

Chassis Dynamometer as a Development Platform for Vehicle Hardware In-the-Loop “VHiL”

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ABSTRACT

This manuscript provides a review of different types and categorization of the chassis dynamometer systems. The review classifies the chassis dynamometers based on the configuration, type of rollers and the application type. Additionally the manuscript discusses several application examples of the chassis dynamometer including: performance and endurance mileage accumulation tests, fuel efficiency and exhaust emissions, noise, vibration and harshness testing (NVH). Different types of the vehicle attachment system in the dynamometer cell and its influences on the driving force characteristics and the vehicle acoustic signature is also discussed.

The text also highlights the impact of the use of the chassis dynamometer as a development platform and its impact on the development process. Examples of using chassis dynamometer as a development platform using Vehicle Hardware In-the-Loop (VHiL) approach including drivability assessment and transmission calibrations are presented. The importance of the utilization of the vehicle test bed for future implementation of the Vehicle Hardware In-the-Loop (VHiL) is discussed as well. Case study of model-based automotive system integration for the evaluation of integrating hybrid electric modules into an existing platform is discussed and initial results are presented.

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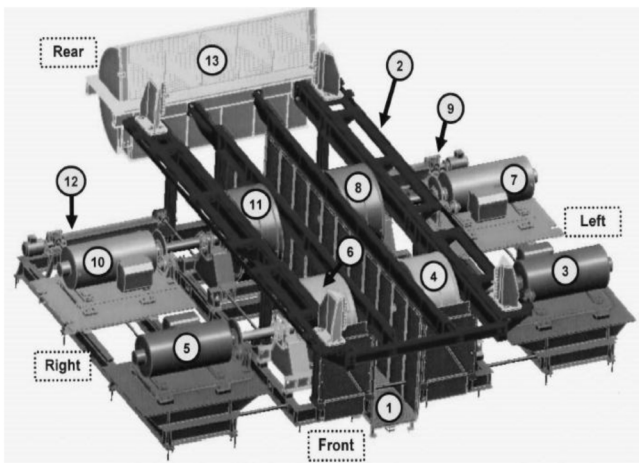
INTRODUCTION

Product development process at OEMs requires intensive testing phases for different powertrain components and the complete vehicle at the end of the process; such tests are carried out at various types of test beds built for product validation. However; product validation processes become more complex and time consuming with ever increasing number of vehicle variances. Hence new approaches become necessary. Chassis dynamometer is a key element in the development process, it allows repeatable tests to be carried out, in a controlled environment with access to the lab equipment's [1], however; chassis dynamometer is a good tool for simulating road load in much less expensive way in compare to road testing on a dedicated track where tests are subject to a weather condition problems. Nonetheless; today's advanced automotive technology implies comfortable, safe and energy efficient vehicle. This leads to a high demand on advanced automatic control devices, especially with highly cross linked controller that are placed for optimized functionality. Consequently, upgrading of classical chassis

dynamometer to a higher level of automation as development platform becomes important. Automation of chassis dynamometer is often limited to data acquisition and signal processing whereas the control of the testbed was left to the operator. Therefore; additional improvement of chassis dynamometer as a powerful “VHiL” becomes a necessity. Efforts were spent towards chassis dynamometer test automation. This includes making the test vehicle as an integrated part of the testbed in order to connect the test bed controller with the vehicle system and test equipment's. This adds additional benefit for the chassis dynamometer as vehicle being tested in a closed loop system. This paper presents the state of the art of using the chassis dynamometer as a development platform with a higher level of automation. Using the chassis dynamometer as a development platform for vehicle hardware in the loop (VHiL) is discussed. A case study of model-based automotive system integration for the evaluation of integrating hybrid electric modules into an existing platform is discussed and initial results are presented.

CHASSIS DYNAMOMETER

There are several lay outs of the chassis dynamometers. Although all have the same features in common, in any chassis dynamometer there is at least one roller (single axle) or more (double axel) that support the vehicle and allows the wheels of the vehicle to run during testing, as the tractive force of the tires of the vehicle transmitted to the rollers. There are means of absorbing this power from the wheels, the dynamometer measures and controls the speed and force of its rollers such that it acts as (infinite) rolling roads. Chassis dynamometer is used to simulate the road loads including rolling resistance, drag forces, the inertia of rotating parts of the vehicles' powertrain and gravitational forces due to road slope. [Figure 1](#) illustrates a model assembly view for 4WD chassis dynamometer [2].



