Downsizing Capability Evaluation of Active Control Turbocharger (ACT)

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Abstract This study aims to evaluate the downsizing capability of active control turbocharger (ACT) by means of computer simulation approach. One dimensional simulation package was used to model a commercial 13L diesel engine equipped with variable geometry turbocharger (VGT) and a 10L diesel engine equipped ACT. The 10L ACT engine delivered up to 34.42% of higher brake power than 13L VGT engine at 1000RPM and below, but for the higher engine speed, 13L VGT engine delivered higher brake power (up to 14.5%) than 10L ACT engine.

Introduction

Turbocharging has been recognized as the most significant enabler in engine downsizing [1-3]. Figure 1 depicts the downsizing trends for the three most influential regions in the world. It can be observed that for the next 10 years to come, average engine displacement in the US will reduce from 3.6L to 2.9L as automotive manufacturers move from V8 and V6 engine blocks to 4 cylinders. In Europe, which has a mature turbo market, 4 cylinders will remain the architecture of choice, but with the improving turbo technologies, the engine displacement will further reduce from an average 1.8L to 1.4L or even smaller. In China, where the turbo experience is more recent, will see a move of engines sizes from 1.8L to 1.6L. By 2015, it is predicted that up to 50 percent of all turbocharged engines in China will be 1.7L or smaller [2].

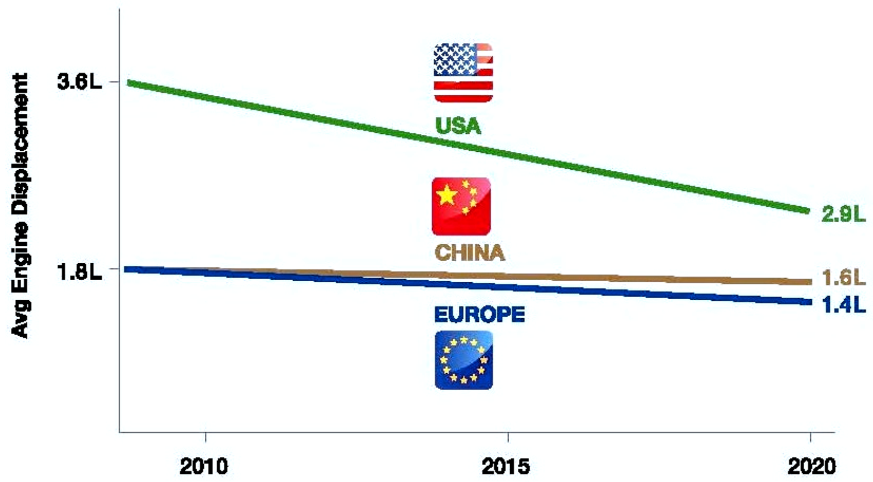

Figure 1: Engine Downsizing Trend for USA, China, and Europe [2]

Currently, the Variable Geometry Turbocharger (VGT) is the most widely used boosting options, and it has overcome many of the conventional turbocharging problems such as turbolag and engine speed matching. However, VGT does not completely address the pulsating nature of the exhaust pulse. An advanced turbocharging technique called Active Control Turbocharger (ACT) was proposed to overcome the shortcoming of the VGT. ACT is a turbocharger system with system and method of operation, which regulates the turbine inlet area throughout each engine exhaust gas period, thereby actively adapting to the characteristics of the high frequency, highly dynamic flow. ACT is essentially an improved version of the conventional VGT [4].

This paper evaluates the downsizing capability of the ACT by means of 1D simulation approach by comparing the performance of a 10L commercial diesel engine equipped ACT to a 13L VGT engine.

13L VGT Engine Modelling and Validation

One dimensional simulation package, AVL boost was used to model commercial 13L and 10L, inline six cylinders, 4 strokes diesel engine equipped with VGT. The engine geometrical data and is depicted in Table 1:

Table 1: Engine geometrical data

Engine parameters	13L	10L
Bore [mm]	135	125
Stroke [mm]	150	140
Compression Ratio	16.5:1	16.5:1
Valves/Cylinder	4	4
Engine Displacement [L]	12.88	10.3
Speed Range [RPM]	800-2000	800-200

The turbine performance maps were obtained through cold flow experiments at the Imperial College London. During the simulation, a UDF was used to alter the VGT rack position at different engine speed to obtain the optimum performance for the engine. The simulation results were compared with engine manufacturers at F/A=0.057, and the result is shown in Figure 2. It can be seen that simulation results matched very well with the manufacturer's data for both brake power and torque at F/A=0.057.

