

The Concept to Measure the Overall Car Performance

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Received: 25 January 2012 ; Accepted: 11 April 2012

Abstract

The overall car performance investigating on-road experiments is necessary for research and development in automotive engineering. Car acceleration capability is a final result depending on engine performance, transmission system design, suspension optimization, shape and dimension, aerodynamic, friction reduction technology, driving skill, and other factors. The purpose of this research is to present the concept to measure the overall car performance from acceleration capacity. We found that this concept is possible and convenient because we can collect digital input signals from an existing electronic control unit and transfer it to additional processor to analyze and display the final result in every mobile display, such as laptop, tablet, and smart phone. The method is cheaper and easier for installation and usage.

Keywords: car performance, acceleration, measurement

Introduction

The research and development in automotive engineering have been done for long time and are still ongoing as long as we need to take advantage from it. A number of previous research studies have focused on various topics, for example, conceptual development and shape design (1, 2), aerodynamic analysis (3, 4), engine performance improvement (5, 6), brake and suspensions optimization (7-10), and car utility system development (11, 12). There also have been a number of research studies on emissions and alternative fuels (13-15), cost management in product developing processes (16), and many others. Car performance can be defined by several criteria, such as speed acceleration capacity, brake and control capabilities, etc. For this research, we mainly focus on speed acceleration capability only. There are various implementations to increase the overall car performance, such as engine performance improvement, transmission and suspension system optimization, lubrication technology development, aerodynamic design, or driver course training, etc.

Engine performance developments involve increasing the engine outputs; power and torque, and decreasing the engine input; specific fuel consumption (17). The engine outputs depend on many operating parameters, such as air-fuel ratio, compression ratio, intake air temperature and pressure, load and engine speed, ignition timing (for spark ignition engine), injection parameter and swirling design (for compression ignition engine) (18). An engine performance map is normally used to describe the effect of operating parameters related to the engine outputs (19). However, the simple way to present correlation between engine power, torque and operating speed is normally shown by engine performance curve (sometimes the specific fuel consumption is also shown) (20). Although it is very useful, the engine performance curve is not usually shown in car specification. Commercially, the engine specification is detailed to consumers only the maximum power, maximum torque, and engine speed at these points. In automotive engineering analysis, there are two ways to get this curve; first, measured by dynamometer, or second, simulated by calculation (21-23).

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Car performance is a final result depending on engine outputs, transmission selection, tire size, aerodynamic effect, rolling friction, and other factors. Twenty percentages (20%) of indicated power from combustion is sent through transmission and tire system to drive the car forward or so-called driving force, while air resistance and rolling resistance against car motion in the opposite direction (24). So, the car is driven forward with one acceleration value by the net force following the Newton's second law of motion. Currently, car performance is measured with many types of dynamometer in a laboratory experiment, and it is costly.

Our previous research studies have focused on an engine performance development by using offset piston to improve the engine power (5), and a combined turbocharger set to increase a thermal efficiency (6), and now we are in the process of installing a dynamometer for our experiment. We also have an idea to develop a method for measuring the overall car performance for on-road experiment (25-27).

The main objective of this research is to develop and present a concept to measure the overall car performance for the on-road real-time experiment and describe our conceptual framework for future implementation. The remaining of the paper is organized as follows; first, we explain the information of a dynamometer; second, we present the theoretical car performance calculation method; third, the simulation results are shown; fourth, we present the conceptual implementation framework; and finally, this article concludes with the discussion.

Dynamometer

The laboratory experimental tool to measure the output performance of an engine or a vehicle is a dynamometer. It can be classified into various types depending on the criteria used for consideration. By installation, we separate dynamometers into two types; first, the engine dynamometer that directly connects an engine to a dynamometer; and second, the chassis dynamometer that can experiment by driving a car on the roller without taking the engine off. Both of them are used to measure and present the output power and torque of the engine

at an operating speed (20). Moreover, we can classify dynamometers by a power transfer method and also split it into two types; the absorption dynamometer, and the transmission dynamometer (28). For the absorption type, dynamometers measure and absorb the engine output power to which they are coupled. The power absorbed is usually dissipated as heat by some means, such as prony brake, rope brake, mechanic or hydraulic friction, eddy-current dynamometer. For the transmission type, the power is transmitted to the load coupled to the engine after it is indicated on some types of scale. These are also called torque-meter. (28)

Inertia dynamometer is also included in the transmission type. The rolling mass (called drum) is designed to have enough inertia, directly connected to the engine, and loaded of the engine. Then, the engine is run and accelerated from low to maximum speed and measured the angular acceleration and angular velocity of the drum. Angular acceleration results are analyzed with the inertia of drum to calculate the engine torque. Angular velocity results are simply converted to the engine speed. Engine power is calculated from these data and the engine performance curve is presented. The inertia dynamometer is applied to be the chassis dynamometer as well by using the similar method. The concept of measuring the engine torque by acceleration data is applied in this research because it is convenient to install and measure it in a car. However, in the measuring process, the car is driven in maximum acceleration to let the engine work in full load. Therefore, to avoid an accident, the experiment should be done in the safety area such as test drive area, or raceway only. For future application, we will apply this research to design the equipment and install it in our race car called Formula SAE and measure the overall car performance.

