

Powertrain Cycle for Emission Certification

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ABSTRACT

In August of 2011, the US Environmental Protection Agency issued new Green House Gas (GHG) emissions regulations for heavy duty vehicles. These regulations included new procedures for the evaluation of hybrid powertrains and vehicles. One of the hybrid options allows for the evaluation of an engine plus a hybrid transmission (a powertrain). For this type of testing, EPA has proposed simulating a vehicle following the hybrid vehicle test procedures, including the use of the vehicle cycles and the A to B comparison testing - as required for the full vehicle evaluation option.

This paper proposes an alternative approach by defining a powertrain cycle. The powertrain cycle is based on the heavy duty engine emissions cycle - the transient FTP cycle. Simulation and test results are presented showing similar performance over the engine and vehicle cycles. This approach offers several advantages as compared to the procedure described in EPA's GHG rule. Linking the powertrain cycle to the engine cycle ensures an equivalent evaluation as compared to the engine test, and allows evaluation against the engine standard instead of requiring A to B comparison. The use of a normalized powertrain cycle provides for a vehicle independent powertrain evaluation, potentially allowing for a powertrain certification to be applied to many vehicles - as is the case in heavy duty engine emissions certification. Finally, aligning the powertrain test procedure with the engine test program allows manufacturers to build on their existing experience with engine test cycles and test protocols.

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INTRODUCTION

Increasing interest in better characterizing emissions from heavy duty vehicles has led to a range of proposed regulations and procedures. These approaches include the recently enacted HILS procedure for hybrids [1], the US GHG rules, and the still under development hybrid Global Technical Regulation (GTR) and the European CO2 rules. These procedures all have to address the unique challenges presented by the heavy duty vehicle industry: the size of the vehicles, the non-integrated nature of the market, the proliferation and small volumes of the segments. Around the world heavy duty emissions regulation has in the past focused on the engine, but there is now increasing interest in considering the impact of the entire vehicle. Hybrid systems are a good example of a technology that is helping to motivate a more systems based approach to evaluating emissions: an evaluation at the engine alone will not account for the fuel savings of a hybrid. At the same time a full vehicle level evaluation may be burdensome for manufacturers, and may not provide a transparent way to evaluate powertrain technology.

This paper proposes a powertrain cycle methodology that would allow a creation of a cycle to evaluate performance of the entire powertrain. This approach offers many of the benefits of a vehicle level evaluation, without sacrificing the advantages of the engine testing program. While the development of the powertrain cycle methodology was motivated in part by the US EPA GHG rules, the approach described here is applicable more broadly.

US HEAVY DUTY EMISSIONS REGULATIONS

In 1970's the US EPA introduced regulatory requirements for criteria emissions for heavy duty vehicles. In contrast to the light duty market where EPA chose to regulate emissions from complete vehicles, in the heavy duty market EPA chose to regulate engines. Not only is regulation of heavy duty engines a practical approach, one could argue that regulating engines is in fact more appropriate than regulating vehicles. The authors suggest that the purpose of the regulation is to characterize emissions across a range of operating conditions that are consistent with real world operation, and to ensure that emissions do not exceed a standard. Engine regulation

requires both steady state and transient operation across the full engine operating range. Vehicle regulation may or may not exercise the engine across the full operating range, and so may not characterize or constrain emissions across the full powertrain operating range.

In 2011, EPA introduced heavy duty GHG rules which regulate both the engine and vehicle. The engine program builds on the existing criteria emissions program, while the vehicle program employs a simulation based approach. Vehicles performance is evaluated through simulation, and engine performance is measured in a test cell. This approach is practical for the heavy duty market, and the engine standard ensures CO₂ and criteria emissions performance of the powertrain is fully characterized across the operating range.

Hybrid powertrains were recognized as a special case. Hybrid certification options allow for certification of hybrids as either part of the engine program or vehicle program. For hybrid engine certification, the procedures build on existing engine test procedures [2]. For hybrid vehicle certification, two options are provided: chassis dynamometer testing and simulated chassis dynamometer testing [3]. In each option all of the hybrid hardware is included in the test, as shown in figure 1.