1	Inspection walkway	8	Left rear roll
2	Main frame	9	Left rear wheelbase adjusting unit
3	Left front drive unit	10	Right rear drive unit
4	Left front roll	11	Right rear roll
5	Right front drive unit	12	Right rear wheelbase adjusting unit
6	Right front roll	13	Exhaust shutter for vehicle cooling
7	Left rear drive unit		

Figure 1. Model assembly view for 4WD chassis dynamometer [2]

Types of Chassis Dynamometers

Chassis dynamometers can be categorized either according to the type of the power absorption unit, prime movers, or the types of rollers, below are two types of chassis dynamometer depending on the type of rollers:

Inertia Dynamometers: Such type of dynamometers use a large roller with known mass and inertia, the wheels of the tested vehicle has to spin these rollers and the chassis dynamometer controllers then calculates power and torque applied based on the rollers dynamics.

Braked Dynamometers: This type of chassis dynamometers uses smaller rollers and provides a resistance on the rollers in order to absorb the power of the wheels in more efficient and controllable manner. Smaller drums are attached to some sort of variable resistance (such as eddy current, hydraulic retarders). The dynamometer controller measures the effort the vehicle is spending and calculates the corresponding power and torque at any point during the test. Braked dynamometers are categorized into two different types, whereas most are roller type, at which the tested vehicle wheels spins smaller roller that are attached to power absorber unit. Other type of dynamometers is hub-mount dynamometers. These are quite different in that the driven wheels of the test vehicle has to be removed where an adaptors are used to lock the wheel hubs to a control pods, the pods will support the vehicle in this case and there will be no need for strapping down the vehicle. Though it has the disadvantage of taking longer set up time, hub-mounted dynamometers has some advantages over the braked dynamometers in that they eliminate variability due to strapping down the test vehicle such as: tire pressure, wheel slippage, wheel alignment, noises ...etc.

Nonetheless; chassis dynamometers can be classified based on the position of the driving motor in according to the rollers of the chassis dynamometer. Such classification include center mounted chassis dynamometers (motor is positioned between the rollers of the dynamometer) which is considered to be the most common type and is mainly used for emission testing and mileage accumulation testing. Other type is chassis dynamometer with inline mounted motors with respect to the rollers; where the motors are mounted in line to one side of the rollers. Such type of dynamometers is used for noise, vibration and harshness testing (NVH). [Figure 2](#) illustrates two types of chassis dynamometers configuration (a) Center Mounted Chassis Dynamometer and (b) Inline Mounted NVH Chassis Dynamometer [3].



Figure 2. (a) Center Mounted Dynamometer, (b) Inline NVH Dynamometer [3].

Chassis dynamometers use different types of power absorption units as well as to power the prime movers (AC, DC electric motors). Several technical specifications are used

with chassis dynamometer including: Power (hp), Max. Speed (mph), Environmental conditions (anechoic chamber, environmental chamber), Test standards (steady state testing, sweep testing and transient testing), 2-WD, 4-WD, Single or Double rollers, Load control mode (road load simulation, speed control, tractive force control and acceleration control). However, chassis dynamometers can have one or two rollers per axle, single roller or twin rollers; [figure 3](#) illustrates cross section for single roller [\(a\)](#) and twin roller [\(b\)](#) [4].

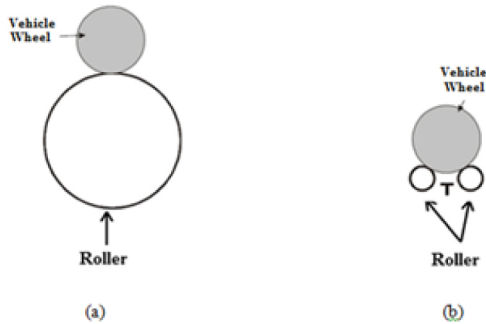


Figure 3. Chassis dynamometer:(a) Single roller. (b) Twin rollers [4]

Road Load Simulation

In order to simulate similar loads on the rollers of the chassis dynamometer as those on real road conditions, the road load forces have to be determined by executing a coast-down testing[5]. To allow the same balance of power to be applied to vehicle being tested on the rollers of the chassis dynamometer, a coast-down test has to be performed prior to positioning of the test vehicle on the rollers of dynamometer. Coast-down test is performed on the road (straight and flat) where the vehicle is allowed to coast down freely (gear is in neutral) without applying any braking from a high speed (i.e. 130 km/h). If there is no strong wind; the drag forces, wheel rolling resistance, and the internal losses due to friction of the rotating components will cause the vehicle to stop gradually. Recording the speed progression over time, the driving resistance can be then calculated as a function of the speed, the rate of change in vehicle speed is proportional to the total load force.

