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1D THERMODYNAMIC SIMULATION OF TRANSIENT CYCLE IN AVL BOOST FOR A EURO IV TURBOCHARGED DIESEL ENGINE

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ABSTRACT

European Transient Cycle (ETC) is a transient operation cycle for heavy duty diesel engines, by variation of engine load and speed that simulates real world driving conditions in Rural, Urban and Highway scenarios, with a cycle time of 1800 seconds. This is a part of the Homologation procedure to get an engine type approved. The transient engine operation has an impact on the turbocharger operating parameters such as boost pressure, mass flow variations which will affect the engine emissions. For the first time transient simulation attempt was done in AVL BOOST. Turbocharger lag is the most notable feature of an engine since the transient operation drastically differentiates the torque pattern from the respective steady state operation. In this 1D simulation study has been conducted on 130 hp EGR engine model to evaluate the transient response and part load performance. The study has employed ETC cycle as the transient input.

Key words: 1-D Thermodynamic simulation, ETC Performance prediction, Turbocharger lag, Transient response, AVL BOOST.

INTRODUCTION

The turbocharged compression ignition engine is now a days the most preferred prime mover in medium and medium-large units applications such as truck driving, land traction, ship propulsion, electrical generation. Moreover, it is continuously increasing its share in the highly competitive automotive market due to its reliability that is combined with excellent fuel efficiency. At the same time, the stringent regulations concerning engine exhaust emissions dominate the automotive industry, forcing manufacturers to new developments. Such as high pressure common rail injection systems, exhaust gas recirculation

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and variable geometry turbochargers are applied for reduction of fuel consumption, pollutant emissions and noise. According to researches and references[1] approximately 24% of the world's soot emissions come from diesel engines of which 60% is transportation related to heavy vehicles, light motor vehicles, ships etc.

In the past years, various emission directives in the form of Transient Cycles have further more directed engine manufacturers in the European Union, Japan and the US to appropriate dealing of vehicles transient performance, since it is well established that the non-stationary operation contributes much more to the total amount of emissions than the stationary one[2]. However, majority of daily driving conditions that involves transient operation only a very small portion of a vehicle's operating pattern is true steady-state i.e. when driving on motorway.

Hence the experimental and modelling analysis of transient diesel engine operation has turned out to be important objective to the engine manufactures. All the engine manufactures and researchers all over the world are paying attention to the transient diesel engine operation, in the form of Transient cycle certification for new vehicles is mandatory. Our work follows the experimental test bed data collection and developing one dimensional (1d) model setup in AVL boost and correlating the experimental results with the theoretical data in European transient cycle (ETC).

European Transient Cycle (ETC)

The transient cycle of warmed-up engine operating conditions, which are based closely on road-type-specific driving patterns of heavy-duty engines installed in trucks and buses. The conditions are classified in to three types: 1. Urban 2. Rural 3. Motoring. The pollutants will be examined either after diluting the total exhaust gas with conditioned ambient air or by determining the gaseous components in the raw exhaust gas and the particulates with a partial flow dilution system. Using the engine torque and speed feedback signals of the engine dynamometer, the power shall be integrated with respect to time of the cycle resulting in the work produced by the engine over the cycle. The emissions like HC, NO_X and CO will be determined over the cycle by integration of the analyser signal[8]. The raw or diluted exhaust gas flow rate shall be determined over the cycle to calculate the mass emission values of the pollutants. The mass emission values shall be related to the engine work to get the grams of each pollutant emitted per kilowatt hour.

Modeling methodology

Modeling of the gas exchange process

The intake and exhaust processes are treated as one-dimensional. The governing equations for the one-dimensional flow in the intake and exhaust runners are given below. The one-dimensional pipe flow is described by the Euler equation:

$$\frac{\partial U}{\partial t}+\frac{\partial F(U)}{\partial x}=S(U) \qquad \text{…(1)}$$

$$\frac{\partial U}{\partial x}+\frac{\partial F(U)}{\partial x}=S(U)$$

Where U represents the state vector and F is the flux vector. The source term on the right-hand side comprises two different source terms:

$$S(U) = SA(F(U)) + SR(U) \qquad \text{…(2)}$$

Where S_A is the source caused by axial changes in the pipe cross-section and S_R is the source taking into account homogeneous chemical reactions, heat and mass transfer terms between the gas and solid phase, and friction sources[6,7].

