Examination of PN Emissions of a Hybrid City Bus under Real World Urban Driving Conditions

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Particle emissions from city busses are especially high because of their frequent “stop-and-go” operations and corresponding transients of their diesel engines. It is well known from the literature that while a diesel engine accelerates rapidly from idling to full power, particle formation also accelerates rapidly because of turbocharger lag and combustion instabilities. In this sense hybridization of the city busses, beside many other advantages, also one of the best alternative approaches to minimize particle formation at its source. Since the secondary power source (battery or ultra-capacitor) of a hybrid city bus may provide most of the power need during rapid acceleration of the bus, the internal combustion (IC) engine may accelerate smoothly from idling to full power. Smooth acceleration of the IC engine significantly minimizes turbocharger lag and improve turbulent mixing and combustion. As a result particle formation can be minimized at its source. Therefore, hybridization of city busses may help to comply with the strict Particle Number (PN) regulations taking place over the next years.

Figure 1 and 2 compare the city bus accelerations without and with the secondary power assistance in terms of city bus traction power, engine power, and PN emissions. In these figures, speed for the first accelerations rise up to 55 km/h but the following accelerations are limited with a speed of 20 km/h for better simulation of urban driving conditions. As can be seen from Figure 1, if there is no power assistance from the secondary power source (ultra capacitor), the bus acceleration from 0 to 20 km/h speed corresponds to an engine transient from idle to maximum power and the lambda from about 5.3 to 1.6. At this condition, PN emissions sharply increase from about $1.0 \times 10^6$ to almost $8.0 \times 10^6$/cm$^3$. Once the engine power becomes steady at the maximum, the lambda increases to 1.9 and PN emissions reduces to as low as $1.0 \times 10^6$/cm$^3$ again.

But, when there is power assistance from the secondary power source as shown in Figure 2, while the bus accelerates from 0 to 20 km/h speed, PN emissions remain well below that of the Figure 1. PN emission is little above $4.0 \times 10^6$/cm$^3$ only in the acceleration that corresponds to 450$^{th}$ seconds. In the following accelerations PN emissions remain below $4.0 \times 10^6$/cm$^3$. This corresponds to 50% reduction of the peak PN emissions at its source.
Figure 1. Effects of city bus acceleration on PN emissions without the Secondary Power Source Assistance.

Figure 2. Effects of city bus acceleration on PN emissions with the Secondary Power Source Assistance
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Literature Cited


Introduction

Particle emissions from city buses are especially high because of their frequent “stop-and-go” operations and corresponding transients of their diesel engines.

It is well known from the literature that while a diesel engine accelerates rapidly from no power to full power, particle formation also accelerates rapidly because of turbo-charger lag and combustion instabilities. In this sense hybridization of the city buses, beside many other advantages, also one of the best alternative approaches to minimize particle formation at its source.

Since the secondary power source (battery or ultra-capacitor) of a hybrid city bus may provide most of the power need during rapid acceleration of the bus, the internal combustion (IC) engine may accelerate smoothly from no power to full power.

Smooth acceleration of internal combustion engine significantly minimizes turbocharger lag and hence particle formation at its source. Therefore, hybridization of city buses may help to comply with the strict Particle Number (PN) regulations taking place over the next years.

In this work, PN emissions from a hybrid city bus were examined under real world urban driving conditions. Effects of “stop-and-go” operation of the bus on PN emissions, including size distributions, were examined in detail.

Test vehicle;

TEMSA Avenue Hybrid City Bus; 12 m long, 15 tons loaded weight
Engine: Cummins ISB6.7 Euro 5, 250 HP@2500 rpm
Hybrid system: SIEMENS ELFA with ultra-capacitors

Data sampling;

SEMTECH DS for gaseous emissions and engine operating parameters
Rotating Disc Thromboidl System from Matter Engineering
TSI 3790 for PN measurement
TSI 3090 EEPS for Particle size distribution

Results;

Figure 1 indicates speed-distance profile of “Karahan-Go” route. This is a typical route for Sakarya municipality buses. As can be seen from the figure, “stop-and-go” operations of the bus are very frequent on this route.

Figure 2 indicates a typical acceleration of the bus from zero to 70 km/h speed together with corresponding engine operating parameters and PN emissions. In this condition, while the excess air ratio (lambda) decreases immediately from approximately 5.0 to 1.7, engine speed and power start to rise up. Turbo-charger lag can be reason for such sharp decrease in lambda. During this period, turbulent engine combustion is highly instable and PN emissions rise up immediately to the maximum. Once engine speed and power become stable at the maximum, the lambda rises up to 2.0 and PN emissions decrease sharply. Diesel engines are very efficient power source to deliver high power demands of heavy duty vehicles, but it comes together with PN emissions. Engine transients from zero to higher powers are the main reason for very high PN emissions. As can be seen from the Figure, during this period while the engine delivers such a high power for this acceleration, PN emissions rise up to approximately 7.00E+6 #/cm³ of exhaust gas.

However, hybridization of city buses with a secondary power source, which can be an ultra-capacitor or a battery, can provide significant advantages in terms of reducing PN emissions at its source. Since the secondary power source may provide most of the power demands during the accelerations of the bus, engine transients from zero to higher powers can be very smooth with better mixing and combustion process.

Figure 3 and 4 indicate a comparison for the city bus accelerations without and with the secondary power assistance in terms of city bus traction power, engine power, and PN emissions. As can be seen from the figures, if there is no power assistance from the secondary power source (ultra-capacitor), the bus acceleration from 0 to 20 km/h speed corresponds to an engine transient from idle to maximum power and the lambda from about 6.7 to 1.6. At this condition, PN emissions sharply increase from about 1.0*10⁶ to almost 8.0*10⁶ #/cm³. Once the engine power becomes steady at the maximum, the lambda increases to 1.9 and PN emissions reduces to almost 5.0*10⁶ #/cm³ again.

But, when there is power assistance from the secondary power source, while the bus accelerates from 0 to 20 km/h speed, PN emissions increases from 1.0*10⁶ to only 4.0*10⁶ #/cm³. This is about 50% reduction of PN emissions at its source.

Conclusions

City bus operation in urban areas requires frequent accelerations and every acceleration requires highly transient operation of the bus engine from no power to full power.

These engine transients from no power to full power are the main reason for high PN emissions due to the sharp decrease of the lambda and the combustion instabilities.

In hybrid city buses, most of the demanded power of the bus acceleration can be provided by the secondary power source and hence the engine transients can be minimized. More stable operation of the engine reduces significantly (up to 50% in this work) the PN emissions at its source.

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