

# Influence of the Driver Style difference in the Acceleration Process on the Energy Consumption of the EV Bus

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**KEYWORD:** Energy consumption; Acceleration process ;Driver style

**ABSTRACT:** The relationship between the difference of the driver behavior and energy consumption in the same bus line was studied through analyzing the acceleration process of the driving cycles in order to solve the problem that the practical benefits in endurance mileage of the electric buses differed a lot. It shows that 47% of the energy was consumed in the process of out station and the difference reached 28.9% between the drivers. The essential reason of the difference was the deviation of the motor operating path in the efficiency plane which was the result of accelerator pedal used in different way. The end speed of acceleration and the distribution of the accelerator pedal was useful to express the driver style. An effective management to the motor operating path in the out station process is very helpful to the improvement of the whole energy consumption besides the minimization of the acceleration dispersion.

## 1.Introduction

The research of decreasing energy consumption and extension of the driving range is a key problem to the development of the pure electric vehicle(EV). However, due to inappropriate driver behaviors the practical endurance mileage of the electric buses are significantly reduced.

Numerous studies have shown that driving style (DS) has important implications on vehicle fuel consumption. Gonder conducted experiments on a light-duty vehicle and found that different DS can generate difference of approximately 30% in fuel consumption in the urban driving cycle. The difference can reach 20% in the high-speed way driving cycle. They also believe that by changing DS, aggressive drivers can reduce fuel consumption by 20%, whereas mild drivers can decrease consumption by 5–10%<sup>[1]</sup>. Sivak and Schoettle discovered through an investigation that among the fuel-saving technologies of light-duty vehicles through which drivers can make strategic decisions, the method of changing DS generates the best fuel-saving result<sup>[2]</sup>. Professor Chris Bingham found that the net energy consumed difference can reach 32% between drivers even they drove the same test EV car to finish the same driving cycles without any additional driving request. It showed that the management of driver behavior could provide the most significant energy benefits in all technical means<sup>[3-5]</sup>. The dynamics in real world driving was much more than the standard ones such as NEDC. During real world driving, the change rate of the accelerator pedal was more complicate which is the reflection of the driver operation patterns. The conclusion pointed out that it is better to improve the economy and the battery life by changing the pedal gently<sup>[6]</sup>. The similar view can be found in<sup>[7-10]</sup>.

It has been proved that the energy consumption was greatly affected by the driver behaviors. This paper was focused on the relationship between the difference of the driver behavior and the energy consumption of the acceleration process under the same bus road condition.

## 2.Data acquisition

There were 26 bus stations and 44 crosses of the No.600 EV bus in Tianjin as the research object which means frequent stop-go. The bus line was shown in Fig.1.



Figure 1. The No.600 bus line

The longest distance between two adjacent stations was 982m while the shortest one was only 65m and 200m was the average value including crosses. The traffic condition could be divided into two parts based on the time consumed of one driving cycle: smooth traffic and the opposite such as the rush hour in the morning per working day. The selected driving fragment of the driving cycles should reflect the internal driving trend of the driver which means the driver could operate the bus as his will without any other limits. By comprehensive consideration, the principle of data sample selection was shown as Tab.1.

Table.1 Principle of data selection

Parameter	Value
Stations distance	>300 meters
Consuming time	<3400 seconds
Date	working day
Time zone	10:00h~11:30h; 20:00h~22:30h

Five drivers named A to E were selected as the research object who had driven the same EV bus over 2 years under the same bus line and Totally over 100,000 km driving cycles data was acquired through vehicle data acquisition system.

### 3. Ds variation in acceleration process

#### 3.1 End speed of acceleration

The bus out operation was the typical acceleration operation besides important driving fragment of the driver behavior. A whole bus out process was defined by the speed curve from the init value to the end of speed( $V_{end}$ ) which the init value was usually set at 0 km/h. Thus, the energy consumption and the information of the driver behavior of the bus out process was directly influenced by the  $V_{end}$  which means the end of the bus out process. The  $V_{end}$  depends on two aspects, one is the traffic condition of the bus line, and the other has relationship with the driver internal speed respect which is an important parameter in the evaluation index of the DS.

It was shown in Fig.2 to compare the energy consumed and the  $V_{end}$  for all the research drivers in the bus out process at the same bus station. The higher the  $V_{end}$  was, the higher the energy was consumed and the more energy variation was between all the drivers. More 32.7% energy was needed to operate the bus to reach 36km/h  $V_{end}$  for the driver E compared to the driver C. The driver C has the best bus out driving behavior.

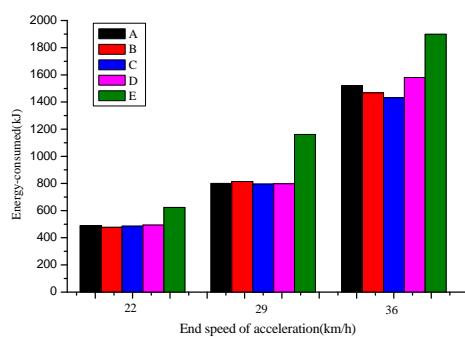


Figure 2. Energy-consumed in different drivers

More details can be obtained in Fig.3. The energy consumption differed a lot when the bus reached the same  $V_{end}$  between all the research objects. When the  $V_{end}$  was smaller than 25km/h, all the five slope of curves almost were equal. It shows that all the drivers operated the bus under similar acceleration strategy and the energy variation was pretty small. When the  $V_{end}$  became higher which means good traffic condition, the energy difference became more significant since the DS variation. Different acceleration strategy was realised by the drivers even for the same speed respect. It was shown that the whole acceleration process can be divided into two parts: low speed zone and

high speed zone. The turning point happened in the speed zone (25,30) km/h. After the turning point, the slope of curve became much sharper which means more energy was consumed when the same unit vehicle speed was reached. It is feasible to minimize the energy consumption reaching the  $V_{end}$  by adjusting the bus out acceleration strategy to optimize the slope of curve .

