Analysis on Relationship of Estimated VSP from Coast-down Test and Fuel Consumption

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1.Introduction

Recently, implementation of road traffic counter measure to reduce carbon dioxide (CO_2) emitted from cars is needed. In order to evaluate countermeasure, the method to estimate fuel consumption and CO_2 emissions based on average speed has been applied. But, in this method, it is not possible to estimate fuel consumption with high accuracy for hybrid car (HEV) to vary greatly depending on running condition. On the other hand, Vehicle Specific Power (VSP) has a possibility to estimate it more precisely than the existing method. VSP was developed as an index to express running situation of vehicle in the United States. The parameter of VSP should be caribulated when VSP is applied in Japan. Therefore, the objective of this study is to estimate parameter of VSP by carrying out coast-down test. Fuel consumption characteristics of HEV was analyzed using the VSP.

2. Summary of Existing Studies

Several studies have tried to develop method and estimated the fuel consumption of cars. For example, Matsuki compared the relationship between fuel consumption and driving characterstic in the view point. The difference of inter-vehicle headway distance. It was carried out using a fuel consumption measuring device. Also, Hyodo et al., acquires the data by three experimental method using GPS, examined electricity consumption estimation formula based on the car energy consumption basic formula because it has become a challenge to estimate the mileage of the electric vehicle in recent years. In the existing research, there is no existing analysis on VSP for HEV. In order to verify the characteristic of fuel consumption, the comparison analysis between VSP and fuel consumption of HEV is conducted in this study.

3. Methodology

(1) Outline of VSP

The VSP is an index to define running resistances, rolling resistance and air resistance by using a vehicle speed, acceleration, road gradient data. The VSP is also used as one of model equation to evaluate exhaust gas of cars. In this study, the VSP is employed on the basis of the MOVES2010 model. The equation to estimate of VSP formulated as follow.

$$VSP = (A/M)\cdot v + (B/M)\cdot v^2 + (C/M)\cdot v^3 + (a + g\cdot \sin\theta)\cdot v \quad (1)$$

where A, B, and C are the road load coefficients in units of [kilowatt second]/[meter], [kilowatt second^2]/[meter^2], and [kilowatt second^3]/[meter^3], respectively. The detenominator term, m is the fixed mass factor for the sourcetype (1.4788 metric tons), g is the acceleration due to gravity (9.8 meter/second^2), v is the vehicle speed in meter/second, a is the vehicle acceleration in meter/second^2, and sin q is the (fractional) road grade.
After VSP estimation, the VSP value is classified into 23 mode. (Fig. 1)

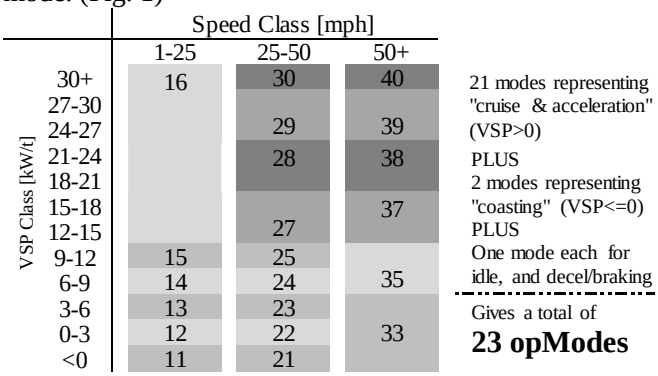

Fig. 1 VSP classes and operating mode

(2) Outline of Experiment

The Coast-down test was conducted for the estimation of parameters related to the running resistance in December 7, 2014. Experimental subjects car was PRIUS PHV. It equipped with fuel consumption measuring device and the GPS logger. Specifically, after the warm-up, vehicle speed accelerates up to 60 mph on a flat road. After then, the gear was changed into neutral and its speed naturally decreased until 20 mph. The distance between 60 and 20 mph was mesured. However, it was impossible to measure the distance at one time running on short test track. Therefore, the test track was divided by two points and the running speed at each point was measured by a speed gun. Measurement was carried out five times. The parameter was estimated by using of the missing values fewest data. Fig. 2 shows the experimental schematic diagram.

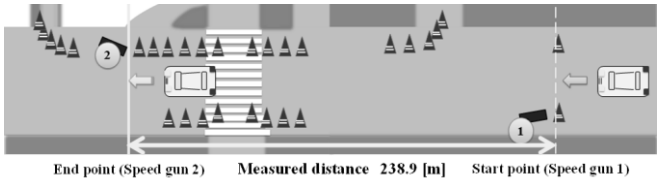

Fig. 2 Experimental schematic diagram

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(3) Result of Experriment

Table 1 shows the speed of the start point and end point was measured. The parameter was estimated by using first data because first data has higher reliability than the other data in terms of difference of first and second speed.

