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Hybrid turbocharged SI engine with cooled exhaust gas recirculation for improved performance

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Abstract

Turbocharging with its most advanced forms is left with enough room for the improvement while operating in the lower engine speeds. The impacts of the same have been more visible with petrol engines due to low mass flow rate of exhaust gases. Mathematical model of the SI engine is generated using MATLAB, making use of two-zone combustion model and the thermodynamic relations developed using unsteady flow energy equation. The performance of engine when naturally aspirated, turbocharged and hybrid turbocharged is analysed using the model developed. Enough care is taken to address the occurrence of knock, which determines the extent of turbocharging; using wavelet analysis of the acoustic emissions from the engine. The possibility of technologies such as supercapacitor batteries for hybrid turbocharging, cooled EGR for controlling knocking and dissociation have also been considered in the proposed system. The results exhibit remarkable improvement of 40% in low end torques which pave the way for further downsizing of petrol engines.

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Keywords: Hybrid turbocharging; Supercapacitor; Cooled EGR; Knocking; Misfire; SI engine.

1. Introduction

Automotive researches have always been focused on developing high performance engines; enhancing the dynamic response irrespective of the manoeuvring conditions. Turbochargers with its sufficient boost pressure have

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remarkably improved the engine performance, fuel economy and lowered emission values, which led to the downsized IC engines. For the better utilisation of combustion chamber volume, turbocharging is done in both the petrol and diesel engines, however is not effective in all ranges of engine speed. At lower engine speeds, the power produced by turbine is very less due to the reduced flow rate of exhaust gas and hence the turbine speed, which in-turn force the compressor to stall. Turbolag is more severe in petrol engines than in diesel engines due to its light weight, smaller flywheel and wider mass flow range. A constant boost is intrusive over its full operating range for maintaining high performance at low engine speeds [1].

Nomenclature

T	Instantaneous temperature (k)
P	Instantaneous pressure (Pa)
ρ	Density of gas mixture (kg/m^3)
m	Mass of gas mixture (kg)
$\dot{m}$	Rate of change of mass (kg/s)
C_v	Specific heat at constant volume (kJ/kg K)
$\dot{Q}$	Heat transfer rate (kJ/s)
h	Specific enthalpy of gas mixture (kJ/kg)
V	Instantaneous cylinder volume (m^3)
R	Characteristics gas constant (kJ/kg K)
$\bar{S}_P$	Mean piston speed
k	Adjustable parameter that fixes the shape of the combustion progress curve
x_b	Mass fraction burned
α_{wall}	Fraction of mixture that burns in the duration of combustion
a	Adjustable constant that determines the duration of combustion
θ	Crank angle (degree)
θ_o	Crank angle at the start of combustion (degree)
k_{wall}	Ratio of slow burn duration to standard burn duration
$\Delta\theta$	Combustion duration (degree)

Suffixes

u	Unburnt
b	Burnt
in	Inlet
ex	Exit

Variable geometry turbocharging (VGT) uses pivoted nozzles to adjust according to varying exhaust flow rate there by reducing the turbolag to an extend and hence lowering NO_x emissions [2]. In VGTs, even though all the parts are exposed to extreme temperatures making them wear quickly, the very complex design and its sophisticated control systems enhanced the research for much simpler designs.

Chadwell and Walls [3] suggested a new technology called Super-Turbo, in which a turbocharger is coupled to continuously variable transmission through the engine crankshaft allowing it to act as a supercharger during lower engine speeds [4]. Later on, lot of advances had occurred in this field leading to the introduction of hybrid turbo. Honeywells e-Turbo has an electric motor and generator mounted on the same shaft of the turbocharger in which the extra torque is met by the electric motor at lower engine speeds. While at higher engine speeds, the excess energy is used to generate electricity and is stored in batteries [5]. Mitsubishis “hybrid turbo”, is a conventional turbo charger with a high-speed motor generator built in. The motor generator incorporated into this type of turbocharger assists the turbo when the exhaust gas energy is insufficient, thereby improving the transient response delay [6]. Similarly, Ford Motors Turbocharger Power Assist System (TPAS) is capable of supplying torque to the turbocharger shaft in the motoring mode and absorbing power from the turbocharger shaft and storing it in the