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Mathematical Modelling of Car Crash Test

Abhinav S. Athalye, H. G. Phakatkar, U. S. Chavan
Dept. of Mechanical Engineering, Vishwakarma Institute of Technology, Pune 37, India
abhinav.athalye@gmail.com

Abstract

The vehicle crash tests are complex and complicated experiments, so it is advisable to establish their mathematical models. This paper contains an overview of the kinematic and dynamic relationships of a car in a crash. It is also containing basic mathematical models representing a collision together with its analysis. The main part of this paper is devoted to methods of establishing parameters of the vehicle crash model and to real crash data investigation i.e. – creation of a Spring Mass Model, Kelvin Model, and Maxwell's Model for a real experiment (Dodge Neon), its analysis and validation.

Keywords- Mathematical Modelling, Car Crash test, Maxwell's Model, Kelvin's Model.

I. Introduction

A crash test is a form of destructive testing usually performed to ensure safe design standards in crashworthiness and crash compatibility for various modes of transportation or related systems and components. Crash tests are frequently used to help evaluate car safety. Different car safety programs and organizations (e.g. Euro NCAP, NHTSA, NCAC) specify how such tests should be performed, what factors should be investigated and how car safety should be assessed. Crash tests are not only performed when the car design is completed and a prototype is ready but also throughout the whole development and validation process. Car crash test standards and procedures designate detailed test procedures and requirements. Considerable resources are required to successfully conduct car crash tests. These involve skilled and trained personnel along with a large variety and quantity of sophisticated monitoring and measurement equipment and post-crash data analysis software. The objective of this work is to predict behavior of the system through Mathematical Modelling and to validate the results with Experimental Results.The main objective of this project is to establish a mathematical model of a vehicle collision. The purpose of this task is to simulate how the crash looks like – i.e. what are the main parameters describing the collision – without performing any real test. Real world experiments are difficult to realize – there are needed appropriate facilities, measuring devices, data acquisition process, qualified staff and of course – a car. Therefore, it is justified to propose a mathematical model of a collision and analyze it instead of a real experiment to approximate its results. In our main interest, it is to analyze in detail a Kelvin model. Having knowledge concerning one such a system we are able to extend the model e.g. to a couple of Kelvin elements in order to obtain a more accurate response (we can represent car elements and connections between them exactly by multiple spring – mass – damper models). Many researches have been done so far in the area of vehicle crash modelling. [1]This paper deals with establishing an appropriate mathematical model representing vehicle soft impacts such as localized pole collisions. In simulation of the vehicle collision, elements which exhibit viscous and elastic properties are used. Models utilized by us consist of energy absorbing elements (EA) and masses connected to their both ends. We focus on finding a model with such an arrangement of springs, dampers and masses, which simulated, will give a response similar to the car's behavior during the real crash. Due to the fact that real crash tests are complex and complicated events, their modeling is justified and advisable. Every car which is going to appear on the roads has to conform to the worldwide safety standards. However, crash tests consume a lot of effort, time and money. The appropriate equipment and qualified staff is needed as well. Therefore, our goal is to make possible simulation of a vehicle crash on a personal computer. [2] The project “Improvement of Vehicle Crash Compatibility through the development of Crash Test Procedures” (VC-Compact) is a research activity sponsored under the European Commission 5th Framework Programmed. It consists of two parallel research activities, one focusing on car-to-car compatibility and the other on car-to-truck compatibility. The main objective of the car-to-car research is the development of crash test procedures to assess frontal impact crash compatibility. The carto-truck objective is to develop test methods to assess energy absorbing frontal underrun protection for trucks. [5] The ideal frontal crash test procedure will be able to evaluate occupant protection while ensuring that the vehicle will not jeopardize its crash “friendliness” with its collision partners. The test conditions (e.g., impact speed, impact angle, and test device) must be representative of the frontal crash environment to which passenger vehicles are exposed on the highway.