Table 1 Speed of start point and end point

[km/h]

	1		2		3		4		5	
	gun 1	gun 2	gun 1	gun 2	gun 1	gun 2	gun 1	gun 2	gun 1	gun 2
1st	100.0	90.5	101.8	86.4	101.1	89.7	104.8	89.6	100.2	90.2
2nd	90.5	76.2	85.4	71.9	94.8	76.8	87.0	70.6	89.1	79.8
3rd	75.3	62.4	71.4	57.2	87.3	74.5	71.9	59.4	×	×
4th	×	46.5	59.0	47.4	82.0	×	60.4	48.6	78.8	69.7
5th	63.0	52.9	46.1	35.4	74.2	60.7	50.1	38.3	69.7	59.2
6th	53.5	42.2	34.4	23.2	58.3	49.0	37.7	26.9	56.2	48.8
7th	41.5	30.4			51.0	39.9			48.3	38.3
8th					40.8	31.2			40.9	30.4

… Re-run because it was the unmeasurable

Parameter estimated were used the following formula.

$$A = \frac{A_t PF}{50} * \left(GTRL_{@\,50mph}\right) \quad (2)$$

$$B = \frac{B_t PF}{2{,}500} * \left(GTRL_{@\,50mph}\right) \quad (3)$$

$$C = \frac{C_t PF}{125{,}000} * \left(GTRL_{@\,50mph}\right) \quad (4)$$

The default values from the EPA report was applied (AtPF = 0.65, BtPF = 0.48, and CtPF = -0.13) and $GTRL_{@50mph}$ was estimated using the following formula.

$$GTRL_{@\,50mph} = \frac{\left(0.5 * ETW / 32.2\right) * \left(V_1^2 - V_2^2\right)}{550 * ET} \quad (5)$$

where ETW is equivalent test weight in pounds, V_1 is initial velocity in feet/second, V_2 is final velocity in feet/second, ET is elapsed time for the vehicle on the road to coast-down from 55 to 45 mph.

The estimated a result, it was A = 0.596373 [kw-s/m], B = 0.008806 [kw-s^2/m^2], and C = -0.000048 [kw-s^3/m^3].

4. Analysis of VSP and fuel consumption

The VSP of free running data which was calculated on May 17, 2014., was estimated by using the parameter. It was classified into the operating modes of fig. 1. The average value of each mode was calculated to verify the characteristics of HEV fuel consumption.

The fuel consumption collected originality 50 Hz was aggregated into 1 second and 5 seconds. That is why the possibility of aggregation for same interval of GPS is verified in terms of accuracy. The aggregated fuel consumption is compared with the VSP with same aggregation. The graph on the relationship of the VSP and fuel consumption of each aggregation interval is shown in fig.3 and fig. 4.

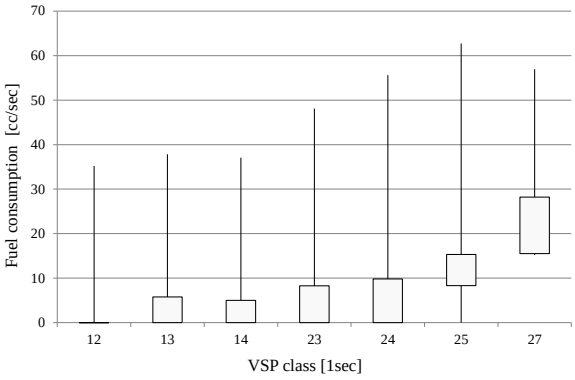

Fig. 3 VSP and fuel consumption relationship (1sec)

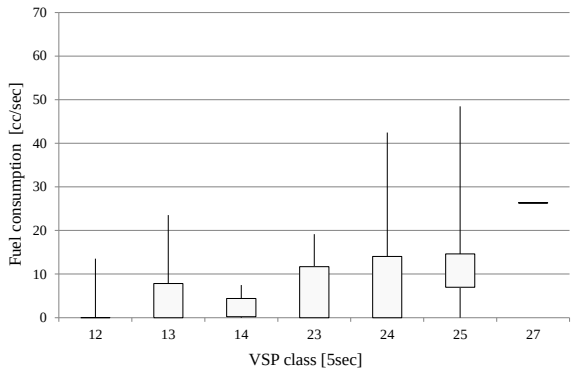

Fig. 4 VSP and fuel consumption relationship (5sec)

From the results, the average value is significantly different in aggregation of 1 second intervals and 5 seconds intervals. The accuracy of 5 seconds interval data is lower than 1 second interval data. Therefore, the acquisition interval of the data needs to be lower than 1Hz. There was low incremental trend of fuel consumption on the low speed operating mode. However, the incremental trend of fuel consumption was found to be increased in proportional to the speed of vehicle in the high speed mode. It was clarified that the relationship of VSP and fuel consumption has clearly trend to increase.

5. Conclusion

This study estimated the parameters related to the running resistance by the coast-down test. In addition, the VSP was estimated from the free running data aggregated 1 second and 5 seconds. It was concluded that the interval of aggregation should be lower than 1 second (1Hz) due to keep accutacy..

Hereafter, it is necessary to perform experiments using accurate GPS than this study. Also, it is necessary to estimate the CO_2 emission reduction in consideration of the fuel consumption from HEV.

References

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