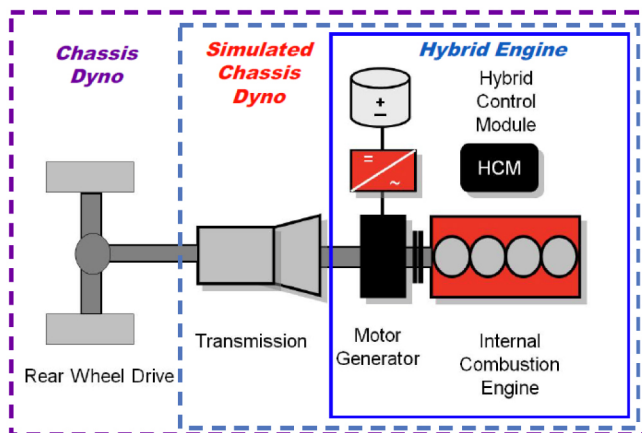


Figure 1. Hardware tested in the three hybrid options of EPA's HD GHG rule

The hybrid engine test option builds on the existing transient engine FTP test cycle and the steady state SET cycle. This allows comparison of the engine and hybrid component performance against the existing engine standard. In the case of the chassis dynamometer and simulated chassis dynamometer tests, the regulations require the use of the GHG vehicle cycles: the ARB transient vehicle cycle, the 55 mph steady state cycle, and the 65 mph steady state cycle. In order to isolate the impact of the hybrid system, the GHG rules include an A to B comparison between a conventional vehicle and a hybrid. This comparison generates an improvement factor which is used to calculate hybrid credits. The use of a specific vehicle in chassis dynamometer testing, or a specific simulated vehicle in simulated chassis

dynamometer testing, will generate performance results that are specific to the particular vehicle simulated.

POWERTRAIN CYCLE

An alternative strategy for powertrain testing is to define a normalized powertrain cycle that would define speed and torque as a function of the powertrain torque curve. This approach would be similar to the use of normalized speed and torque to define engine test cycles, but for a powertrain cycle the speed and torque would need to be defined at the input to the final drive. This strategy would allow a performance evaluation of the powertrain that is independent of the vehicle, and so would offer many of the same advantages of the engine test program:

- Consistently evaluate performance across the entire powertrain operating range
- Reduce proliferation of certifications (one test, many vehicles)
- Easier to implement compared to full vehicle testing
- Allow powertrain to powertrain comparison

While this powertrain cycle would be useful for evaluation of hybrid powertrains, it could also be applied to the evaluation of other powertrain technology. Ideally the powertrain cycles would be aligned with the engine test cycles and so allow an equivalent performance evaluation regardless of which test procedure is selected.

CYCLE CREATION

In order to create a powertrain cycle that is aligned with an engine test cycle, some characteristics of the engine test cycle must be incorporated into the powertrain cycle. However, because the speed and torque are defined after the transmission, it is necessary to incorporate some characteristics of a vehicle cycle as well. A simple approach that gave reasonable results was to use the speed from a vehicle cycle, and the power based on the corresponding engine cycle.

Powertrain FTP

The primary tests used to evaluate engine emissions in the United States are the transient FTP and steady state SET engine tests. The engine FTP was selected as the first candidate for the creation of a normalized powertrain cycle.

The engine FTP defines power versus time, but does not include a precise definition of negative torque (braking). Definition of negative torque (or power) is particularly important for hybrid powertrains, where the amount of brake energy captured can significantly impact fuel consumption. To define an appropriate braking power, the vehicle FTP cycle was used.

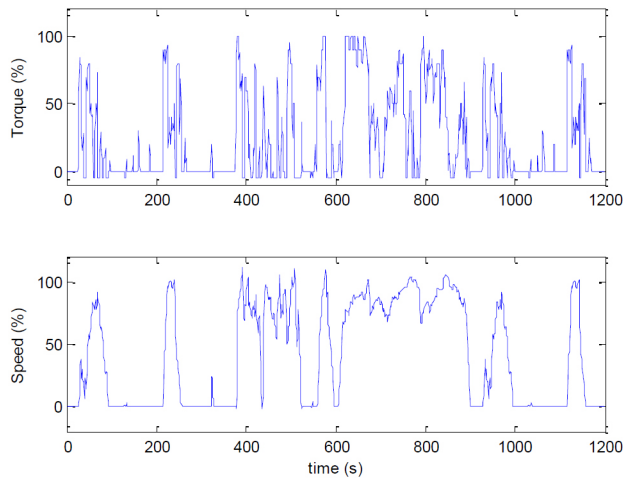


Figure2. Transient FTP engine test cycle

The vehicle FTP is described in Andreae *et al.* [4]. This vehicle cycle was created based the heavy duty engine FTP cycle. Shown below is the vehicle FTP. Because this cycle is based on the engine FTP transient test, the power versus time for this vehicle cycle aligns with the power versus time for the engine FTP test.