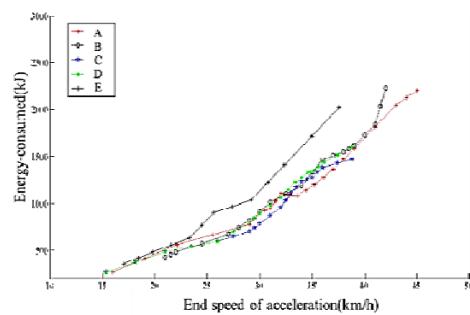


Figure 3. Energy consumption under different bus out  $V_{end}$

### 3.2 Bus out process distance

The relationship between the bus out distance with the energy consumption was shown in Fig .4. It can be found that the longer distance the bus out process took,the less energy was consumed for the unit distance.Because when the bus runs at lower speed, the motor efficience is much worse which means energy waste. As the bus speed clumbing up,the motor efficience went into high value zone.The bus out energy consumption trends to stabilization after 138m bus out distance under driver A,B,C's operation while driver E wasted maximum energy as similar performance shown in Fig.2.

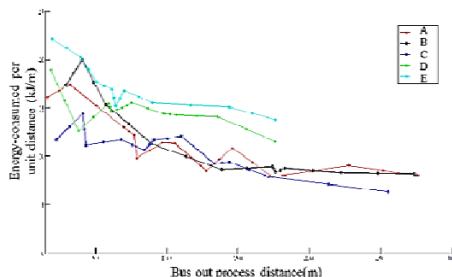


Figure 4. Bus out process distance

### 3.3 Distribution of the accelerator pedal

The bus out process is a continuous acceleration driving cycle fragment with the occupation of the accelerator pedal and no gearshift operation since the EV bus configuration. The working path of the drive motor was decided by the usage of the accelerator pedal depending on the DS which would cause the variation of the motor efficience. The distribution of the accelerator pedal was shown in Fig.5.

The best driver C trends to use soft pedal to finish the acceleration process with only 24.17% deep pedal ratio. On the contrast, driver D and E are likely to operate the bus under high acceleration speed. The accelerator pedal was much more deeply used under driver E's operation with 73.38% distribution belonging to (80%,100%). The more the accelerator was used deeply, the worse the energy performance was. The conclusion was consistent with the analysis result aboved.

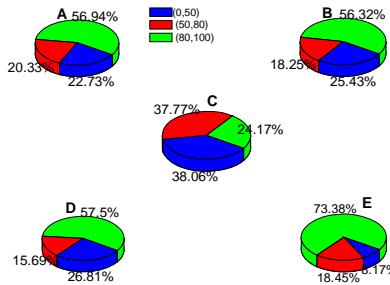


Figure 5. Distribution of the accelerator pedal

### 3.4 Bus out time-consuming

The bus out process takes up a great proportion in the whole bus driving cycle since 26 bus station and 44 crosses. The average bus out time-consuming of one cycle was listed in Tab.2 besides other parameters mentioned above. It can be found that the least time in one driving cycle was consumed to finish the bus out process by driver C since the time ratio was only 16.6%. It can be concluded that the  $V_{end}$  of driver C is smaller than others and did not trend to drive the bus under high speed which resulted in less bus out energy-consumed and drive cycle energy-consumed compared to other drivers' performance. On the contrary, driver E took the least time and the shortest bus out distance to finish the acceleration operation with the worst energy performance. It can be speculated that the driver E tends to operate the bus under high acceleration speed to reach the  $V_{end}$  which usually would make extra energy waste.

Table 2. The bus out parameters list

Serial	Bus out time-consuming (s)	Bus out time ratio (%)	Bus out process distance (m)	Bus out distance ratio (%)	Bus out energy consumed (kJ)	Whole energy consumed (kJ)	Bus out energy ratio (%)
A	740.9	18.6%	4403.7	26.4%	43228.6	85710.3	50.4%
B	719.4	22.3%	4764.0	28.5%	42676.9	82022.2	52.0%
C	767.7	16.6%	3916.8	23.5%	37084.6	78649.3	47.2%
D	611.5	18.2%	2948.5	17.7%	44521.5	89414.1	49.8%
E	615.6	22.7%	2930.2	17.5%	47792.4	94970.1	50.3%

It was worthy for more attention that the overall bus out energy ratio was almost close to 50% with the 28.9% maximum deviation of the bus out energy-consumed between all the drivers. It is an important means and measure to improve the EV bus energy performance based on bus out energy management.

## 4. Summary

The driver behavior parameters in the bus out process were discussed in this paper in order to find out the reason for the energy variation between different drivers. The end speed of acceleration is an important parameter of the DS. The energy-consumed difference of the bus out process can reach 28.9% since the variation of the DS. It is found that the energy-consumed difference was caused by the end speed of acceleration besides the distribution of the accelerator pedal which finally determined the working path of the drive motor in the efficiency plane. It is workable to improve the EV bus energy performance through the bus out energy management since its 47% considerable proportion.

## 5. Acknowledgments

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