F2006SC35

COMPUTER SIMULATION OF AIR INJECTION TO INLET MANIFOLD ON TURBOCHARGED ENGINES

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KEYWORDS – Turbocharged, Injection, Model, Transient, Manifold

ABSTRACT - The drive to reduce engine emissions has placed an emphasis upon turbocharging especially with the trend of engine downsizing (1, 2). Turbocharged vehicles exhibit a weak point of poor drivability under transient running conditions. Reduced air flow in the combustion chamber while fuel is injected causes inadequate air fuel ratio (i.e. rich mixture). The result is an increased formation of emissions such as CO, NOx which contribute to environmental pollution. Air injection increases the air flow during the transient phase reducing the harmful emissions. Experimental work has shown that injecting air into the manifold greatly improves the transient response of the turbocharger (3, 4). This work has shown that air injection has a large effect upon improving the transient response. This paper shows the effects of air injection using computer simulations and the improvement that the air injection has on the response of the turbocharger within the engine system.

TECHNICAL PAPER -

INTRODUCTION - One of the most important challenges facing the modern engineer in engine development is to improve vehicle economy and reduce the levels of green house gas emissions. Car manufactures are keen to improve in both these areas. In Europe through the ACEA agreement (5) manufactures agreed to meet a new vehicle fleet average CO_2 emissions level of 140g/km. Also targets that have been set by the European Union, Euro V which automotive manufacturers need to achieve by 2008 (6) and soon after that Euro VI will be implemented further restricting the outputs of harmful emissions (7).

A method of improving the efficiency and so reducing the harmful emissions of an Internal Combustion (IC) engines is to use a turbocharger. A turbocharger utilises energy from the exhaust gases and uses it to pressurise the inlet to the cylinders. This allows for the density of air in the cylinder to be greater than ambient. Allowing for the fuel to be burnt more efficiently and so reduce the harmful emissions of an engine.

Turbocharged vehicles exhibit a weak point of poor drivability under transient running conditions. The phenomenon known as “Turbo-lag” is particularly apparent in conditions where a sudden load change is applied at low engine speeds with rapid acceleration (i.e. standing start or acceleration-gear change in low revs). Quick changes in rack position-accelerator pedal do not result in instantaneous response of the turbocharger and consequently vehicle acceleration. This delay has the side effect of increased harmful emissions and engine efficiency deterioration. Reduced air flow in the combustion chamber while fuel is injected causes inadequate air fuel ratio (i.e. rich mixture). The result is an increased formation of emissions such as CO_2 and NOx which contribute to environmental pollution. At low engine speeds there is a further operational complication due to the possibility of compressor going into the surge region, resulting in instability leading to engine failure.

In general, the causes of the time delay (turbo-lag) in the transient operation of a turbocharged engine can be classified into three groups: mechanical, thermal and fluid dynamic (8). The first two are associated with mechanical and thermal inertia of the turbocharger rotor and exhaust manifold respectively. Previous work (9) has shown that to improve transient response to gain the greatest improvement the system needs to add external energy to the turbocharger instead of having a passive system.

To facilitate advances in engine technology simulations it is necessary to simulate the systems before physical testing. This allows a reduction in development time and costs. These benefits are caused because it reduces the number of costly physical testing.

This paper presents initial modelling of an air injection system to improve the transient performance of a turbocharged diesel engine. The paper discusses the models details and initial results generated by the model.

ENGINE MODELLING - The model has been developed within the computer software Ricardo WAVE. This allows detailed one dimensional analysis of the intake and exhaust manifolds along with detailed in cylinder performance predictions.

The model is based on a typical automotive diesel engine. The engine has a radial turbine and centrifugal compressor. The model includes Intake manifold system and complex silencer system.