Vehicle in motion experience a set of forces referred to as (road loads), which determine the amount of required force at the driving wheels to propel the vehicle at any given speed and acceleration. [Figure 4](#) illustrates the forces acts on the vehicle while in motion [6]. These forces are tire rolling resistance ($F_{rolling}$), aerodynamic drag force (F_{drag}), the inclination or the grade of the road surface (F_{grade}) and the inertial forces of the rotating components of the vehicle ($F_{inertia}$), the summation of all of these terms forms the tractive effort ($F_{tractive}$) which the propulsion system has -at least- to overcome to keep the vehicle in motion as in [equation 1](#) [6].

$$F_{tractive} = F_{rolling} + F_{drag} + F_{grade} + F_{inertia} \quad 1$$

[Figure 4](#) illustrates a breakdown distribution of these road loads; where each term (rolling forces, drag forces, road gradient, and rotating inertia) from [equation 1](#) can be expressed as a function of vehicle speed and vehicle parameter as in [equation 2, 3, 4, and 5](#) respectively [6].

$$F_{rolling} = c_{rr0}mg + c_{rr1}mgV \quad 2$$

$$F_{drag} = \frac{1}{2} \rho C_D A_f V^2 \quad 3$$

$$F_{inertia} = m M_i \frac{dV}{dt} \quad 4$$

$$F_{grade} = mg \sin(\theta) \approx mg * grade \quad 5$$

Where; c_{rr0} : is static coefficient of rolling resistance (dimensionless), c_{rr1} : is dynamic coefficient of rolling resistance (dimensionless), m : vehicle mass (kg), g : gravity (m/s^2), V : velocity (m/s), ρ : density of air (kg/m^3), C_d : drag coefficient (dimensionless), A_f : frontal area of the test vehicle (m^2), M_i : inertia mass factor (dimensionless), dV/dt : vehicle acceleration (m/s^2), θ : road inclination.

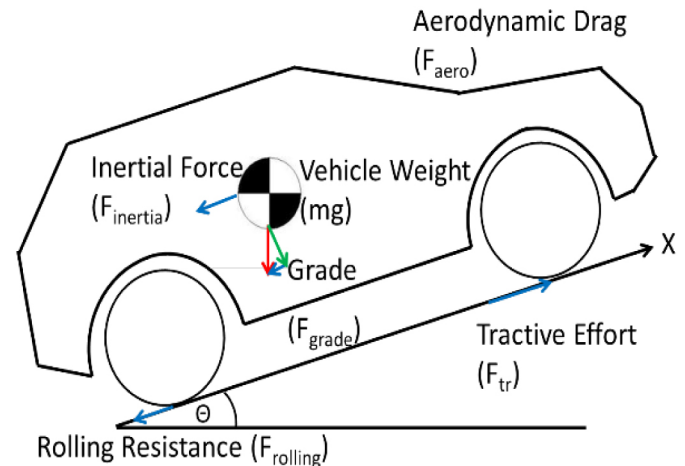


Figure 4. Road loads representation. [6]

On the other hand, different approach was adopted by Environmental Protection Agency (EPA), where the forced experienced by a vehicle is calculated based on a different set of parameters other than those explained earlier, dynamometer target coefficient captures the road load any vehicle may experience. These coefficients were determined using the coast-down testing technique. [Equation 6](#) shows

tractive force as a function of these target coefficients. These target coefficients are nothing but a curve fits with a terms proportional to exponential power of vehicle speed. These target coefficients (A, B, C) are unique for each vehicle under certain operating condition [6]. The last two terms ($mg\sin(\theta)$, $mM_i dv/dt$) are gravitational force due to road grade and the inertial tem.