Single-zone combustion model

The first law of thermodynamics gives the state of the cylinder as follows in a general form:

$$\frac{d(mc.u)}{d\alpha}=-p_c.\frac{dV}{d\alpha}+\frac{dQ_F}{d\alpha}-\sum\frac{dQ_w}{d\alpha}-h_{BB}.\frac{dm_{BB}}{d\alpha}+\sum\frac{dmi}{d\alpha}.h_i-\sum\frac{dme}{d\alpha}.h_e-q_{ev}.f.\frac{dm_{ev}}{dt} \qquad \text{…(3)}$$

The variation of the mass in the cylinder can be calculated from the sum of the in-flowing and out-flowing masses:

$$\frac{dm_c}{d\alpha}=\sum\frac{dm_i}{d\alpha}-\sum\frac{dm_e}{d\alpha}-\frac{dm_{BB}}{d\alpha}+\frac{dm_{ev}}{dt} \qquad \text{…(4)}$$

where subscripts *c*, *i*, and *e* denote the cylinder, inflow, outflow conditions, respectively, *u* is the specific internal energy, *pc* is the cylinder pressure, *V* is the cylinder volume, $Q_F$is the fuel energy, $Q_w$is the wall heat loss, h_{BB} and m_{BB} are the enthalpy and mass flow of the blow-by, respectively, q_{ev} is the evaporation heat of the fuel, *f* is the fraction of evaporation heat from the cylinder charge, m_{ev} is the mass of evaporating fuel, and α is the crank angle[6].

Engine simulation model

The first step in our study was to validate the engine simulation model with respect to experimental results in the conventional compression ignition diesel mode. The simulation model was then modified for transient cycle mode for the purpose of comparing the conventional CI engine model predictions with experimental data was to validate the various aspects of the engine such as performance, exhaust emissions, and their coupling with the in-cylinder zero-dimensional combustion model.

Transient engine model

Fig. 1 shows the engine model created in AVL BOOST v10 for the engine simulation. Transient model creation is unique and is different from the model simulating steady state conditions. This involves providing external torque, speed and fuel demand as per the legislative ETC cycle. The 1D Thermodynamic simulation model was created in AVL BOOST for 130 hp EGR BS-IV engine. E1 represents the engine wherein the firing order, and the transient mode of operation is specified. C1 to C4 are the individual cylinders wherein the combustion profiles based on historic test data have been provided as input. TC denotes the Turbocharger, which is defined as a full model with compressor and turbine maps. CO1 and CO2 represent the Charge Air Cooler and EGR cooler respectively. PID1 is the PID controller which controls the EGR valve restriction R1.

