

Steady State Speeds Load Determinations Using Electric Vehicle Power or Dynamometer Measurements on Conventional Vehicles

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ABSTRACT

Track Road Load Derivations (RLDs) and subsequent load matching on test cell dynamometers has traditionally been conducted using vehicle coastdowns (CDs). Vehicle speed changes during these coastdowns are used to calculate the vehicle mechanical drag forces slowing vehicles when on the road. Track drag force, exerted on a vehicle, can also be quantified by holding a vehicle at a specific steady state speed and measuring the forces required to maintain that speed. This paper focuses on two methods to quantify speed dependent forces which a vehicle must work against when motoring. One method is the traditional coastdown method. The second reference method measures vehicle steady state speed forces necessary to propel the vehicle using both electric vehicle propulsion power flows and dynamometer measured forces. Track CDs require the vehicle to be placed in neutral. Hybrid Electric Vehicles (HEVs) do not necessarily have true neutral mechanical power transmission modes and some vehicles exhibit large variations from CD run to CD run. A steady state approach may prove a useful alternative road load determination method for electric vehicles which may otherwise need modification for the CD method.

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INTRODUCTION

On a test track, a vehicle's propulsion electrical power flow can be used to quantify a vehicle's total parasitic road drags (both a vehicle's mechanical drags and ambient wind drags combined or total road drags) by measuring an HEV's motor electrical power flows during steady state (SS) speeds. On a chassis dynamometer the vehicle mechanical drags of the vehicle itself can be measured by using the dynamometer to motor the vehicle at steady state speeds and then recording the force required at each speed. The same may be accomplished using the vehicle propulsion motor power flows.

In the vehicle emissions field, coasting vehicles on a track and recording its velocity change with time has historically been used to determine vehicle total road drags or Track Target loads. The vehicle deceleration rates and inertial mass are used to calculate the forces (ambient and mechanical) that slow the vehicle down on the road. Society of Automotive Engineers (SAE) Standard J2263 Road Load Measurement Using Onboard Anemometry and Coastdown Techniques is the most commonly accepted standard that delineates this process. The J2263 procedure requires that coastdowns be performed on a track using runs in each direction, that are paired to average out differences which can be associated with the opposing directions of each run pair. Forces are then calculated and graphed verses vehicle speed. A quadratic equation

$$(F=A+B*V+C*V^2)$$

(1)

of force (F) as a function of velocity (V) is then calculated to fit the points. The major variability contributors to the force calculations are vehicle mechanical drive systems and ambient influences, such that there is no one singular, quadratic equation that can repeatedly describe the forces that act to slow down vehicles under any road conditions. A vehicle will have instead families of drag curves acting on it, depending on conditions. Because of these test measurement variations, SAE J2263 requires five paired runs to be used to calculate an average quadratic total road drag equation for a vehicle. This average or mean of all these track coastdowns is used as a singular estimate of total road drag forces needed to be emulated when testing a specific vehicle on a chassis dynamometer.

STUDY DESIGNS

The vehicle total road drag RLD, on a test track, requires the vehicle to obtain a top speed and then to have the vehicle transmission put in neutral. The vehicle is then allowed to coastdown to a low enough speed to cover the operating range of the vehicle in a dynamometer test. Conventional vehicles normally have transmissions with mechanical neutral modes. When a conventional vehicle transmission is placed in neutral the vehicle wheels are mechanically separated from the engine and portions of its drive train components.

The vehicle Track RLD produces a total Track Target quadratic equation that models the sum of windage, vehicle drive train mechanical and tire drags associated with the vehicle on the road. On a dynamometer RLD, the vehicle is allowed to coastdown repeatedly.

The dynamometer iterates through multiple coastdowns, changing the drags it asserts on each coastdown, comparing the times achieved to those calculated from the vehicle Track Target RLD equation for the vehicle. When the vehicle repeats times that match the Track Target RLD equation calculated times, within acceptance limits, the dynamometer set load associated with those replicate runs, expressed as a quadratic equation, is used as dynamometer set coefficients for the vehicle test cell testing.

The vehicle's mechanical drags are assumed to be the same on the dynamometer as when on the road. The sum of dynamometer load and vehicle's own mechanical drag values theoretically emulate the total road drags that the vehicle experiences on the road. When coasting a vehicle down on a dynamometer both the vehicle mechanical drive train drags and the dynamometer set drags act in conjunction to slow the vehicle down. Matching the speed interval times from the Track RLD is considered proof that the dynamometer has correctly simulated the vehicle's track total road drags. The dynamometer can then subtract the equation for the loads that it set, during the coastdown, from the overall Track Target equation to determine what the vehicle's mechanical drag loads are.

