

Engine Control

Vehicles become more electronic

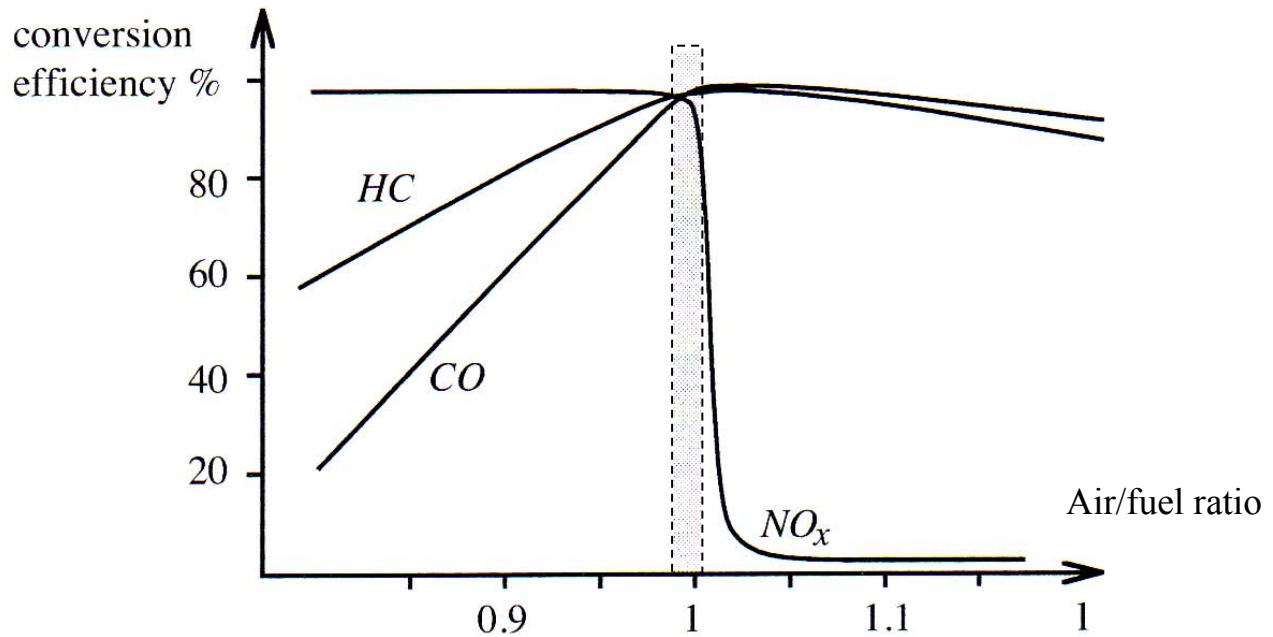
20 years ago, most engine parameters, such as quantity of fuel, ignition timing, were fixed.

Nowadays, ECU are used, a lot of electric and electronic parts

In the future, 1/3 parts value will be in electric and electronic

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Control air/fuel ration for improving emission



Conversion efficiency of 3 way catalytic converter

Fuel Air ratio λ

Most practical AFR sensors actually measure the amount of residual oxygen (for lean mixes) or un-burnt hydrocarbons (for rich mixtures) in the exhaust gas.

λ is the measure of how far from stoichiometry that mixture is.

$\lambda = 1.0$ is at stoichiometry, rich mixtures are less than 1.0, and lean mixtures are greater than 1.0.

$$\lambda = \frac{AFR}{AFR_{stoich}}$$

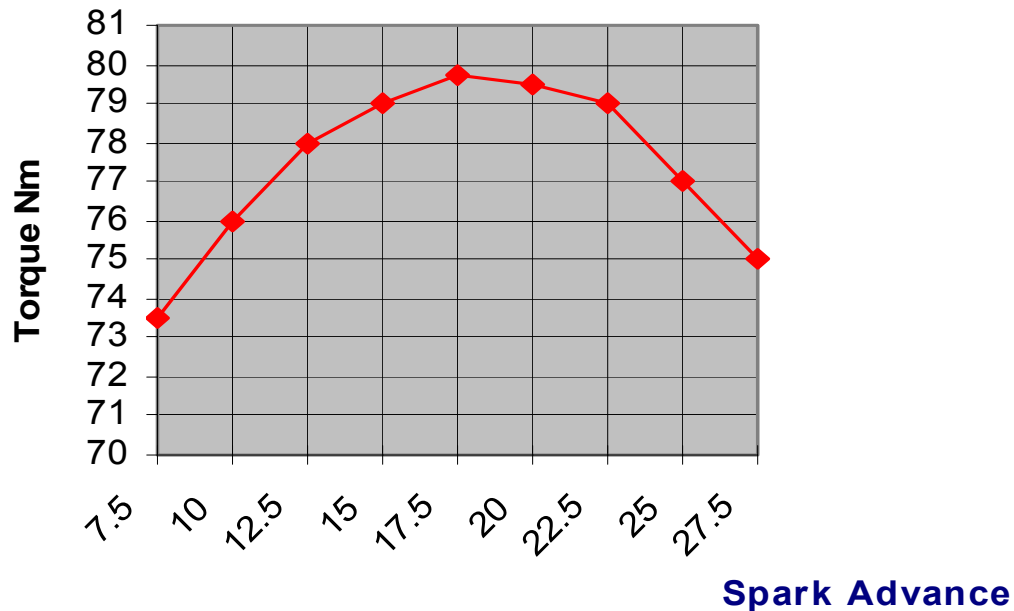
A stoichiometric A/F mixture has just enough air to completely burn the fuel. In practice stoichiometric burning is not totally achieved, due to the very short time available in an IC engine for each combustion cycle. Only 4-5 milliseconds (at 6000 rpm) from spark firing to burning finishing, 80 degrees of crankshaft rotation.