Engine Type	4 Stroke Diesel
Stroke	82.0mm
Bore	78.1mm
Number of Cylinders	4
Combustion System	Direct Injection
Compression Ratio	22.0

Table 1. Specification of Engine

There are many different types of engine model. The two main engine models used are mean value and cylinder by cylinder. Work has shown that for this particular application a “Cylinder by Cylinder” model, where each cylinder is modelled individually, would generate superior results over model types such as “Mean Value Models”, where the engine system as a whole is modelled, as it provides the information on the pressure pulses generated by multi cylinder engines. For this application it is important to model the cylinders separately because there is a necessity to accurately predict pressure output of the engine. The need for the pressure output to be modelled accurately is because of the effect that it has on the response of the turbocharging system (10).

This model uses the Diesel Wiebe Function based on Figure 1. This is most appropriate heat release model as actual heat release profiles were not available. The burn duration over the engine speed range is adjusted using the model parameters.

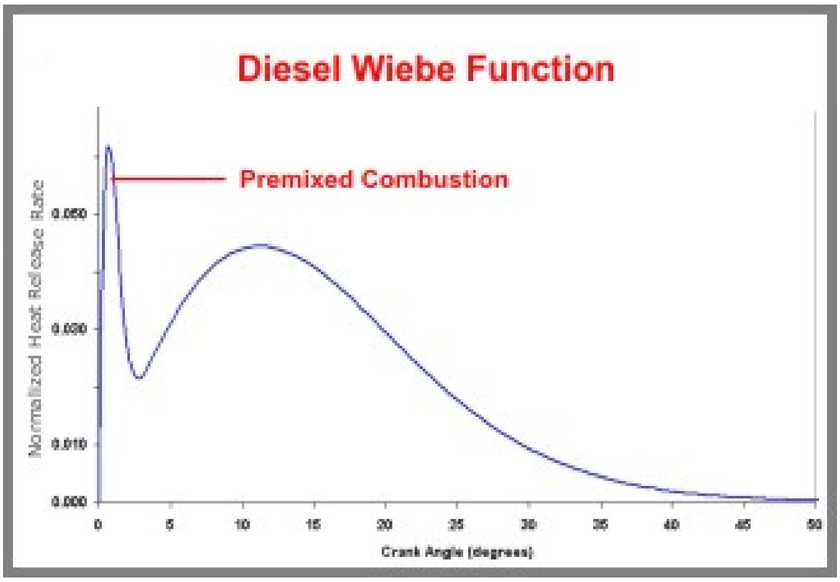

Figure 1. Wiebe Combustion Function (11, 12)

The heat transfer is calculated using the Woschni correlative model for convective heat transfer. This model assumes simple heat transfer from a confined volume surrounded on all sides by walls representing the cylinder head, cylinder liner, and piston face areas exposed to the combustion chamber. The Woschni model is based on Eqn 1.

$$h_g = 0.0128 D^{-0.20} P^{0.80} T^{*0.53} v_c^{\ 0.80} C_{enht}$$

Eqn 1. Woschni correlative model (13)

To model the Turbocharger map based running was used within the Ricardo WAVE package. The maps are created by steady state running as the data for a transient compressor map is not available. The steady state maps are considered to be adequate for the modelling that was carried out.

The manifolds have been modelled in one dimension within the WAVE software package. The air injection system has also utilised the 1D modelling capability. The injection system is feed by an ambient set at the required pressure for the study. The final overall model is shown in Figure 2.