HEVs and Battery Electric Vehicles (BEVs) may not have power trains and/or transmissions that allow the vehicles to have true neutral modes. This can be for a number of reasons; multiple propulsion engines (internal combustion, electric and hydraulic motors), use of planetary gearing systems, single direct drive or multiple direct drive motors to name a few.

Manufacturers have used different methods to perform track RLDs on HEV and BEV vehicles. Vehicles have been modified to install a mechanical clutch just for the purpose of track RLDs and laboratory testing. Vehicles have also had their software modified to simulate types of "virtual" neutrals. Either way, RLDs performed by modifying the vehicle allows for the possibility that the RLD forces, after modifications, may not be the same as the forces exerted on the production model of the vehicle on the road.

The technology in HEV and BEV vehicles now presents the possibility to quantify vehicle mechanical drags and to do it with unmodified test vehicles under actual road conditions. The power used by an electrical motor is directly proportional to the load exerted on the drive motor or motors. The precision needed in the power control design of current HEV and BEV vehicles may allow us to measure motor amperage, voltage and subsequently the power that a vehicle uses to overcome the total road drags (i.e. ambient windage and vehicle mechanical drags) extremely accurately. This measured power should be able to be used with precisely measured vehicle speed to quantify the force exerted on a vehicle at any specific speed.

Using a vehicle held at steady state speeds to evaluate vehicle mechanical drags associated with vehicle drive trains is not a new practice. Automotive manufacturers, dynamometer manufacturers and Environmental Protection Agency (EPA) have used SS speeds to quantify a vehicle's total road drags for some time. On a test track, vehicles can be instrumented with either drive shaft torque meters or torque wheels, in order to record vehicle parasitic loads, as in separate studies performed by both Argonne Labs' Mike Duoba and EPA heavy

duty truck regulators. Recorded torque values have then been analyzed verses specific steady state speeds to model the total road drags that a vehicle works against on the road, with a quadratic equation.

The various drag equations can be used in more than one way. As stated above, RLD coastdowns can be used on a chassis dynamometer, in a trial and error sequence of iterations to determine the dynamometer load curve necessary to match track time data. Knowing the dynamometer set coefficients, which result in acceptable CD time intervals, and subtracting them from the Track Target coefficients subsequently produces a vehicle's mechanical drags. By reversing this calculation, a chassis dynamometer can motor the vehicle at set speeds while the dynamometer measured forces are recorded. This data is then analyzed to determine the specific mechanical drag coefficients associated the vehicle. Once the vehicle's mechanical drags are determined they can be subtracted from a vehicle's Track Target RLD quadratic equation to calculate the necessary dynamometer set load needed to simulate the Track Target RLD quadratic equation.

Actual Programs Performed

Canadian Vehicle Steady State Speed versus J2264 Coastdown Vehicle Loss Measurement

Manufacturer	Vehicle Descriptions
Chrysler	Chrysler Compass 3500 Pound Mass (lbm) Equivalent Test Weight (ETW) Spark Ignition (SI)
Chrysler	Patriot 3625 lbm ETW, SI
Chrysler	Chrysler RAM 2500 Compression Ignition (CI) Diesel 8000 lbm ETW
Ford	Escape Hybrid #1 4250 lbm ETW
Ford	Escape Hybrid #2 5000 lbm ETW
Honda	CR-V 4000 lbm ETW SI
Toyota	RAV4 4000 lbm ETW SI
Toyota	Highlander Hybrid 5000 lbm ETW
Toyota	Highlander 4750 lbm ETW SI

The EPA National Vehicle Fuels and Emissions Laboratory (NVFEL) has investigated using SS speed to measure vehicle mechanical drags (Vehicle Losses) compared to traditional J2264 "Chassis Dynamometer Simulation of Road Load Using Coastdown Techniques" coastdown RLD calculated vehicle mechanical drags since 2004. In 2009 NVFEL agreed to test nine four-wheel drive (4WD) vehicles for Environment Canada on a 4WD dynamometer. The Canadian government emissions testing program purchases vehicles for that use. They are mainstream vehicles that consumers purchase. No special care was taken with the vehicles used in the testing. They were shipped to the NVFEL and each tested multiple

times over a couple of months' period of time. NVFEL took this opportunity to perform vehicle mechanical drag comparisons, between the two vehicle mechanical drag evaluation methods (RLD and SS), on a fair cross section of 4WD vehicles. The group included those listed below.

After all emission tests, J2264 RLDs and SS speed Vehicle Loss tests were performed and the data collected.