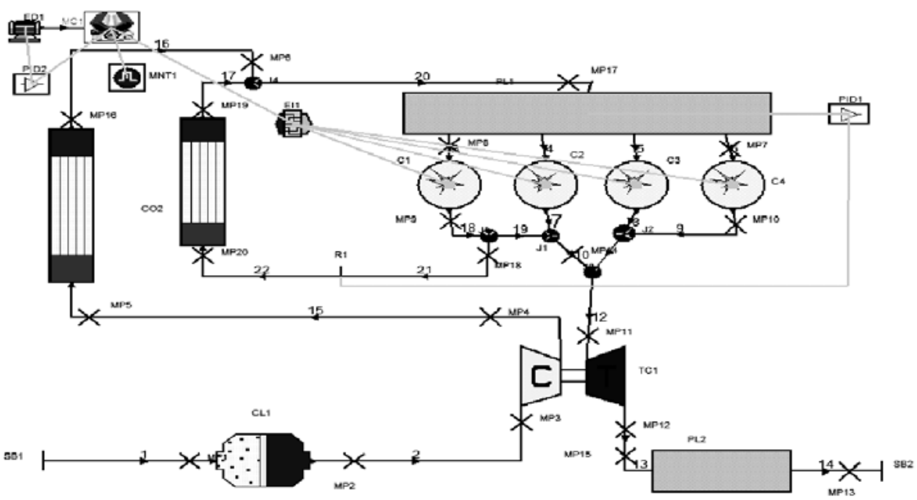

Fig. 1: Simulation model of engine system.

ED1 is the electrical device that simulates the engine dynamometer. It is linked to the engine with a mechanical link MC1. Both ED1 and MC1 are defined as full models. PID2 controller is used to control the engine speed based on the ETC cycle. EI1 is the Electrical Interface unit by which the engine transient fuel map has been defined. CL1 is the air cleaner. PL1 and PL2 are plenums which denote the Intake manifold and silencer volumes respectively. J1, J2, etc., are pipe junctions. SB1 and SB2 are system boundaries where the ambient conditions are given as input. The solid black lines are Pipe connections, while the blue lines denote electrical wire connections. MP1, MP2, etc., are Measuring points from which flow parameters are recorded for a given simulation cycle.MNT1 is an in-simulation monitoring tool which is used to observe the required engine performance and flow parameters during cyclical simulation analysis.The details of the heat transfer model for the ports and the liners can be found elsewhere[7].

Simulation of the transient cycle

For transient cycle simulation of vehicle the following are the important inputs required:

- Driving cycle (velocity vs time)
- Turbocharger full model
- PID for varying the torque in variation of engine speed in ETC.

Engine interface

The Engine Interface Element is used to supply data to elements in a BOOST model which are connected by wires. In the current BOOST version the link to external applications via the Engine Interface is not available. Actuators are served with data from Data Sets only. In the present case fuelling maps, rate of injection maps, rail pressure maps, combustion parameter maps are specified in the Engine interface element[6]. Required input for a Data Set definition is its name, the unit of the evaluated value(s) and the type of the Data Base which can be either a Constant Value or one of the following:1. Table 2. List of Tables 3. Regular Map 4. Cyclic updated Table 5. Map of Tables

Engine moment of inertia

For input to BOOST model, all other inertia of vehicle has been neglected. Only engine inertia by virtue of flywheel is accounted for[3].

$$G_e = G_{fl} + G_{coupl} + \eta_{cyl} (G_r + G_1) + G_{var} \quad \ldots(5)$$

RESULTS AND DISCUSSION

The transient input is based on the rural driving setting (Initial 600 seconds out of 1800 seconds) of the ETC cycle. Fig. 2 shows the comparison results of experimental versus simulated speed of the transient cycle for 600sec. The noise during idling can be eliminated by fine tuning the proportional integral differential (PID) controller, since the controller is varying the speed to match the loading of the engine in the circuit.

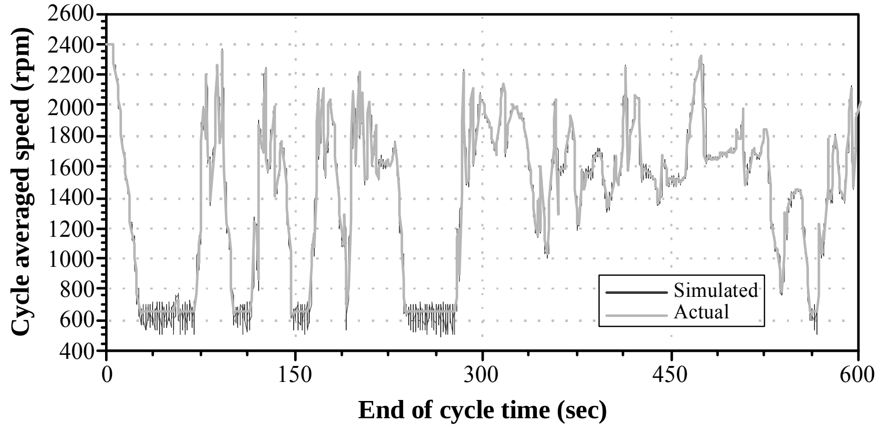

Fig. 2: Comparison of experimental and simulated values of speed

Fig. 3 shows the comparison results of experimental versus simulated torque results of the transient cycle for 600 sec. The magnitude of the load torque input to the electrical device was reversed to simulate the dynamometer loading on the engine.