Finally, to provide assurance of protection in potentially serious injury crashes, the test procedures must be severe enough to represent a crash in which occupants could be seriously injured or killed. This report examines several potential frontal crash test procedures, and evaluates how well each candidate frontal test procedure meets these objectives. Specifically, this report evaluates (1) the full frontal fixed barrier test, (2) the oblique frontal fixed barrier test, (3) the generic sled test, (4) the frontal fixed offset deformable barrier test, (5) the perpendicular moving deformable barrier (MDB) test, (6) the oblique moving deformable barrier test and (7) the full frontal fixed deformable barrier (FFFDB) test. Each procedure is compared with the 48 Kmph fixed rigid barrier test and the generic sled test currently prescribed in FMVSS No. 208. [7]

II. Experiment

The Full Frontal Fixed Barrier Crash test (or Rigid Barrier test) represents a vehicle-to-vehicle full frontal engagement crash with each vehicle moving at the same impact velocity. A schematic of the test configuration is shown in Figure 2-4. The test is intended to represent most real-world crashes (both vehicle-to-vehicle and vehicle-to-fixed object) with significant frontal engagement in a perpendicular impact direction. For FMVSS No. 208, the impact velocity is 0 to 48 Kmph (0 to 30 mph), and the barrier rebound velocity, while varying somewhat from car to car, typically ranges up to 10 percent of the impact velocity for a change in velocity of up to 53 Kmph. Note that although the rebound velocity varies somewhat from vehicle to vehicle, it is small compared to the impact speed, and the rigid barrier test therefore exposes the belted or unbelted occupant to approximately the same change in velocity (48 Kmph plus the rebound velocity) for any vehicle.

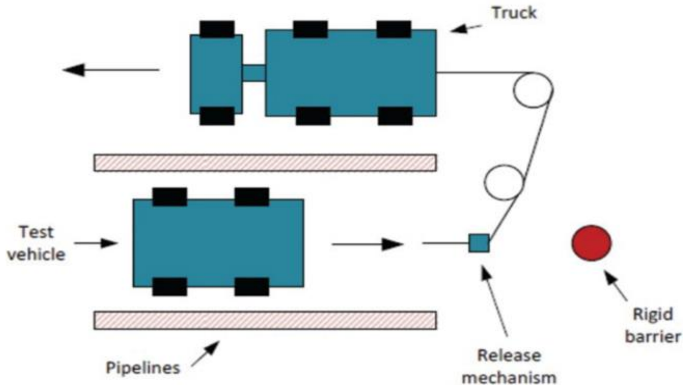
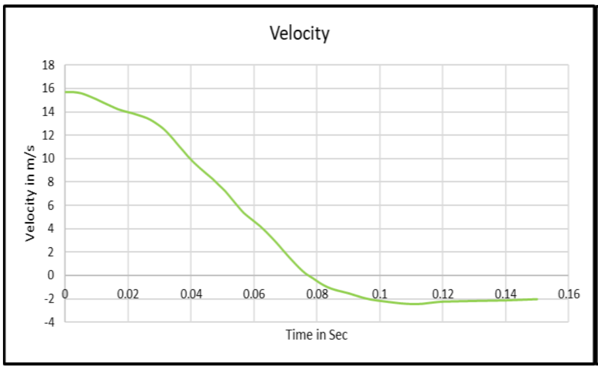


Fig. 1 Experimental Arrangement



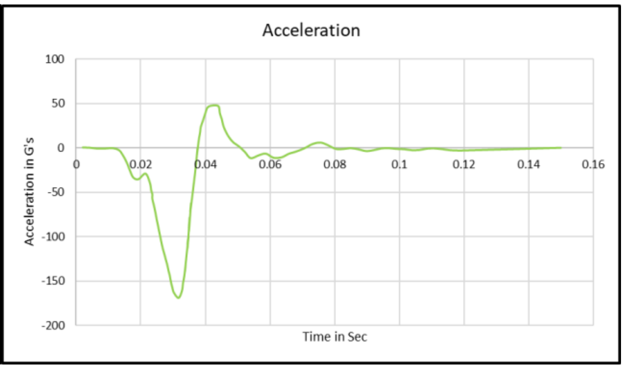


Fig. 2 Acceleration Graph of Testing Fig. 3 Velocity Graph of Testing

It is a full systems test which evaluates the protection provided by both the energy-absorbing vehicle structure and the occupant restraint system. Together with performance requirements, it ensures that the vehicle provides the same minimum level of protection in single vehicle crashes also regardless of the vehicles mass or size.

