanent set

For the rail to be considered damage free, no more than 2mm permanent set change in the length of the rear compartment rail is allowed after test. Permanent set is calculated by the change in X (longitudinal) length of the rail.

3.5 Deformed Bumper Shape in IGES format

To assess the component damages, the deformed bumper shape will be overlaid to vehicle rear end in Unigraphics (UG). From the degree of bumper intruding to the vehicle, the damage to the other rear end components, such as head light, tailgate etc., can be evaluated. This step used to get the repair-ability cost of each damaged part from

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costing engineers.

IV. CONCLUSION

For RCAR test, front and rear fascias can be modeled and simulated using above techniques to get reliable results. The above mentioned methods of quality checks(modelling and simulation) can be used for other tests(pedpro, high speed impact etc).

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