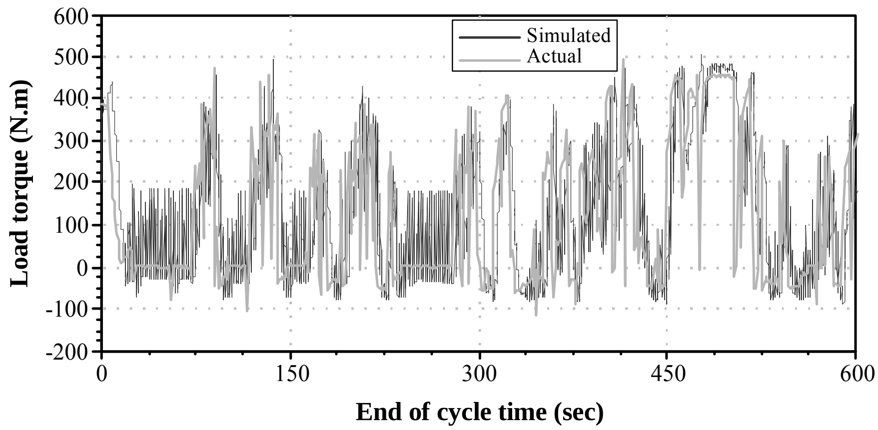

Fig. 3: Comparison of experimental and simulated values of torque.

The ETC speed control was established using the PID circuit which monitors the engine speed and compares with the ETC reference speed as time based steps. If there was a deviation in the engine and the ETC reference speed, the dynamometer loading torque was varied to minimize the speed deviation. The noise during idling can be eliminated by fine tuning the PID. During the idling, throttling will be zero in ETC.

Fig. 4 shows the comparison results of experimental versus simulated in-cylinder pressure for the transient cycle for 600sec. Boost pressure of turbocharger is almost correlated with the experimental results, the fluctuations and the pressure lag with respect to time can be controlled by adjusting the PID controller ranges.

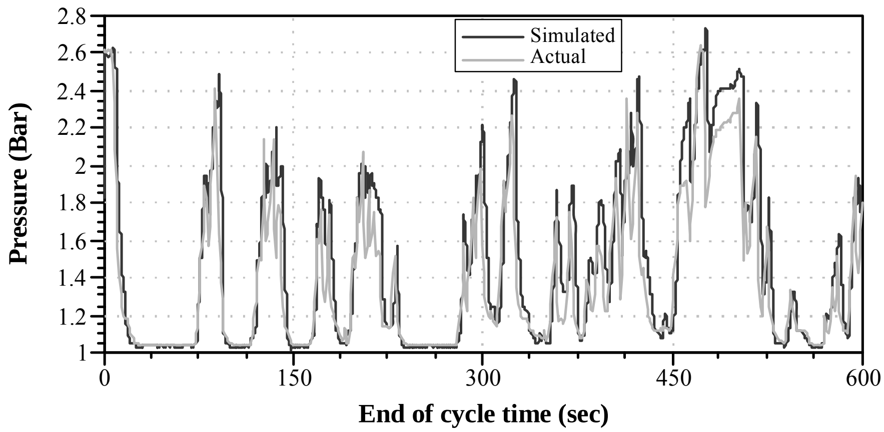

Fig. 4: Comparison of experimental and simulated values of boost pressure

Fig. 5 show the comparison results of experimental and simulated values for normalized fuel flow for the full range of engine speeds in transient cycle for 600 sec.