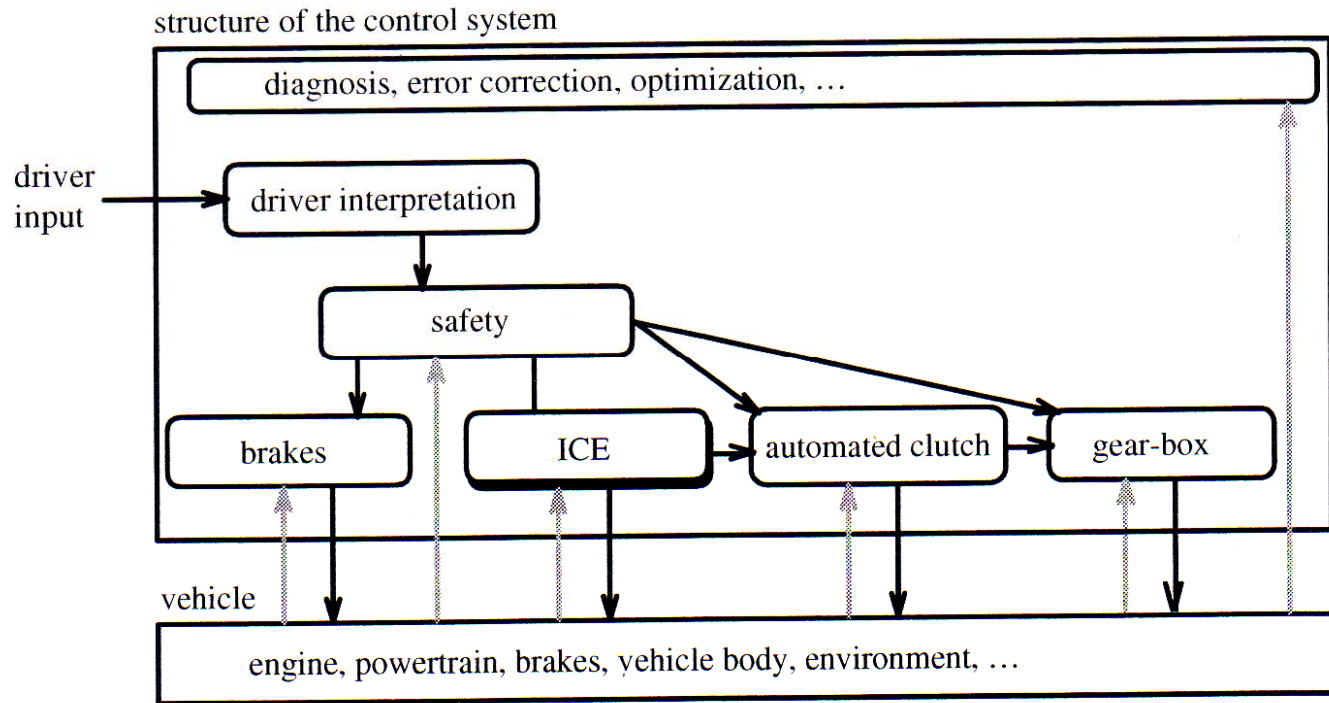
Control ignition for improving efficiency and emission

SI engines: sparking timing avoid knocking

Diesel engines: fuel injection timing

Full load 1500 rev/min ignition loop





A complete control system for a vehicle

Engine control unit (ECU)

Before ECUs, most engine parameters, such as quantity of fuel, ignition timing, were fixed.