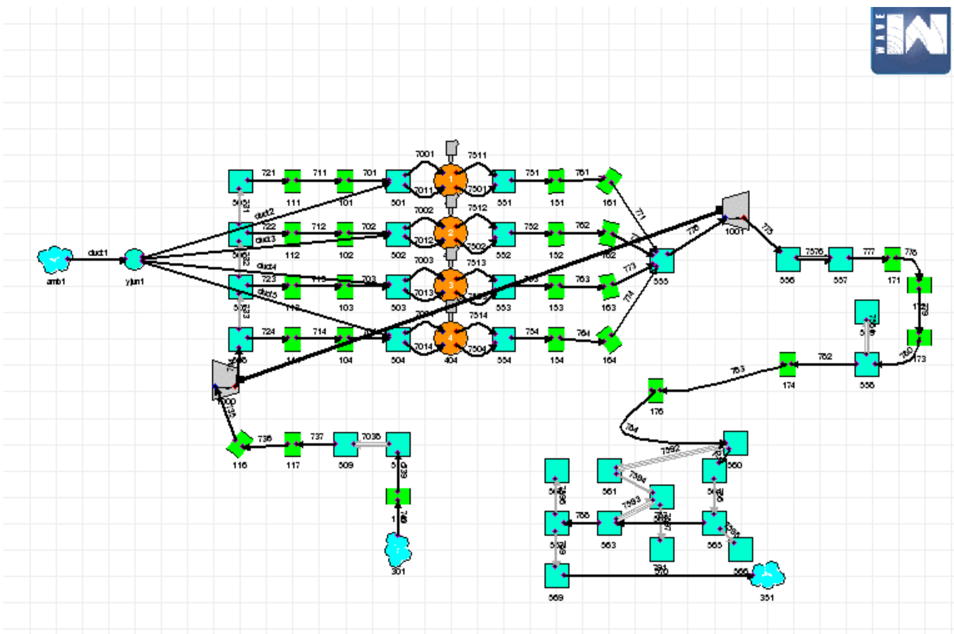

Figure 2. Final Simulation Model

SIMULATION STRATEGY - To generate the results for this paper it was important to understand what effects the air injection would have. The aim of the air injection system was to reduce the time that the turbocharger takes to reach steady state and also the overall improvement to performance needed to be considered to make sure that the increased turbo performance had the desired effects.

The transient period for the simulation was carried out for 4 seconds. During this time the engine speed was increased from 1000rpm to 4000rpm. This transient simulation was set up to represent a simple engine acceleration event.

A Quasi-Steady model was used to simulate the transient behaviour of the air injection system. Primarily a range of values for different engine speeds ranging from 1000rpm to 4000rpm were selected. These results were then used to judge the critical area. Once identified more results in this important region were generated to improve the resolution. This reduced the computing time by decreasing the resolution in areas of less importance in the transient period.

The simulations were run with and without air injection, the air injection included pressures of 2.5 bar and 3 bar. The air was injected for the entire time of the transient period, similar to previous work experimental work carried out (3).

To asses the effect the air injection had on the turbocharger pressure readings from the compressor outlet were taken. This showed how the turbocharger was responding to the air injection system. To review the effect on overall engine performance, the power output from the engine was simulated. Using power output meant that it was possible to see if the system would have an effect on the drivability of the car.

RESULTS - Figure 3 shows the pressure response of the compressor outlet. The results show an initial delay in response before rapidly increasing to an almost steady state. The results show that when the air injection system is used the time taken for the system to reach a steady state is greatly reduced. This means that the air pressure going into the cylinders is higher at an earlier stage of the process which would ensure that the air/fuel ratio is ideal. The results followed the trend shown in other similar experimental work (3). A rate of change graph was produced to study in more detail the transient period.

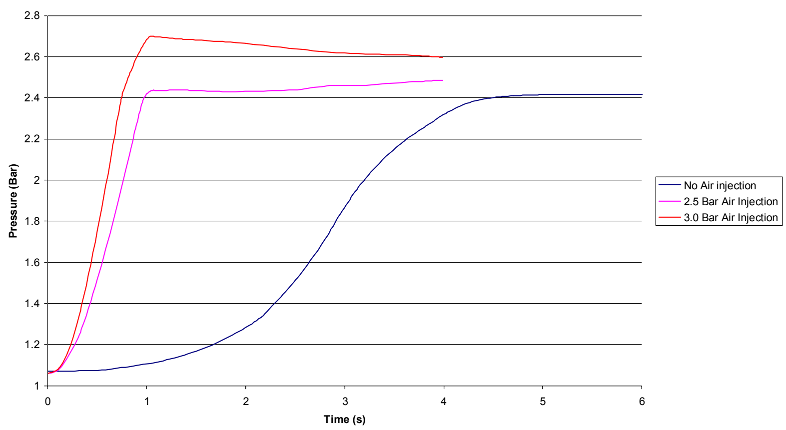

Figure 3. Compressor Outlet Pressure Response

Figure 4 shows the rate of change of the pressure response for the compressor outlet. The rate of change is shown to be much greater and to have been completed much faster for the air injection systems. The 3 bar air injection reduces the response time by three seconds. This means that the compressor reaches its steady state operating conditions significantly earlier than a turbocharger without the air injection system.

