

Design Challenges in the Development of a Large Vehicle Inertial Measurement System

Joshua L. Every
The Ohio State University

Gary J. Heydinger
SEA Ltd.

Dennis A. Guenther
The Ohio State University

Anmol S. Sidhu, Dale A. Andreatta, and Ronald A. Bixel
SEA Ltd.

ABSTRACT

The (Vehicle Inertia Parameter Evaluation Rig) VIPER II is a full vehicle mass and inertia parameter measurement machine. The VIPER II expands upon the capabilities of its predecessor and is capable of measuring vehicles with a mass of up to 45,360 kg (100,000 lb), an increase in capacity of 18,100 kg (40,000 lb). The VIPER II also exceeds its predecessor in both the length and width of vehicles it can measure. The VIPER II's maximum vehicle width is 381 cm (150 in) an increase of 76 cm (30 in) and maximum distance from the vehicle CG to the outer most axle is 648 cm (255 in) an additional 152 cm (60 in)

The VIPER II is capable of performing measurements including vehicle CG height, pitch, roll, and yaw moments of inertia and the roll/yaw cross product of inertia. While being able to measure both heavier and larger vehicles, the VIPER II is designed to maintain a maximum error of 3% for all inertia measurements and 1% for CG height.

When designing a system with increased capacity there are many different factors and properties that must be considered. Some properties increase linearly when scaled such as mass but others such as moment of inertia and stiffness do not. This document presents some of the design challenges encountered in development of the VIPER II and how those challenges were addressed.

CITATION: Every, J., Heydinger, G., Guenther, D., Sidhu, A. et al., "Design Challenges in the Development of a Large Vehicle Inertial Measurement System," *SAE Int. J. Commer. Veh.* 7(1):2014, doi:10.4271/2014-01-0096.

INTRODUCTION

Motivation

The measurement of vehicle mass and inertial parameters has a wide variety of applications. From basic two dimensional models to complex three dimensional simulations the accuracy and even feasibility of performing any analysis is directly related to these measurements. The creation of more accurate vehicle models is of increasing importance as the amount of electronic safety systems in vehicles continues to increase. Development and validation of such systems often depends upon the measurement of mass and inertial parameters [1].

Vehicle mass parameters are also used to evaluate new vehicle designs and in setting standards for vehicle safety. The National Highway Transportation Safety Administration's (NHTSA) New Car Assessment Program (NCAP) uses measurements of vehicle mass properties to determine metrics of vehicle rollover safety [2].

Previously Developed Mass and Inertia Measurement Systems

A variety of systems have been developed to measure the mass and inertia of vehicles. The Inertia Parameter Measurement Device (IPMD) was developed by NHTSA in 1986 and measured CG location and roll, yaw and pitch

moments of inertia [3]. No specification on maximum test vehicle size or weight is given but, all tests reported from this system were conducted with passenger cars and light trucks.

In 1994 SEA Ltd. designed and built the Vehicle Inertial Measurement Facility (VIMF) [4]. The current generation of VIMF is capable of measuring the CG location and the three principle moments of inertia similar to the IPMD and has the added capability of measuring the roll-yaw cross-product of inertia. The maximum test vehicle mass for this machine is 4,540 kg (10,000 lb). The maximum vehicle size is limited to a maximum vehicle width of 244 cm (96 in) and the vehicle length is limited such that the distance between the CG and the outermost axle is less than 274 cm (108 in).

The Vehicle Inertial Parameter Evaluation Rig (VIPER) was designed and built by SEA, Ltd. in 2000. This machine measures the same set of vehicle parameters as the VIMF. The VIPER is capable of measuring vehicles with a mass of up to 27,220 kg (60,000 lb) and with vehicle width up to 305 cm

(120 inches). The test vehicle length is limited such that the distance between the CG and the outermost axle is less than 495 cm (195 in) [5].