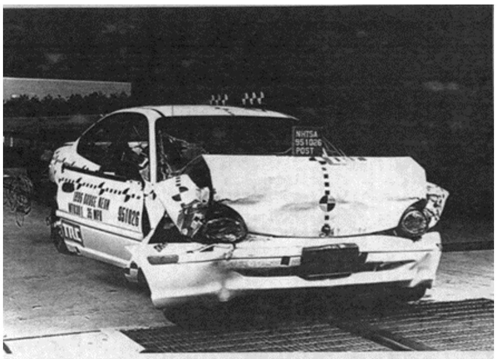


Fig. 4 Frontal Crash of Dodge Neon

Calculating parameters for Mathematical Modelling-

- Test No.: 2320
- Study Title: 1996 Dodge Neon into Flat Frontal Barrier
- Test Type: New Car Assessment Test
- Test Configuration: Vehicle into Barrier
- Closing Speed (Kmph): 56.5

Parameters			**Dodge Neon**
Name	**Symbol**	**Unit**	
Mass	m	Kg	1354
Initial Velocity	V0	Kmph	56.6
		m/s	15.72
Max. Crush	Cm	m	0.512
Separation time	Ts	s	0.05
	we	rad/s	30.70746528
Max Time	Tm	s	0.051153565
	A		482.789593
Frequency	f	Hz	4.887244889
	Zeta		0.0365
	f*Tm		0.244362244
			0.244352377
E. Stiffness	K	N/m	**1276752.166**
E. Damping Coe	C	Ns/m	**3035.187283**

Table 1 Stiffness and Damping Coe. Calculations

III. Analytical Design

1. Spring Mass Model.

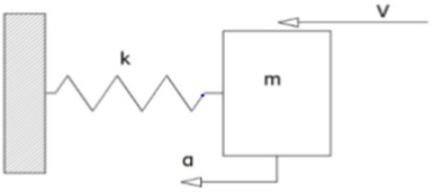


Fig. 5 FBD of Spring Mass Model

C: Dynamic crush
V: Initial barrier impact velocity
A: Peak sinusoidal deceleration magnitude of the effective mass
w: Effective weight (or W)
k: Effective spring stiffness (or K)
Te: Circular natural frequency of the effective mass
f: Vehicle structural natural frequency, Hz

