

HMMWV Axle Testing Methodology to Determine Efficiency Improvements with Superfinished Hypoids

Brian David Dykas
US Army Research Laboratory

Denise M. Rizzo
US Army TARDEC

Doug Fussner and Randy McDonnell
Southwest Research Institute

Mark Riggs
The Ohio State University

ABSTRACT

A dynamometer test methodology was developed for evaluation of HMMWV axle efficiency with hypoid gearsets, comparing those having various degrees of superfinish versus new production axles as well as used axles removed at depot maintenance. To ensure real world applicability, a HMMWV variant vehicle model was created and simulated over a peacetime vehicle duty cycle, which was developed to represent a mission scenario. In addition, tractive effort calculations were then used to determine the maximum input torques. The drive cycle developed above was modified into two different profiles having varying degrees of torque variability to determine if the degree of variability would have a significant influence on efficiency in the transient dynamometer tests. Additionally, steady state efficiency performance is measured at four input pinion speeds from 700-2500 rpm, five input torques from 50 - 400 N·m, and two sump temperatures, 80 °C and 110 °C. This paper will summarize the vehicle modeling and duty cycle development. It will detail the testing configuration and methodology. Finally, it will summarize and explain the results and discuss the next steps.

CITATION: Dykas, B., Rizzo, D., Fussner, D., McDonnell, R. et al., "HMMWV Axle Testing Methodology to Determine Efficiency Improvements with Superfinished Hypoids," *SAE Int. J. Passeng. Cars - Mech. Syst.* 6(2):2013, doi: 10.4271/2013-01-0605.

INTRODUCTION

It has been established that various methods of surface engineering can have large impacts on the power transmission efficiency of gearing [1,2,3]. However, ground vehicles (both military and commercial) are subject to more stringent cost constraints than air vehicles such as helicopters. As a result, surface processing techniques are often not undertaken to optimize fuel efficiency, although these processes are becoming more common and economical in recent years [4]. Efforts to determine superfinish effects on gear geometry [5] and to model efficiency of gears having various surface textures [6,7] have demonstrated promising improvements in efficiency that have been verified by many entities, although much of the efficiency data is proprietary to the organizations making the measurements.

With a goal of evaluating superfinishing of automotive gearing for military applications, a dynamometer test project was devised. The primary goal of the current evaluation is to experimentally measure gear efficiency with and without various superfinish surface treatments, in comparison to new production and used axles removed at depot maintenance. A parallel basic research thrust included computational modeling of interacting gears to refine predictive tools for improved gear surface design, following on previously reported gear efficiency tools [8,9].

The current work is a subsystem-level evaluation of gear efficiency on actual vehicle driveline components. Dynamometer testing of an HMMWV axle ring and pinion was conducted using various test specimens to determine if significant gains in gear efficiency can be achieved with varying degrees of superfinish over a typical military drive

cycle. To best quantify the achievable benefits of surface engineering in geared components, it is desirable to choose a component/subsystem where surfaces interact most. This generally occurs in gearing with lower speeds and higher torques, so reduction stages closest to the wheel output are of most interest. Additionally, gearing in which more relative sliding of surfaces occurs tends to amplify any effects of surface engineering on efficiency due to the relatively high losses [10]. For this reason, the hypoid gearing in the HMMWV axle was selected as an appropriate notional subsystem on which to conduct these efficiency experiments.

Considerable development of axle efficiency test methods has been conducted over the past several decades including considerable attention in the 1970s and through the 1980s [11,12,13,14,15]. Speed, load, and temperature have large influences on the efficiency performance of a specific axle/lubricant combination, and methodologies for mapping the performance of axles have been extensively reported, and work continues to develop a standard procedure [16]. Axle characterization methods include both loaded measurements as well as the measurement of unloaded “spin losses” for the range of expected vehicle speeds. Because military vehicles typically operate on drive cycles that differ substantially from typical highway vehicles, a dynamometer test protocol was developed specific to the HMMWV. Limited resources were responsible for additional constraints placed on the protocol, such that fewer data were collected than would ordinarily be necessary to determine statistical significance. As such, this work represents an initial consideration of axle efficiency improvements attributable to superfinished gears in light military vehicles. Further tests would need to be undertaken to provide sufficient confidence in performance improvement to substantiate analysis of cost savings.

VEHICLE SIMULATION

To ensure the mission applicability, simulations run on a model of the High Mobility Multipurpose Wheeled Vehicles (HMMWV), shown in Figure 1, were used to provide the input duty cycle and maximum load conditions. Two types of simulations were run:

1. Mission profile as defined by the Peacetime Operational Mode Summary/Mission Profile (OMS/MP) [17], and
2. Tractive effort to determine maximum input speed and torques



Figure 1. High Mobility Multipurpose Wheeled Vehicles (HMMWV)

Vehicle Model

The HMMWV Heavy Variant M1097A2 was modeled using Gamma Technology (GT) Suite software, shown in Figure 2 [18]. This model is capable of estimating automotive performance, such as acceleration or gradeability, as well as predicting fuel usage over a drive cycle. Furthermore, various parameters can be monitored to provide a characteristic duty cycle for each component over a vehicle drive cycle.