HEV Electric Power Propulsion versus J2264 Coastdown Vehicle Loss Measurement

NVFEL then investigated using vehicle electric propulsion power at SS speeds to measure vehicle mechanical drags (Vehicle Losses) compared to both traditional J2263 "Road Load Measurement Using Onboard Anemometry and Coastdown Techniques" and J2264 "Chassis Dynamometer Simulation of Road Load Using Coastdown Techniques" coastdown RLD calculated vehicle mechanical drags.

A GM Volt Hybrid Electric Vehicle (HEV) 3750 lbm ETW was used for all the track and dynamometer steady state (SS) speed electric propulsion power measurements.

Track Data Generation

The primary Volt electrical measurements, during the track runs of the SS Method, employed a Hioki Model 3390 Power Meter using their 9279 induction clamp. The Hioki Power Meter satisfies SAE J1711 "Recommended Practice for Measuring the Exhaust Emissions and Fuel Economy of Hybrid-Electric Vehicles, Including Plug-in Hybrid Vehicles". The meter calibration was up to date and it was an instrument used for Compliance testing at the EPA National Vehicle Fuels and Vehicle Emissions Laboratory (NVFEL).

The current induction clamp was installed on the main battery feed to the motor inverter. Voltage was acquired from a voltage tap installed on the high-voltage side of the DC-DC converter. Vehicle Rechargeable Energy Storage System (RESS) or propulsion battery voltage was measured using DC voltage leads tapped off the vehicle battery cables. Vehicle electrical power usage was measured with the Hioki 3390 as well as calculated from its amperage and voltage measurements. Speeds were recorded using instrumentation called VBOX by RACELOGIC, a high accuracy GPS data logging system for vehicle on road testing. Signals from both of these instruments were integrated to evaluate power measurements with speeds.

It would be simpler and more economical to perform the SS method on any HEV or BEV vehicle if the vehicle's CAN Bus measured values could be used accurately enough for the measurements, instead of using external instrumentation. To determine the viability of using CAN Bus data for the SS method, the Volt's CAN Bus data were recorded independently of the Hioki meter during all the SS runs. The CAN Bus data was then aligned with the Hioki/VBOX data, using the vehicle speed traces recorded in each data set to match them up.

The electrical and speed values, both track and dynamometer, used in this study were selected from 30 to 60 second SS interval averages, during the most stable speed sub-sections. Because of this interval averaging, of the electrical and speed measurements, it was assumed that the VBOX and Hioki Power Meter different acquisition rates data would not introduce analysis errors due to any slight misalignment of the time stamped data streams.

Vehicle driven steady state speed values throughout the study were fairly impossible to reproduce exactly from each run to run performed. To facilitate more exact speed, force and electrical power load comparisons; all data were idealized from raw data into quadratic equations which were then used to calculate specific values using the exact same speeds for all the coastdown and steady state speed, power and load force evaluations.

The vehicle SS speed electrical values were generated on laps of an oval track at Chrysler Chelsea Proving Grounds. All SS speed data were obtained on the track straightaways and SS speeds intervals were matched in opposite direction pairs to average out ambient influences. The Track paired runs in each direction were performed five times and averaged to parallel the SAE J2263 procedure.

The J2263 values, in both directions, were generated with CDs on a straight away track at Chelsea constructed for performing the J2263 RLD procedure.

Once the track total road drag values for the GM Volt were determined with both the traditional coastdowns and the SS method, the vehicle was brought to EPA's NVFEL for the test cell portion of the study.

Dynamometer Data Generation

In this GM Volt testing, it was necessary to determine what vehicle mechanical drag values were included in the track determined J2263 RLD quadratic targets. The GM Volt performed RLDs using SAE J2264 "Chassis Dynamometer Simulation of Road Load Using Coastdown Techniques" procedure. Four separate consecutive runs of the SAE J2264 procedure RLDs were performed on the GM Volt, three of which were used to evaluate its vehicle mechanical drag variability on the dynamometer.

In order to conserve the charge in the vehicle battery, first the dynamometer motored the GM Volt to warm the vehicle tires/drive train components, then the first RLD coastdown was used as an additional vehicle warm up. The calculated vehicle mechanical drag values of the last three SAE J2264 procedure runs were averaged and the averaged vehicle mechanical drags were compared against vehicle mechanical drag values from each individual run's calculated vehicle mechanical drags.

Using the J2264 procedure, RLDs were performed, in both the Canadian and GM Volt portions. The vehicle mechanical drags were quantified using MAHA 48" 4 Wheel Drive Dynamometer "Vehicle Loss Test" mode software. The dynamometer motors the vehicle through SS speed steps. Each SS speed step was held for a set amount of time, in this case 30-60 seconds. This is analogous to the SAE J2452