

The Design of a Suspension Parameter Identification Device and Evaluation Rig (SPIDER) for Military Vehicles

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ABSTRACT

This paper describes the mechanical design of a Suspension Parameter Identification Device and Evaluation Rig (SPIDER) for wheeled military vehicles. This is a facility used to measure quasi-static suspension and steering system properties as well as tire vertical static stiffness. The machine operates by holding the vehicle body nominally fixed while hydraulic cylinders move an "axle frame" in bounce or roll under each axle being tested. The axle frame holds wheel pads (representing the ground plane) for each wheel. Specific design considerations are presented on the wheel pads and the measurement system used to measure wheel center motion. The constraints on the axle frames are in the form of a simple mechanism that allows roll and bounce motion while constraining all other motions. An overview of the design is presented along with typical results.

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INTRODUCTION

Accurate computer simulation for design and analysis of vehicle and tire behavior requires suspension parameters obtained by vehicle suspension testing. Suspension parameters are important for suspension and steering system development, tire design, and vehicle dynamic simulations, as the suspension determines the position of the wheels on the road. Kinematic characteristics (movements of the wheel due to suspension displacement) and compliance characteristics (movements of the wheel due to road plane tire forces) must be known to accurately predict the movement and location of the vehicle chassis and wheels. Early on, the development of vehicle suspension and steering systems was conducted mostly by subjective techniques during road and proving ground testing. Presently, the trend is to use computer simulation to improve the effectiveness and reduce the time of the design and development of a new vehicle [1]. Suspension parameters have also proven useful for tire design as successful and efficient tire design and development requires an understanding of the combined tire and wheel

system. Simulation tools have been used to predict wheel and tire behavior and these tools require suspension parameter data from heavy vehicles, which can be obtained by suspension measurement devices [2, 3, 4].

Suspension parameter data is also valuable for simulating vehicle dynamics during rollover and driving maneuvers. The National Highway Traffic Safety Administration (NHTSA) has many applications for vehicle dynamics simulations for the offices of Crash Avoidance Research, Rulemaking, The National Advanced Driving Simulator, and Intelligent Vehicle Highway Systems (IVHS) studies [5]. Overall, computer simulations are widely used to predict vehicle response in real-world scenarios for everything from design and research to accident reconstruction and rulemaking [6]. This paper is specifically concerned with the need for a Suspension Parameter Identification Device and Evaluation Rig (SPIDER), identified by the U.S. Army Tank Automotive Research, Development and Engineering Center (TARDEC). By measuring suspension parameters and using them in simulation and design, TARDEC can improve the safety of



Figure 1. A 3-axle truck being tested on the SPIDER. For this test, only Axle 1 is being tested on the front axle frame. Vehicle Axle 2 is inactive on the rear axle frame.

military vehicles and trailers. The system that most influences the dynamic structural behavior is the suspension system [7].

GENERAL DESIGN CONSIDERATION

What makes the SPIDER unique is its need to accommodate a wide range of vehicles. The lightest military vehicles and trailers could be tested on some of the passenger vehicle suspension evaluation rigs while the heaviest military vehicles could not easily be tested on existing heavy vehicle suspension measurement facilities. Not only does the SPIDER have to support heavier loads than most rigs, but also it has to accommodate a wide range of track widths, wheel bases, number of axles, chassis designs and armor plating. Early on in the design it was decided that the vehicle body was to be fixed, while moving the wheel pads to produce the necessary bounce and roll motion. This decision was made because it is easier to accommodate a wide range of vehicles, as it is easier to design vehicle restraints to fit all of the vehicles rather than designing a bounce and roll apparatus to accommodate all vehicles. Also, the range of forces in the actuators is narrower with the vehicle body fixed than it would be if the vehicle body moved.

The SPIDER can accommodate military vehicles with track widths up to 110 inches. The maximum allowed vertical

motion from the drive-on position is ± 11.5 inches and the maximum roll angle is ± 5 degrees. Up to two axles can be tested at a time, however a single axle can also be tested. In the case of tandem axles on a vehicle, they must be tested together. An axle frame that is part of the main test hardware supports each axle. The axle frames are the yellow horizontal structures shown under the axles in Figure 1.

The end of each axle frame is attached to a hydraulic cylinder. The bottom of the cylinder, the rod end, is attached to the axle frame, and a pylon attached to the T-bed supports the stationary top of the cylinder. The pylons are the tall blue structures shown in Figure 1. Attached to the axle frame are wheel pads for the left and right wheels. These pads can support very wide sets of dual tires and are free to move in the longitudinal (x) and lateral (y) directions on linear rails with circulating balls. The required steer motion of the wheel pad is allowed by a large steer bearing under each wheel pad.

Wheel Pad and Top Plate Design

Wheel pads were designed using linear motion guides and a thrust type bearing to allow for independent lateral and longitudinal motion along with steer rotation. In the future, there are plans to add lateral, longitudinal, and steer compliance testing capabilities to the SPIDER. The present system, while complex, will allow these tests to be added more easily than if a simpler free-floating plate had been

used. Figure 2 shows the final wheel pad design and a photograph of an actual wheel pad unit.