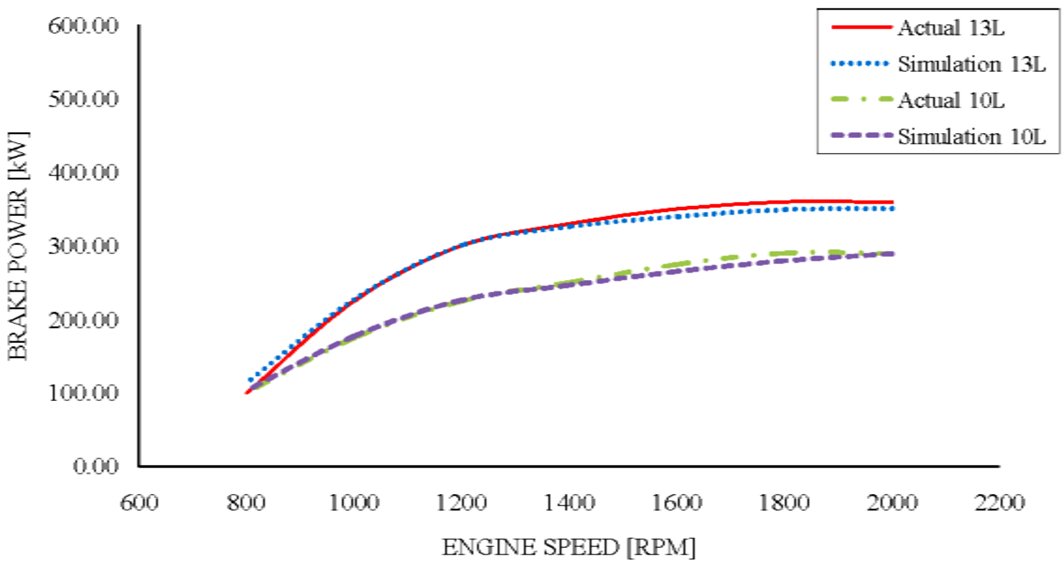

Figure 2: Brake power between comparison between actual and simulated VGT engine

ACT Simulation for 10L Diesel Engine

In ACT operating mode, the instantaneous position of the turbine rack is given by, [4]:

$$\theta_{ACT} = \theta_{ACT,min} + a\left[1 - \left(\frac{\sin(\omega t)}{\sin(\omega t)_{min}}\right)\right] \tag{1}$$

Where,
$$a = \theta_{ACT,max} - \theta_{ACT,min} = \theta_{VGT} - \theta_{ACT,min} \tag{2}$$

On the other hand, the frequency of the exhaust pulse emitted into turbine is given as:

$$f = NGC/30n \tag{3}$$

Where, f and ω are exhaust frequency, N is engine speed, G is number of Group connected to turbine, G is number of cylinder per group, C is number of cylinders per group, n is number of stroke, θ is the rack position, and t is time.

Downsizing Evaluation

Downsizing evaluation was carried out by comparing the engine performance and emission reduction of 10L ACT engine as compared to 13L VGT engine. Both engines were run at same speed ranges and load (F/A=0.057) such that equivalent comparison can be drawn. Figure 3 depicts the brake power comparison between 10L electric ACT engine and 13L VGT engine. At 1000RPM and below, 10L ACT engine delivered more brake power than 13L VGT engine, with maximum increment up to 32.42%. For 1000RPM and above, 13L VGT engine delivered higher brake power than 10L ACT engine, with maximum increment up to 14.5%. Downsizing capability of ACT seemed to be questionable at the first glance. However, it should be noted that the difference between the engine displacements was actually 3L. Thus, the difference in brake power in this application could be regarded as compromisable due to large difference in engine displacements.