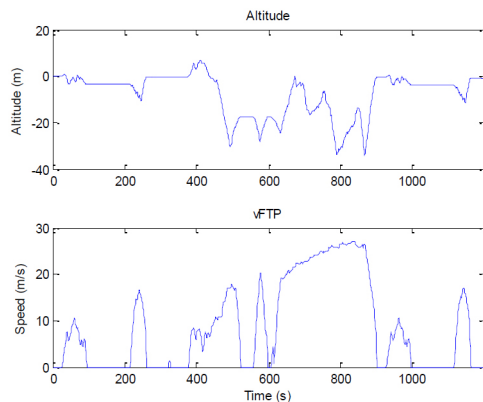


Figure 3. Vehicle FTP cycle as described in Andreae et al. [4]

The vehicle cycle allows calculation of a braking power for a given set of vehicle characteristics. The brake power was normalized by peak engine power, which is a reasonable approach because brake energy will scale with vehicle mass, which for commercial vehicles approximately scales with engine power.

Simulation was used to estimate total brake energy available for different class vehicles. The vehicle models from EPA's GEM model [5] are reasonable representations of commercial vehicles, and so these vehicles were used for the comparison. The de-normalized brake energy for each engine was found to match reasonably well with the simulated brake energy for each vehicle.

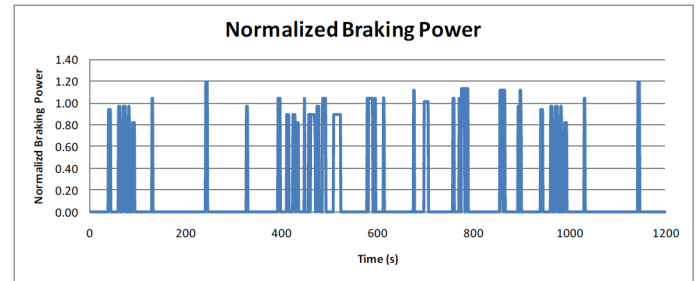


Figure 4. Normalized braking power based on the vehicle FTP cycle

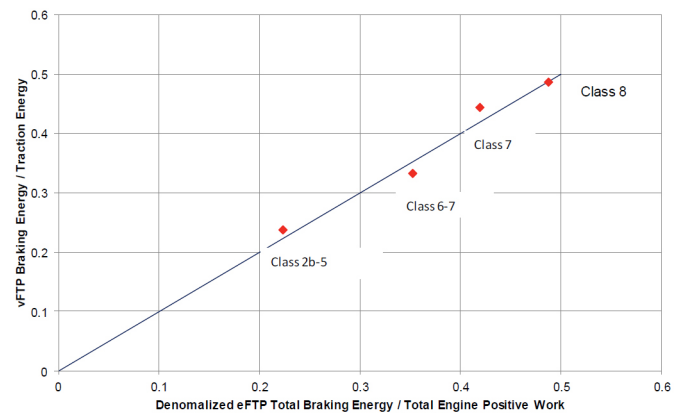


Figure 5. Plot showing simulated brake energy over the vehicle FTP compared to de-normalized brake energy based on Figure 4.

Once brake power was defined the definition of power was complete, and the powertrain cycle could be defined. As a starting point, the GEM class 8 vehicle was selected as a reference vehicle.

Table 1. Vehicle characteristics for the GEM class 8 vehicle

Engine Rated Power	kW	337
Accessory Load	kW	1.36
Rolling Resistance f		0.006
Aero Drag Cd		0.7
Frontal Area	m ²	9.8
Vehicle Mass	kg	30391
Tire Radius	m	0.4892
Transmission Efficiency		0.97
Differential & Driveshaft Efficiency		0.98
Air Density	kg/m ³	2.64