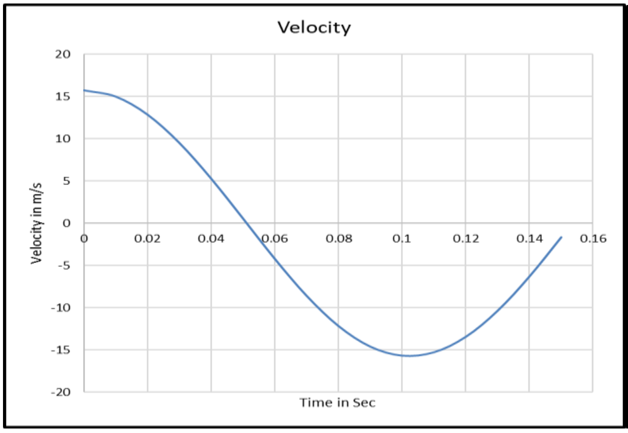


Fig. 6 Acceleration Graph of Spring Mass Model

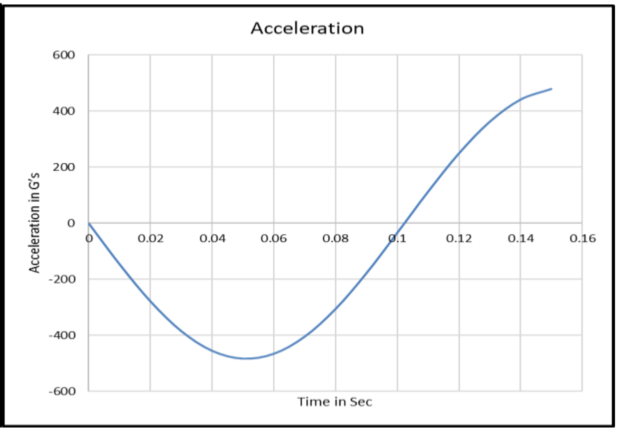


Fig. 7 Velocity Graph of Spring Mass Model

2. *Kelvin's Model.*

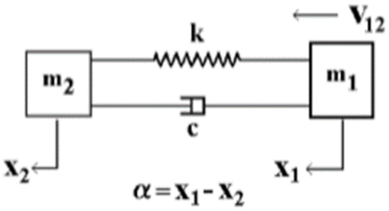


Fig. 8 FBD of Kelvin's Model

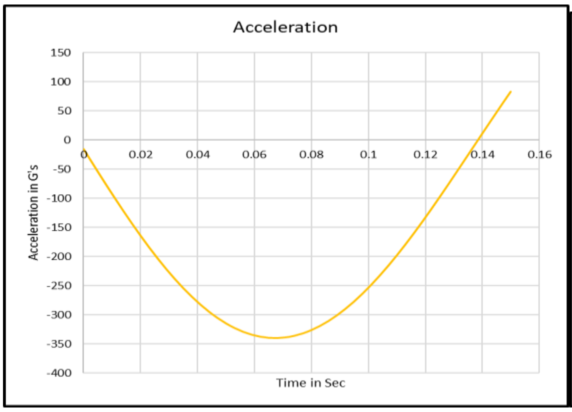


Fig. 9 Acceleration Graph of Kelvin's Model

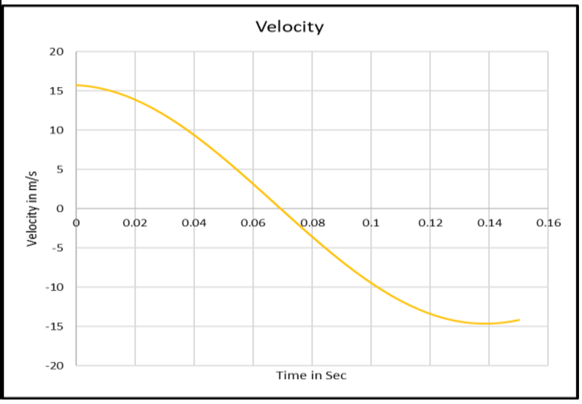


Fig. 10 Velocity Graph of Kelvin's Model

3. Maxwell's Model

The Maxwell element consists of spring and damper elements connected in series, as shown in Fig. The element, massless and uni-axial, does not consider the bending or torsion stiffness. The end points of the element can be attached to any bodies. The Maxwell model is suitable for modeling material responses that exhibit relaxation and creep, a time dependent phenomenon. In vehicle impact modeling, it is suited for the localized impact where the vehicle effective stiffness is low.

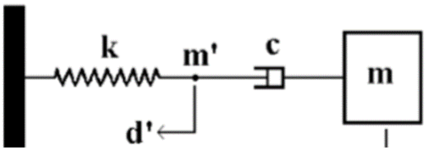
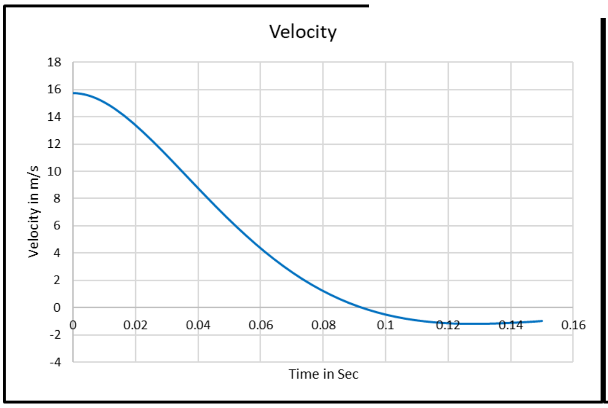