Basic Theory of Operation

Similar to most existing inertia measurement machines, the VIPER II utilizes system free response to measure vehicle properties. A photograph of the VIPER II with a test vehicle is shown in [Figure 1](#). The theory of the VIPER II is very similar to that of the VIMF. Both systems utilize three different types of pendulums to measure vehicle properties. Pitch moment of inertia and CG height are measured using a standard, stable pendulum. Roll moment of inertia is measured using a spring stabilized inverted pendulum. Yaw moment of inertia and the roll/yaw cross product of inertia are measured using a torsional pendulum. Pictures depicting the VIPER II in pitch/CG height and roll mounting configurations are shown in [Figures 2](#) and [3](#), respectively.



Figure 1. Photograph of the VIPER II in roll configuration with a test vehicle.



Figure 2. Photograph of short platform supported in pitch inertia/ CG height tests configuration.





Figure 3. Photograph of short platform supported in roll inertia configuration.

The method of computing the inertia parameters from the period of oscillation is not presented in this document. If further information on this process is desired the reader is directed to reference [5].

VIPER II SYSTEM SPECIFICATIONS

The VIPER II is able to measure larger and heavier vehicles than its predecessors. The maximum mass for a test vehicle on the VIPER II is 45,360 kg (100,000 lb). The maximum vehicle size is 381 cm (150 in) in width and the distance from the CG to the outermost axle is restricted to being less than 648 cm (255 in). This increase in capabilities allows for accurate inertial and mass parameter measurements of vehicles that were previously immeasurable. The VIPER II system specifications are contained in [Table 1](#).

Table 1. VIPER II system specifications.

Minimum Vehicle Mass	1,360 kg (3,000 lb)
Maximum Vehicle Mass	45,360 kg (100,000 lb)
Maximum Axle Static Load	133,450 N (30,000 lb)
Maximum Number of Axles	Unlimited
Maximum Turret Weight	27216 kg (60,000 lb)
Minimum Track Width	140 cm (55 in)
Maximum Track Width	300 cm (118 in)
Maximum Vehicle Width	380 cm (150 in)
Maximum Tire Width	81 cm (32 in)
Maximum Vehicle Length	1520 cm (600 in)
Maximum Distance from Vehicle CG to Farthest Axle.	635 cm (250 in)

The VIPER II is capable of measuring vehicle CG height, roll, yaw and pitch moments of inertia as well as the roll/yaw cross product of inertia. Though the VIPER II is capable of measuring larger and heavier vehicles than its predecessors it maintains a high level of accuracy. The specified maximum percent error for inertia measurements is 3% and the maximum percent error

for CG height measurements is 1%. The design of the VIPER II requires that these levels of error can be maintained for all vehicles within the machine capacity.

In order to be able to test a wide variety of vehicles and maintain the required level of accuracy the VIPER II utilizes two vehicle support platforms. The short platform is used for vehicles with a mass up to 13,600 kg (30,000 lb) and with a distance from vehicle CG to outermost axle of less than 254 cm (100 in). The long platform is used for vehicles exceeding the capacity of the short platform yet still within the capacity of the machine.

DEVELOPMENT OF THE VIPER II

The equations used to compute the inertia of test vehicles on both the VIMF and the VIPER II model the system as only having two degrees of freedom. Therefore in order for the system to accurately measure vehicle properties all degrees of freedom other than those measured must be limited. In previously developed machines the maximum allowable deflection was limited to 0.25 cm (0.1 in). Thus, an analysis was used to determine if this specification could be achieved for the VIPER II short platform over the full range of vehicles it could carry.

Short Platform Design

The short platform of the VIPER II is made from aluminum to keep the platform weight as low as possible while maintaining the required strength and stiffness. The desire to keep the weight to a minimum is important because the inertia properties of the platform carry an inherent uncertainty that is proportional to the platform mass. This uncertainty is directly added to the full system maximum error so any reduction in platform weight directly relates to a reduction in full system error.

Finite element analysis and form synthesis techniques were used to create a design for the short platform that combines the required strength and stiffness while maintaining an acceptable weight. The mass of the finished design is 1841 kg (4059 lb).

The finite element analysis conducted on this platform was mainly used to analyze the platform deflection under various loading scenarios and for both support configurations. These scenarios were designed to represent the full spectrum of loading that this platform is expected to experience. The locations on the platform to which loading was applied are shown in [Figure 4](#) and the loading cases evaluated are listed in [Table 2](#). [Table 2](#) also lists the maximum deflection resulting from each applied load.