Car Performance

To perform the car performance curve, we have to know the engine torque data at every operating speed. These data are informed by the engine performance curve. But if we do not have the engine curve, calculated simulation is needed (21, 23). We can calculate the output torque and power from the engine, and then simulate the

engine performance curve from the details of car specification; maximum power, maximum torque, and engine speed at these points as shown in equation 1. (22)

$$T_i = 30 \frac{P_{\max}}{\pi N_i} \left(A \left(\frac{N_i}{N_{P_{\max}}} \right) + B \left(\frac{N_i}{N_{P_{\max}}} \right)^2 - C \left(\frac{N_i}{N_{P_{\max}}} \right)^3 \right)$$

$$A = \frac{DE(2-E)-1}{E(2-E)-1}, B = \frac{1-A}{1-E/2},$$

$$C = \frac{BE}{2}, D = \frac{T_{\max}}{T_{P_{\max}}}, E = \frac{N_{P_{\max}}}{N_{T_{\max}}} \quad (1)$$

Then, we use the engine torque and engine speed data to calculate with the transmission system and tire data to find the driving force and car velocity as shown in equation 2. (22)

$$F_{ij} = \eta \frac{T_i i_j}{r}, V_{ij} = 0.12 \pi r \frac{N_i}{i_j} \quad (2)$$

Driving forces at each speed have to be reduced by resistances that is summarized from air resistance and rolling resistance. Air resistance is related to car square of velocity value, cross-section area, and drag coefficient of the car. Rolling resistance depends on the weight and rolling coefficient. The total resistance can be calculated as shown in equation 3. (22)

$$R_{ij} = k_a A V_{ij}^2 + k_r W \quad (3)$$

After reducing the driving force by total resistance, we have the net force data. Car acceleration performance can be calculated from the net force and equivalence mass that is depended on gear position. The car acceleration can be calculated as shown in equation 4. (22)

$$A_{ij} = \frac{F_{ij} - R_{ij}}{m_j}$$

$$m_j = (1.05 + 0.07 i_j^2) m \quad (4)$$

Finally, the overall car performance curve is represented by accelerate capability curve that presented correlation between accelerate performance related to the engine speed or car velocity.

Simulation Results and Discussions

For a better understanding about the concept to measure the overall car performance by the accelerate capability, we presented a case study simulated from specification data of Ford car; model Fiesta 5Dr 1.4L Style AT as shown in table 1 (29).

Table 1 Car specification data (29)

Dimensions & Weight	
Overall Width (mm.)	1,722
Overall Height (mm.)	1,496
Weight (kg.)	1,127
Engine	
Maximum Power (kW/rpm)	70/5,750
Maximum Torque (Nm/rpm)	126/4,200
Transmission	
Gear Ratio 1st Gear	2.816
Gear Ratio 2nd Gear	1.498
Gear Ratio 3rd Gear	1.000
Gear Ratio 4th Gear	0.726
Final Gear Ratio	4.203
Tire Size	185/55 R15

Base on engine specification, we calculated output torque at engine speed from 600 to 7,200 rpm and set the speed range as 600 rpm. Transmission efficiency was assumed as 90% in calculating process. Simulated engine performance curve was shown in Figure 1.

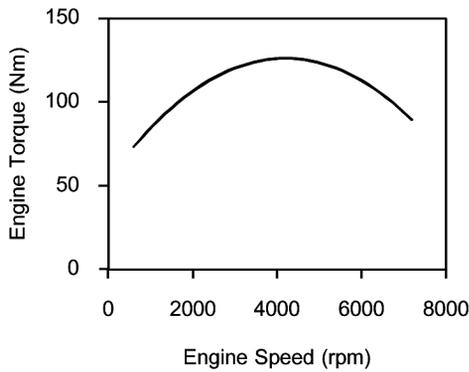


Figure 1 Simulated engine performance curve

For the engine speed lower than 4,200 rpm, the engine output torque correlates with engine speed positively. The maximum torque is equal to 126 Nm at 4,200 rpm as shown in specification and decreases when the engine speed is over 4,200 rpm. However, this engine performance curve is not the exact data because it is calculated by mathematical simulation. It is always better if we have the information from the real performance curve.