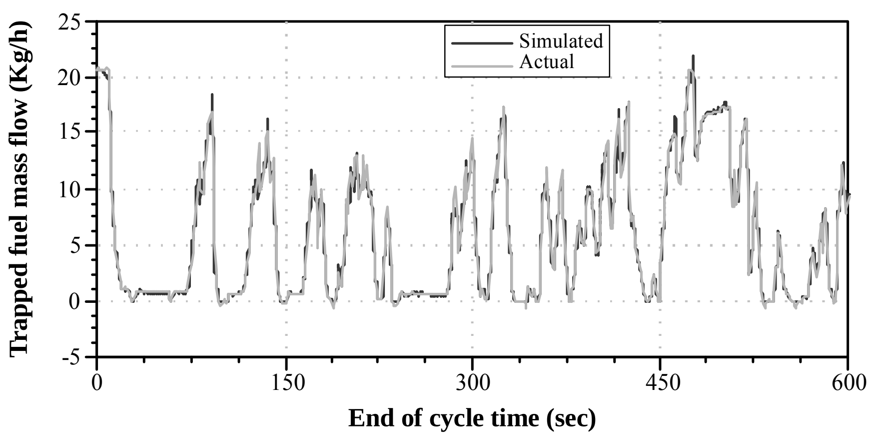

Fig. 5: Comparison of experimental and simulated values of normalized fuel flow

The fuel input was given as time based fuelling table to the individual cylinders. Since the fuelling is not influenced by other parameters in the circuit, follows the time based command of the interface unit. So the exact correlation with experimental is obtained.

The transient input is based on the rural driving setting (Initial 600 seconds out of 1800 seconds) of the ETC cycle. Fig. 6 shows the comparison results of experimental versus simulated results of the normalized air flow of transient cycle for 600sec.The ETC speed control was established using the PID circuit which monitors the engine speed and compares with the ETC reference speed as time based steps and to eliminate the noise in idling PID has to be fine-tuned.

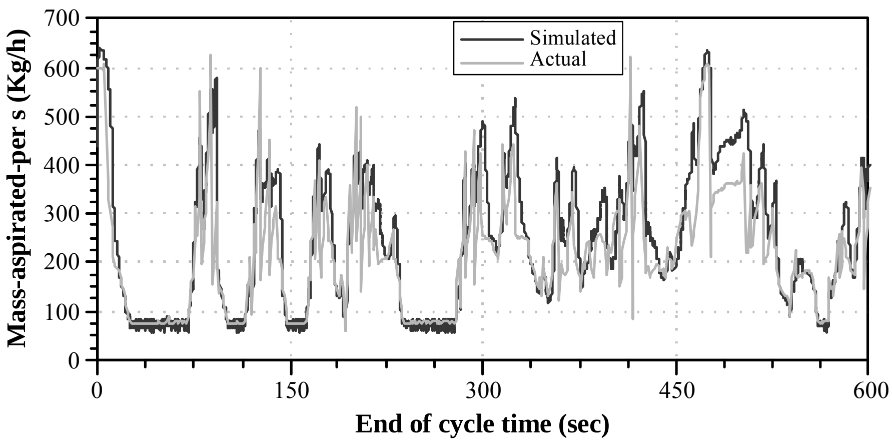

Fig. 6: Comparison of experimental and simulated values of air flow

CONCLUSION

In the present paper, quasi-dimensional simulations of transient operation for a heavy-duty, diesel-fuelled engine have been reported for prediction of performance of engine in ETC for the first time to the best of our knowledge. The transient model is applied to a turbocharged diesel engine on the basis of predicting transient behavior. Transient combustion model has been developed and implemented in a full cycle simulation of a turbocharged diesel engine for the purpose of predicting engine and turbocharger performance. The model can also be used for preliminary engine concept design studies and turbocharger matching. The model has an advantage that it can also be used for the prediction of emissions with combination of phenomenological models.

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