

Idealized Vehicle Crash Test Pulses for Advanced Batteries

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ABSTRACT

This paper reports a study undertaken by the Crash Safety Working Group (CSWG) of the United States Council for Automotive Research (USCAR) to determine generic acceleration pulses for testing and evaluating advanced batteries subjected to inertial loading for application in electric passenger vehicles. These pulses were based on characterizing vehicle acceleration time histories from standard laboratory vehicle crash tests. Crash tested passenger vehicles in the United States vehicle fleet of the model years 2005-2009 were used in this study.

Crash test data, in terms of acceleration time histories, were collected from various crash modes conducted by the National Highway Traffic Safety Administration (NHTSA) during their New Car Assessment Program (NCAP) and Federal Motor Vehicle Safety Standards (FMVSS) evaluations, and the Insurance Institute for Highway Safety (IIHS). These crash modes included: Frontal rigid flat barrier test at 35 mph (NHTSA NCAP), 40% offset frontal deformable barrier test at 40 mph (IIHS), Side moving deformable barrier test at 38 mph (NHTSA side NCAP), Side oblique pole test at 20 mph (US FMVSS 214/NHTSA side NCAP), and Rear 70% offset moving deformable barrier impact at 50 mph (US FMVSS 301).

The accelerometers used were located in the vehicle where deformation is minimal or non-existent, so that the acceleration represents the "rigid-body" motion of the vehicle. The wide range of variability from vehicle platforms was evident for each of the test modes. The test data were summarized using idealized step-ramp pulses obtained through parametric fit. Two-step Longitudinal and one-step Transverse acceleration test pulses were created based on the raw test data. These idealized vehicle crash test pulses may be used for evaluating the crashworthiness of advanced batteries for passenger vehicle applications.

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1. INTRODUCTION

Vehicle crash response is one consideration in the nascent application of advanced batteries to mass-produced electric passenger vehicles. The advanced batteries, with the Lithium-Ion chemistry being the prevalent type currently, may respond to external mechanical load differently than conventional lead-acid batteries. Also, their larger size dictated by capacity requirements and current technology should be considered.

In a vehicle crash, the advanced battery pack will potentially be subjected to two types of loading, direct contact and inertial. Contact load is caused by relative displacement of adjacent vehicle components or outside objects (e.g., poles, impacting vehicles, etc.). Inertial load occurs as the battery experiences deceleration/acceleration with the vehicle, and is always present in a crash even if the battery does not have any impingement.

To address both standardization and engineering aspects of batteries, it is desirable to have a set of test conditions and criteria to account for the crash loads. A battery test procedures manual was created in 1996 by a team composed of the United States Advanced Battery Consortium (USABC) and Department of Energy (DOE) National Laboratories personnel [1]. A mechanical vibration test is specified in this document, but it aims to reflect conditions encountered in normal operating conditions, not the mechanical overload conditions of a vehicle crash. Crash loading was later addressed in a 1999 USABC battery abuse test manual [2], where shock pulses along with penetration and drop test conditions were specified for battery module and/or packs. Battery temperature and chemical venting were monitored in these tests. The shocks are specified by velocity change and duration, without detailed time history, and the maximum velocity change in the manual is 13.3 m/s. More recently, a test pulse was specified in the SAE Recommended Practice J2464 [3], and this pulse is carried into SAE J2929 [4].

The objective of this study is to provide additional information, to help in battery performance evaluation, which captures the impact response of current vehicle crash modes. The current study focused on the inertial loading. Standardized full vehicle crash test data of the Model Years 2005-2009 passenger vehicles in the United States vehicle fleet are utilized. The acceleration time histories were taken from a large number of vehicles (461), and a final set of crash pulses are distilled from these and may be used to define conditions for testing and qualification of the battery and its mounting structure.

In the following, details are given on the data source and the data processing methods, then a set of idealized vehicle crash test pulses is presented.

2. RAW DATA AND DATA PROCESSING

Data from crash tests of 2005-2009 model year vehicles conducted by the NHTSA (frontal, side, and rear) and the IIHS (offset frontal) were gathered and considered for this study. The test data were directly downloaded from the NHTSA and IIHS public websites. [Table 1](#) summarizes the data sources, and it shows the number of vehicles for each test type. Also shown in [Table 1](#) is the location of the accelerometers whose time histories were used in this analysis. The locations are from areas of the vehicle where deformation is minimal or non-existent, so that the acceleration represents the “rigid-body” motion of the vehicle. All acceleration data used in the analysis were filtered with the SAE CFC 60 filter.

Table 1. Summary of Data Sources and Number of Tests

Direction Mode	Longitudinal		Transverse		
	Frontal	Rear			
Protocol	NHTSA NCAP Fixed flat wall impact	IIHS 40% overlap offset impact	FMVSS 301 70% overlap offset impact	NHTSA side NCAP moving deformable barrier impact	FMVSS 214 Fixed pole impact
Speed	35 mph	40 mph	50 mph	38 mph	20 mph
Number of vehicles	201	110	16	107	27
Sensor location	Floor pan at seats or rear part of vehicle*	Near vehicle C.G.	Floor pan at seats or rear part of vehicle	Floor pan above rear axle	Floor pan above rear axle

* The average of channels at the left and right side of sensor locations was used

[Figure 1](#) presents the time history of the crash tests in the longitudinal direction, including the NHTSA frontal NCAP ([Fig. 1\(a\)](#)), the IIHS frontal offset tests ([Fig. 1\(b\)](#)), and the FMVSS 301 rear offset tests ([Figure 1\(c\)](#)). Also highlighted in [Figure 1](#) are the acceleration pulses from the top 10% of the vehicles that have the least vehicle deformation estimated through double integration of the acceleration time histories. Approximately, these are the vehicles that are in the top 10 percentile in terms of the average acceleration. Similar to [Figure 1](#), [Figure 2](#) presents the raw acceleration time histories of the tests in the transverse direction, including side NCAP tests ([Fig. 2\(a\)](#)), and FMVSS 214 side pole tests ([Fig. 2\(b\)](#)). The top 10% in terms of severity is also shown. The next step is to extract generic pulses.