Then, we used engine torque and operating speed results, with the tire radius of 292.25 mm. to calculate the driving force and car velocity. Total resistance was also analyzed by using assumption parameter by the following values (22); 0.80 for shape factor, 0.023 for air resistance coefficient, and 0.015 for rolling resistance coefficient. After simulating, we performed the car accelerate capability performance as contour plot between car acceleration (m/s²) and engine speed (rpm) at each gear position as shown in Figure 2. From the figure, the areas under the curve line for each gear position were acceleration that the car can move at each gear position and not over the limit lines.

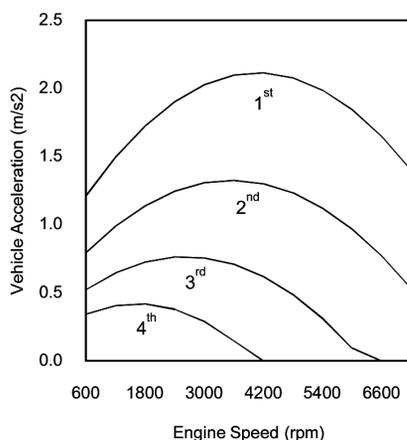


Figure 2 Simulated car performance curve

The overall car performance measured from acceleration capability is a final result from overall parameters, such as engine output, transmission ratio, transmission efficiency, tire size, shape and car dimension, friction, electronic control unit, and driver skill. The concept to measure car performance from acceleration data is also feasible for an on-road experiment. Since currently, most cars have an electronic control unit (ECU), this concept is convenient to track digital input signals such as engine speed and car velocity to additional processor to analyze and display the result. Moreover, we can transfer raw data to process and display object on mobile equipment, such as a notebook PC, tablet PC, or smart phone.

For future research, we will apply this concept to design and develop an equipment to collect digital input signals from existing ECU, to process the data, and to display the result following the conceptual implementation framework as shown in Figure 3.

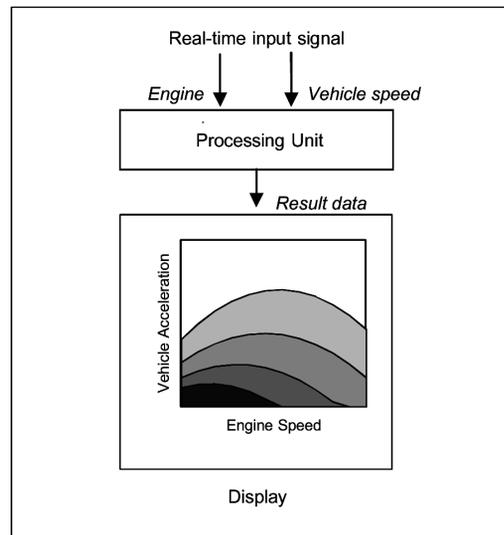


Figure 3 Conceptual implementation framework

Conclusion

The overall car performance depends on various operating factors, such as the engine performance, transmission design, suspension optimization, car dimension and shape design, aerodynamic, friction reduction technology, and driver skill. An on-road experiment is necessary for a designer, driver, tuner, developer, and researcher to investigate the final result (25-27). Overall, car accelerate

performance speeds up a car within the considering time. Thus, the concept to measure the overall car performance from acceleration capability is possible and convenient because we can collect digital input signals from an existing electronic control unit and transfer it to an additional processor for analyzing and displaying the final result in every mobile display, such as laptop, tablet, and smart phone. This concept is also cost effective and easier for installation and usage.

Acknowledgement

We would like to thank the reviewer and the editor of STISWB IV for their helpful comment on this article. We also would like to thank the Department of Mechanical Engineering, Faculty of Engineering and Industrial Technology, Silpakorn University, Thailand for providing research facilities.

Appendix

Table A Calculation parameters

Variable	Description
A	Cross-section area (m^2)
A_{ij}	Car acceleration (m/s^2)
F_{ij}	Driving force (N)
i_j	Transmission ratio
k_a	Air resistance coefficient
k_r	Rolling resistance coefficient
m_j	Car equivalence mass (kg)
m	Car mass (kg)
N_i	Engine speed (rpm)
$N_{P_{max}}$	Speed at max. power (rpm)
$N_{T_{max}}$	Speed at max. torque (rpm)
P_{max}	Max. power (kW)
r	Tire radius (m)
R_{ij}	Total resistance (N)
T_i	Engine torque (Nm)
T_{max}	Max. torque (Nm)
$T_{P_{max}}$	Torque at max. power (Nm)
V_{ij}	Car velocity (kph)
W	Car weight (N)
η_T	Transmission efficiency

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