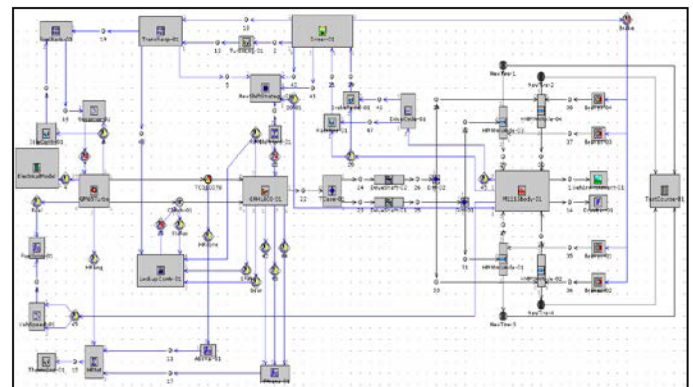


Figure 2. HMMWV GT Model

Duty Cycle

The U.S. Army defines a Peacetime and Wartime Operational Mode Summary/Mission Profile (OMS/MP) that characterizes the operation or use of that vehicle. This profile consists of primary roads, secondary roads, trails and cross country. These classifications are defined by the train profile of the course. Depending on the vehicle and its mission, the amount of time on each terrain type and vehicle speed is adjusted accordingly. For example, a vehicle that is designed to be used on-road will have a large percentage of its OMS/MP on paved roads at highway speeds.

To enable reliable simulation and in-vehicle testing, each OMS/MP terrain type is mapped to a course that can be found at the U.S. Army Aberdeen Proving Grounds (APG). The HMMWV Peacetime OMS/MP is defined as by [Table 1](#).

Table 1. HMMWV OMS/MP

<i>Terrain Type</i>	<i>Portion of Cycle</i>	<i>Vehicle Speed</i>
Primary Roads	50%	80 km/hr
Secondary Roads	40%	32 km/hr
Trails/Cross Country	10%	24 km/hr

The vehicle trace used to run the HMMWV model over the OMS/MP can be found in [Figure 3](#), which is a plot of vehicle speed vs. simulation step. Here, simulation steps have a temporal spacing of approximately eight seconds. The results of the simulation, which resulted in a translation of the vehicle drive cycle into a component duty cycle, can be found in [Figure 4](#), which is a plot of input speed (RPM) vs. input torque (N·m).

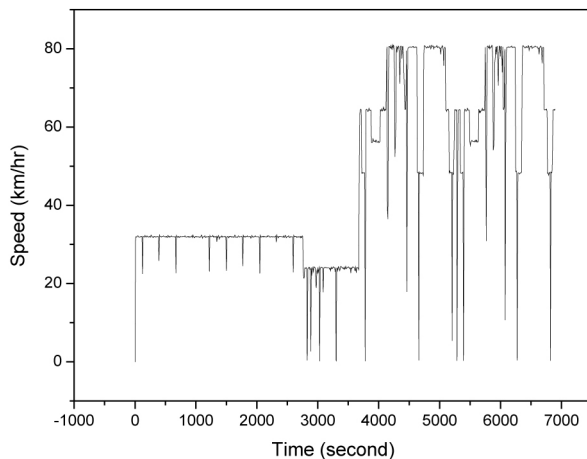


Figure 3. Peacetime OMS/MP for the HMMWV

In addition to determining the axle duty cycle over the OMS/MP, it is important to understand the maximum speeds and torques to which the HMMWV axle would be subjected by the drive cycle; therefore, a tractive effort simulation was completed and the maximum pinion input speed and torque were determined over the entire operating region.

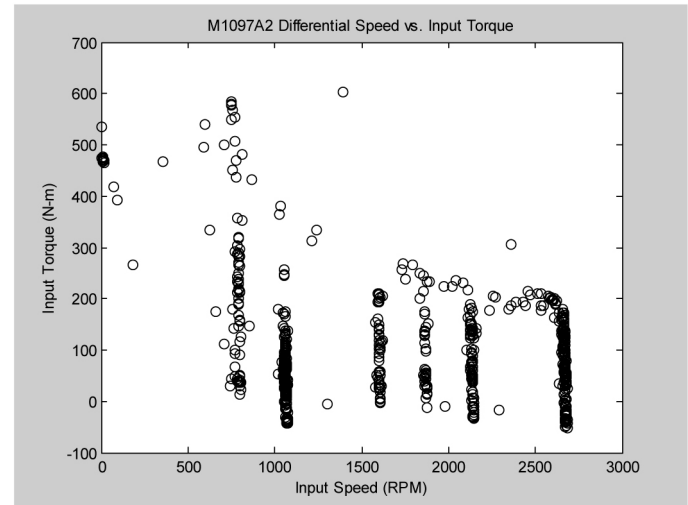


Figure 4. Axle Duty Cycle

The duty cycle and maximum loads were then used to determine the dynamometer test cycle, discussed in the next section.

DYNAMOMETER TESTS

Test Stand

Dynamometer tests were conducted on a test stand at the Southwest Research Institute, shown in [Figure 5](#). The test stand is equipped with DC motoring dynamometers. Power was provided to the axle by a 168 kW input motor capable of producing 534 N·m of torque from zero to 3000 rpm. Axle pinion input torque and speed were measured with an inline 500 N·m HBM T10F torque meter installed directly on the input motor shaft. A driveshaft connects the torque meter to the axle pinion. Two identical 1.74:1 gearboxes were used to sum the two axle outputs and eliminate differential wheel motion. A 350 kW absorbing dynamometer applied load to the axle via the gearbox configuration. Axle output torque and speed were measured with in-line 3000 N·m HBM T10FS torque meters installed directly on each output gearbox. Driveshafts connected the wheel flanges of the axle to the output torque meters. A mounting fixture was fabricated to support the axle, which was installed with a 0 degree pinion angle. [Figure 6](#) shows a schematic of the stand as configured for the axle testing.

The axle was filled with Chevron Supreme LS 80W-90 gear lubricant up to the bottom of the fill hole for all tests. The axle sump oil temperature was controlled using a heater and water spray system for steady conditions, and using forced convective cooling only for drive cycle testing.