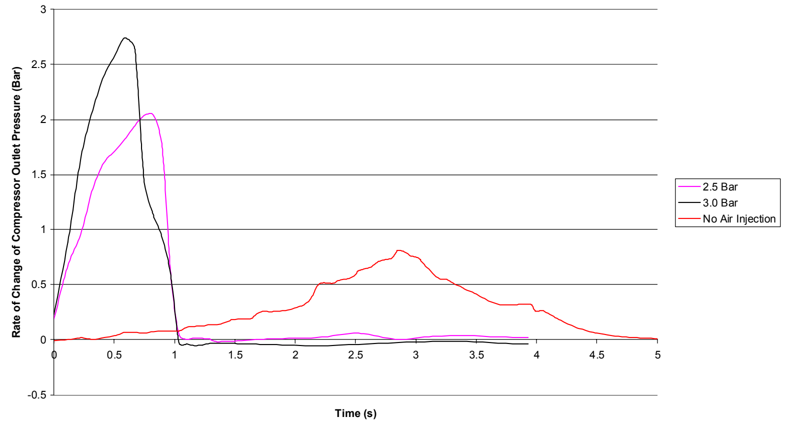

Figure 4. Rate of change of Compressor Outlet Response

The overall affect that the air injection system has on the engine has been shown in Figure 5. This graph shows the power of the engine over the transient period. The poor drivability felt by the driver is due to the delay in the power response from a turbocharged engine. The Graph shows that the Air injected system shows a considerable reduction in the time that the engine reaches equilibrium. This subsequently leads to an improvement in the efficiency of the engine, with a by product of improved drivability.

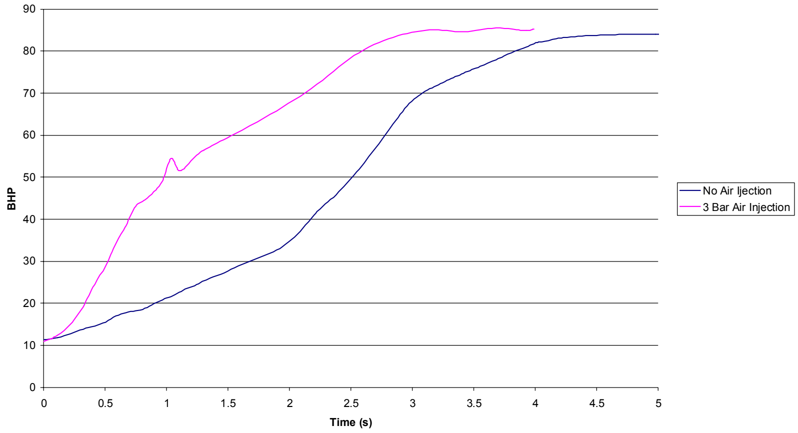

Figure 5. Power Response of Engine System

CONCLUSION - This paper shows the modelling technique and the initial results of a transient turbocharged engine system. The initial results show that this is a promising area to reduce emissions on IC engines.

1. The model has been based on the Weibe combustion and Woschni heat release models, map based turbo simulation and 1 D fluid flows
2. The system has been modelled Quasi-Steadily to reduce computing time
3. Results show significant improvement to the transient response of the compressor outlet which should reduce the formation of $CO2$ and NOx
4. Larger Injection pressures have been shown to have an increased effect on the turbochargers transient response.
5. Overall engine performance has been improved
6. High injection pressures improve performance

NOTATION

D - Bore diameter
P - Cylinder pressure
T - Temperature
v_c - Velocity term
C - User Defined Multiplier

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