$$F_{tr} = A + B*V + C*V^2 + mg\sin(\theta) + mM_i \frac{dV}{dt}$$

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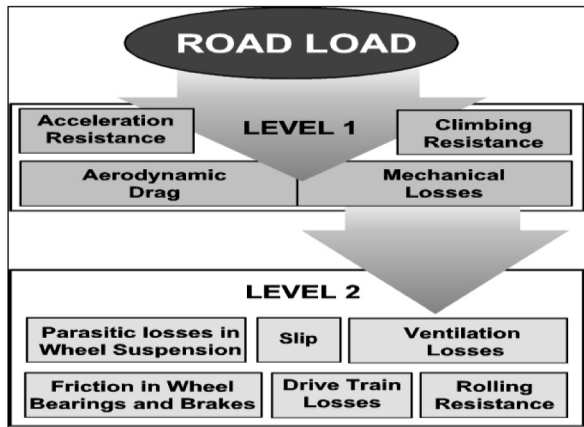


Figure 5. road loads with mechanical losses split into second level [7].

Despite the fact that road load representation in figure 4 is sufficient for roller test; still does not count for the mechanical and frictional losses due to brakes, wheel suspension and drive train losses. Mayer et al [7], analyzed the effect of these losses on the quality of the data measurements by splitting the mechanical losses into a second level of road loads as illustrated in figure 5.

Chassis Dynamometer Applications

The main objective of the chassis dynamometer is to simulate the road loads and evaluating the performance of a complete vehicle. Chassis dynamometers allow engineers to test an entire drive train of a vehicle under well controlled conditions, where sophisticated test procedures can be implemented. Tests in chassis dynamometer are less expensive than those implemented on the test track, and are not subject to limitations due to weather conditions. Several types of tests can be run in a chassis dynamometer; most of these tests fall into one of the following two test modes:

1. Dynamometer rollers driving the wheels (driven mode): in this types of tests the rollers of the dynamometer powered by electric motor act to drive the wheels of the vehicle.
2. Wheels driving the rollers of the dynamometer (absorption mode): in this case vehicle drive train developing

the power to run the wheels of the test vehicle and the rollers of the dynamometer resist the wheel rotation, in this case the energy (electrical energy) produced by the dynamometer has to be dissipated (it can be used for water heating, fed into power grid, ...etc.).

Chassis dynamometers are being used for various automotive measurements and performance applications including but not limited to: performance and endurance, mileage accumulation tests, functional and lifetime tests on vehicle (fuel system, cooling system, brake system, electric and electronic systems, air-conditioning system), electromagnetic compatibility tests, fuel efficiency and exhaust emissions tests, drivability assessment and drive train calibration, noise harshness and vibration testing [3]. However; a new versions of chassis dynamometers were produced for specific tasks such as dynamic roller chassis dynamometer for motor bikes. Next we will discuss some of the main application of the chassis dynamometer for automotive applications.

Fuel Efficiency & Exhaust Emissions: since 1970's chassis dynamometer have been used to characterize fuel economy and exhaust emissions for all types of passengers cars [8, 9], light and heavy duty vehicles, and recently for HEV and PHEV. R. Carlson et al examined the fuel consumption impact of changing driver characteristics on PHEV at Argonne's Advanced Powertrain Research Facility (APRF). Tests were conducted on 4WD chassis dynamometer for a custom-built test platform which is referred to as Modular Automotive Technology Testbed (MATT), created by Argonne testing advanced vehicle technology [10]. Bass et al [11], conducted chassis dynamometer tests using SAE Recommended Practice (J2711) on large buses equipped with an Allison EP Hybrid System. Dynamometer test results assisted specifying the impact of the average speed on fuel economy of HEV bus. Baker et al [12], investigated the effects of wheel slip on vehicle emissions and fuel economy using chassis dynamometer. Baker in his study manipulated some factors during the test including chassis dynamometer parameters (dynamometer rolling surface roughness and strap tension (tight and loose)). Sato et al [13] analyzed the behavior of 4WD on 4WD chassis dynamometer. Sato discussed the factors influence the accuracy of fuel economy tests were conducted on 4WD chassis dynamometer. It was found that most of vehicle losses are the tire loss and stabilizing the tire loss of the test vehicle is important for the test reproducibility. On the other hand, Watson et al discussed transferring chassis dynamometer test results into a real world driving conditions for predicting vehicle fuel economy and emissions [14].