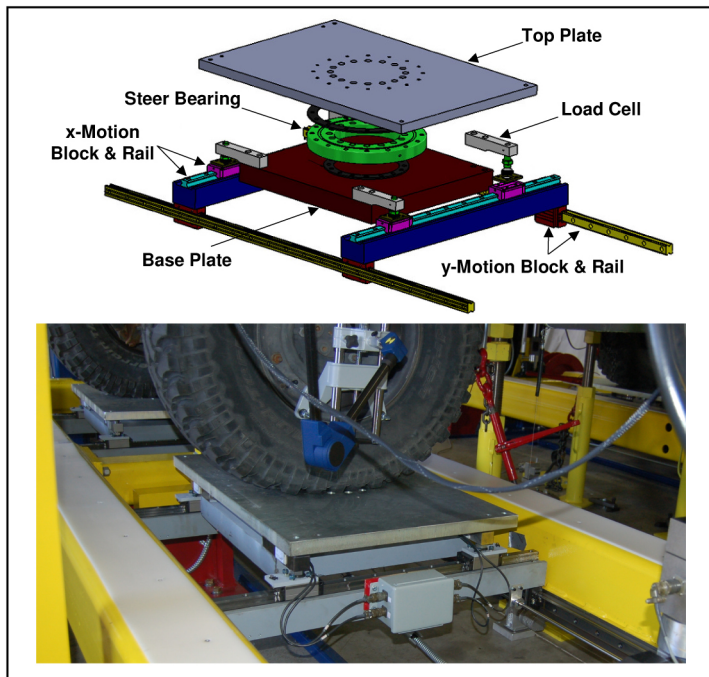


Figure 2. Wheel Pad Final Design and Photograph

The top plate has overall dimensions of 36 inches (914 mm) wide and 24 inches (610 mm) long and a thickness of 1.25 inches (31.8 mm). The design of the plate was based on two cases involving the heaviest vehicles. Case one was when the heaviest axle was fully compressed. The top plate was designed to withstand 50,000 lb (222 kN). For this case, the load will be distributed over the entire surface of the top plate. The second case examined is during vehicle drive on. When the vehicle is initially driven onto the wheel pad, the entire weight of the wheel will be supported near the edge of the top plate, offset from the bearing under the plate. For this analysis, the drive-on load used is 25,000 lb (111 kN) per wheel and the wheel width will be 36 inches (914 mm).

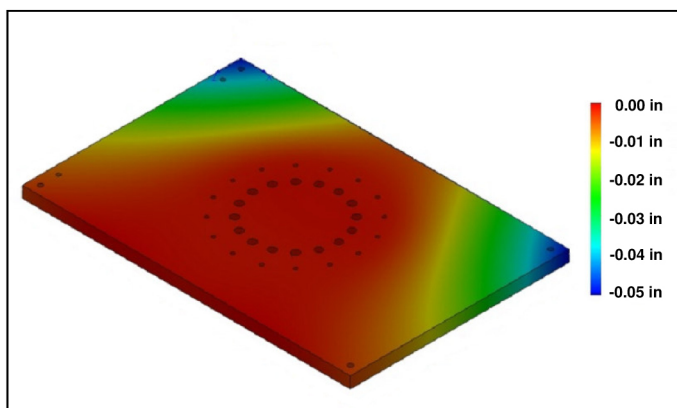


Figure 3. Deflection for Top Plate During Drive On

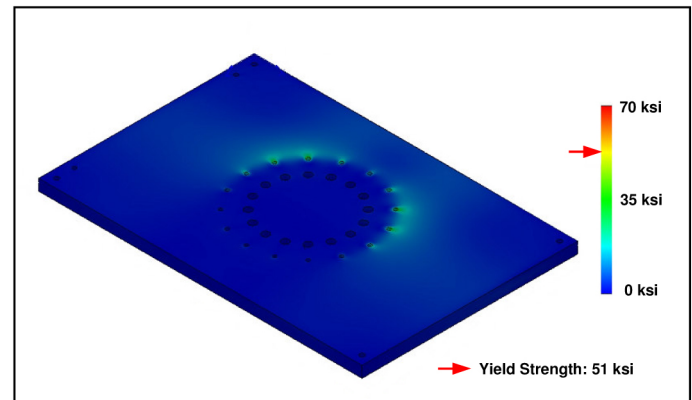


Figure 4. Stresses for Top Plate During Drive On

In both cases the top plate was constrained by fixing the 16 tapped holes that are used to attach the bearing. A contact set was also created to simulate the bearing support under the plate. This was done by first creating a work plane coplanar with the bottom surface of the top plate and a sketch of circles of diameters equal to the Inner Diameter (ID) and Outer Diameter (OD) of the outer race of the steer bearing. Finally the top plate mesh was created using the h-method adaptive meshing, which creates smaller elements in the higher stress gradients. The final stress and deflection plots for the drive-on case are shown in Figures 3 and 4. The stress plot shows that there is a maximum stress larger than the yield stress of steel, but is very localized. The high stresses are caused by stress concentrations and boundary conditions on the edge of the tapped holes and are not of concern, particularly since the material is ductile and this is not a fatigue situation. Away from the edges of the tapped holes, the stresses are reasonably low.

Roll Constraint Design

It is important that during the roll testing the axle frame is subjected to pure roll motion about the correct axis to achieve accurate results. It is possible to do this by simply actuating the hydraulic cylinders in the opposite direction at the same time. However, the axle frame must be constrained in x, y, pitch and yaw. A constraint must be used to force the bounce and roll frame to roll about a pivot on the road plane at the center of the vehicle. Furthermore, there are components under the vehicle's frame between the wheels, and the roll constraint had to be placed outside of the maximum vehicle width. Thus, it was decided to place the roll constraint components on the ends of the roll frame to ensure there would be no interference with any vehicle components while keeping the overall height of the roll frame the same. Two plates were designed to attach to the ends of the roll frame that would slide vertically within a guide on the pylons. The guide is a simple piece of steel with a vertical groove. The plate rides in the groove of the guide, with a lubricant added to reduce friction between the two parts. The ends of the roll plates have a large radius with its center at the roll axis in the