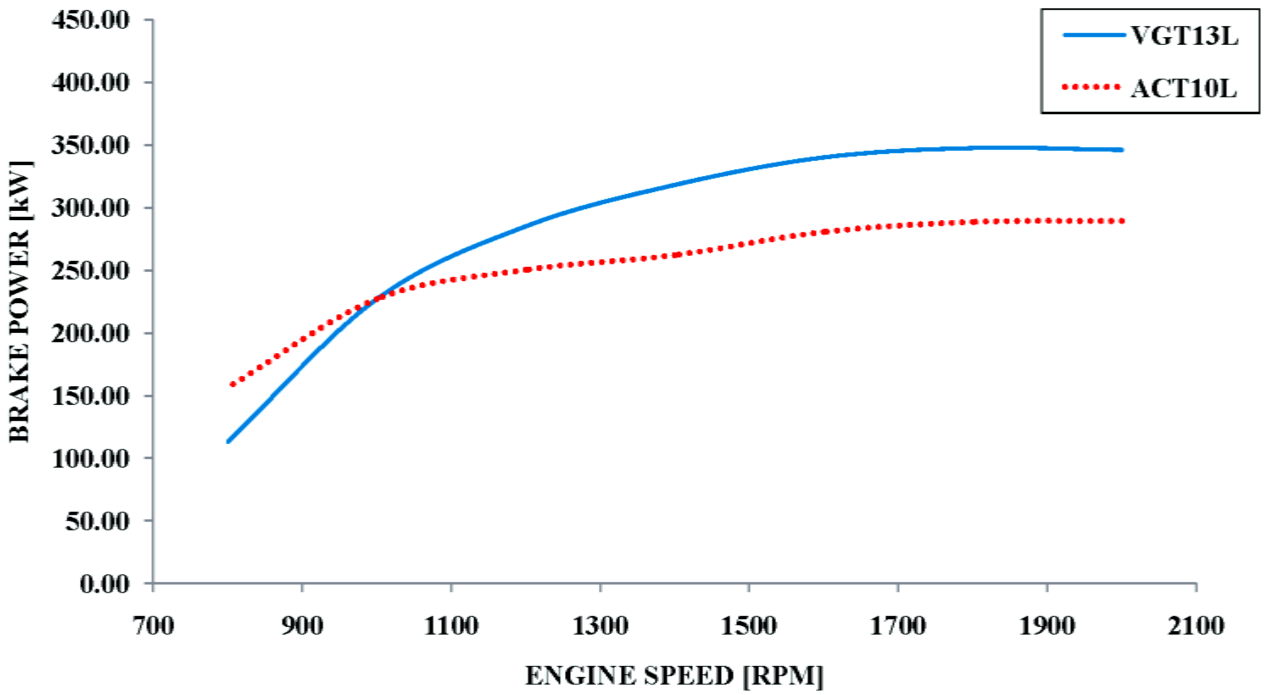

Figure 3: Comparison of brake power between VGT13L, and ACT10L engines

Figure 4 depicts the brake torque comparison between 10L ACT engine and 13L VGT engine. The trend was following the brake power, 10L ACT engine could deliver higher brake torque than 13L VGT engine only at engine speed up to 1000RPM. For the rest of the engine operating speed, VGT 13L engine delivered higher brake torque than 10L ACT engine. It is worth to note that ACT 10L engine can deliver higher brake torque than 13L at 1000RPM and below. This is the most significant contribution of the ACT, as larger displacement engine is usually running at very low engine speed to carry high load.

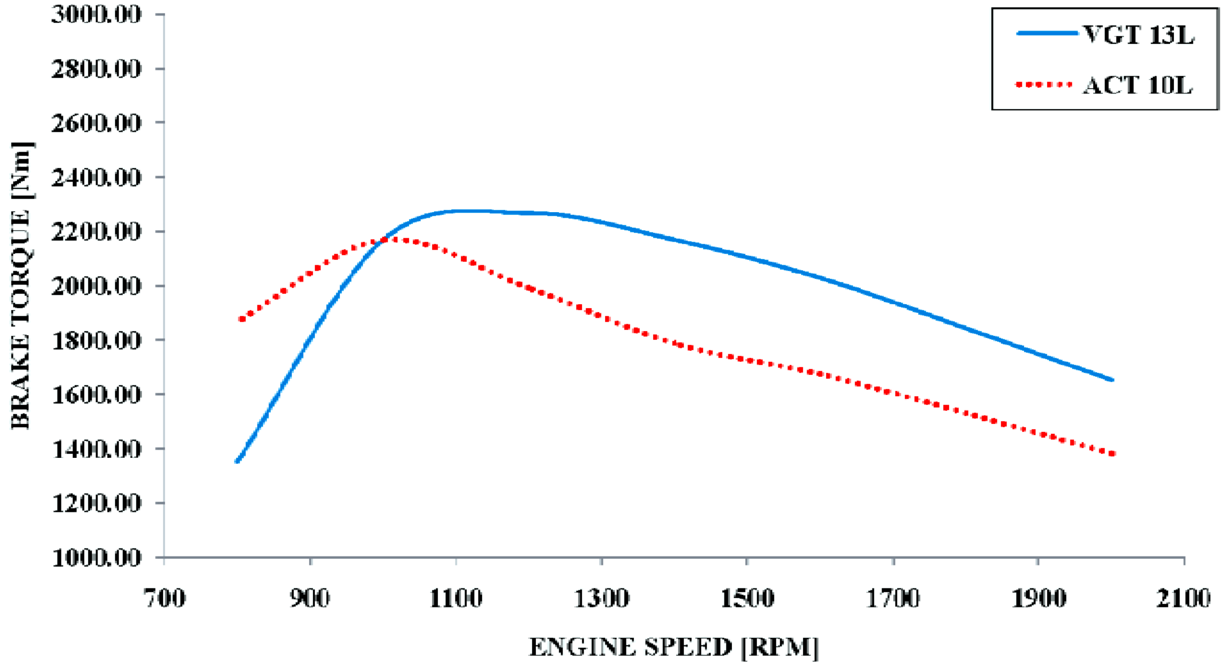

Figure 4: Comparison of brake torque between VGT13L, and ACT10L engines

Conclusion

A 10L ACT engine was modelled and its performance was compared with 13L VGT engine. It was found that 10L ACT engine could deliver higher brake power than 13L VGT engine (up to 32.42%) for 1000RPM and below. For 1000RPM and above, 13L VGT engine delivered up to 14.5% greater brake power than 10L ACT engine. ACT has shown its value at low engine speed, where it could deliver higher brake torque than 13L engine to carry the high load. Due to the large displacement between the two engines, ACT 10L engine cannot compete with VGT 13L engine at 1000RPM and above. Nevertheless, the downsizing capability of ACT has been very obvious at low engine speed.

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