Fig. 11 FBD of Maxwell's Model



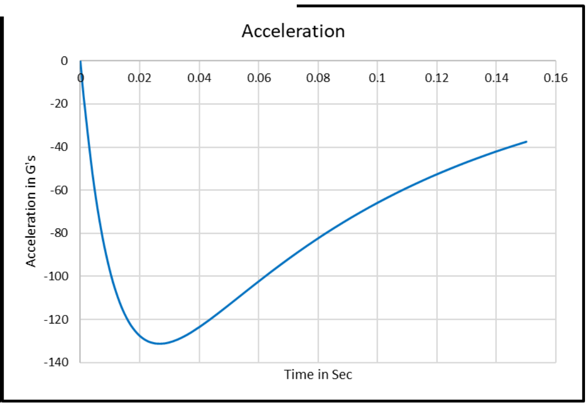
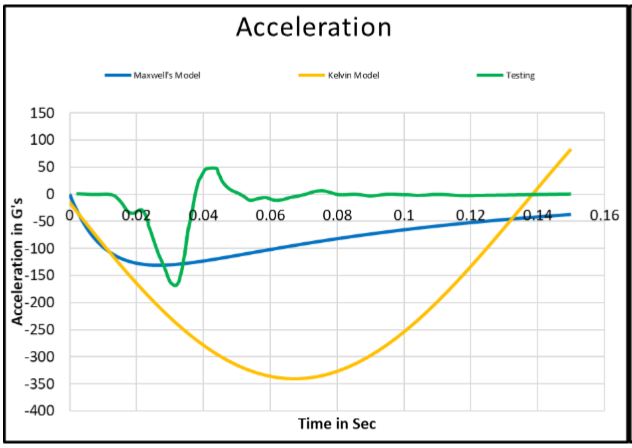


Fig. 12 Acceleration of Maxwell's Model Fig. 13 Velocity of Maxwell's Model

IV. Result Comparison

To represent vehicle to pole collision we established in total five models here (spring-mass model, Kelvin model, Maxwell model). Let us compare their responses with the car's behaviour during the experiment analysed by us - see Fig. 14 and Fig. 15. Characteristics which the best represents the overall car's behaviour during the crash period belongs to the Maxwell model. Although Kelvin and spring-mass models give good approximation in the beginning of the crash (up to the time of maximum dynamic crush), they completely fail when it comes to the crash representation after the rebound. Therefore, the Maxwell model gives the best overall outcome. And the entire shape of the Maxwell model's response resembles closely the real car's crash data.



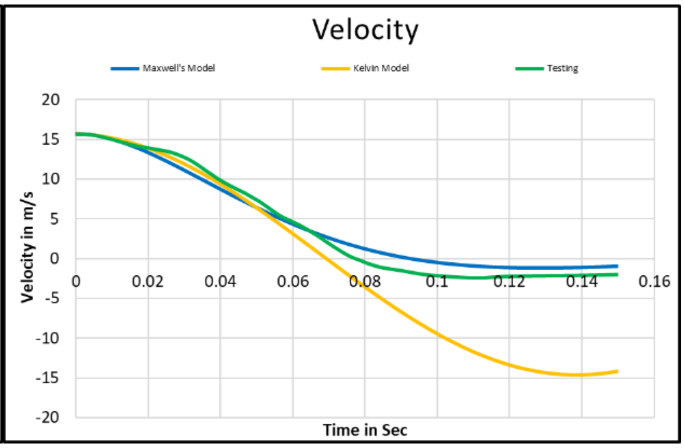


Fig. 14 Acceleration Comparison

Fig. 15 Velocity Comparison

V. Conclusion

We have managed to prepare the crash data for analysis and extract the mathematical model from it. Challenges here were to choose an appropriate test data approximation and time interval in which we want to investigate the collision. Having this done we can determine maximum crush of a car, when it occurs, how the velocity changes and what are the changes in acceleration of a car during a crash. We studied a process of improving the accuracy of the vehicle crash model. First, we simulated the vehicle under a pole impact by using the Kelvin model. Afterwards, by filtering the crash pulse data, more accurate response of the system was obtained. Model establishment was done one more time. Finally, we compared the crash models and it was concluded which of them is more suitable to represent vehicle to pole collision. The obtained results indicate that the Kelvin model is not appropriate for simulation of the collision which we deal with. For the data prepared in the proper way, we establish a proper model. Results obtained from studying Maxwell model provided us with satisfactory results. Comparative analysis of the model's and real car's responses turned out to be appropriate. Therefore, if one wants to simulate a vehicle to pole collision it is advisable to use Maxwell model. Since all the models presented in the current study are lumped parameter ones which are valid only for the data which were used for their creation, they cannot be used to simulate e.g. a high-speed vehicle collision. It is desirable to verify whether the other viscoelastic models which were not discussed in this paper are capable of vehicle crash simulation. The capabilities of mathematical models with nonlinear parameters (stiffness and damping) to simulate a variety of crash events are required to be assessed. It is advisable to examine methods for nonlinear system parameters identification.

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