ECU - An electronic control unit which controls various aspects of an IC engine's operation. Introduced in 1980s.

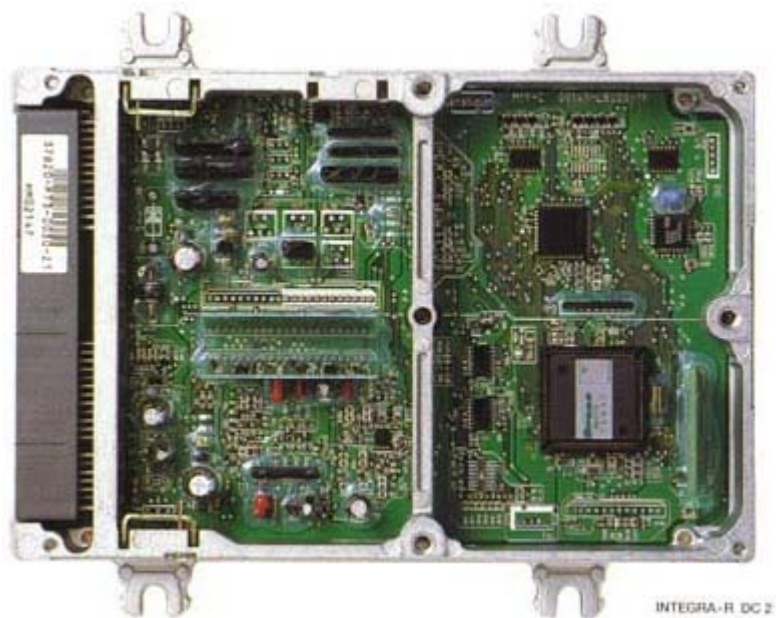
An ECU determines the quantity of fuel, ignition timing and other parameters by monitoring the engine through sensors.

Sensors:

- MAP (manifold absolute pressure) sensor
- throttle position sensor
- air temperature sensor
- oxygen sensor
- etc

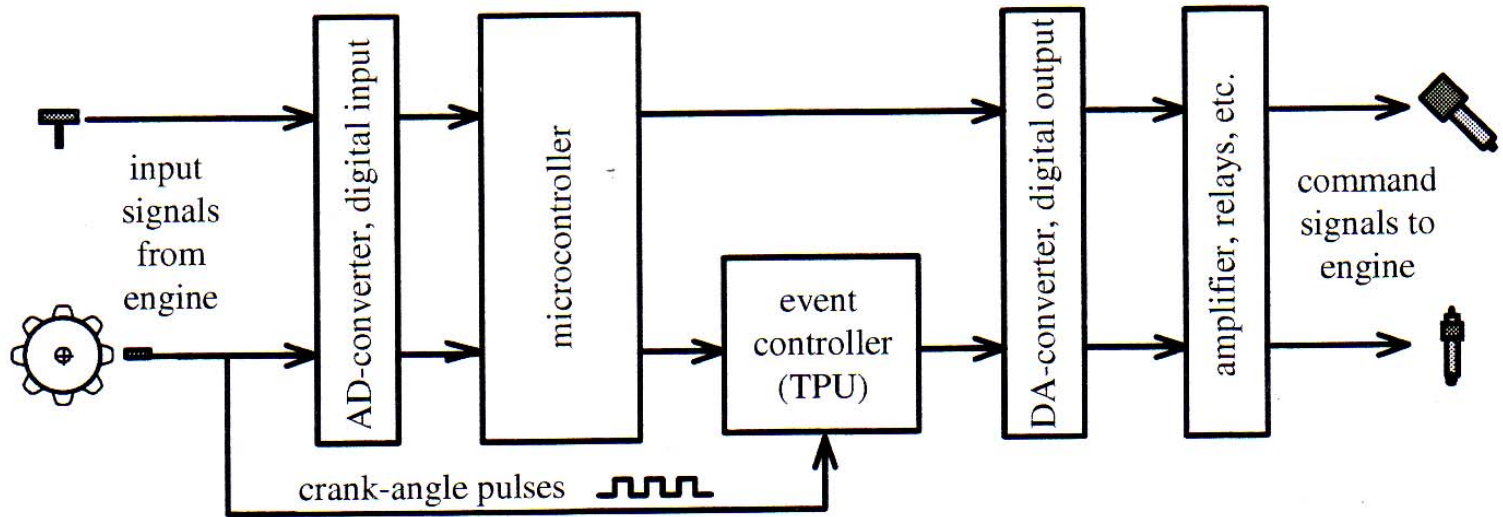
The monitoring and control is done using a control loop (e.g. PID controller).

ECU



INTEGRA-R DC 2

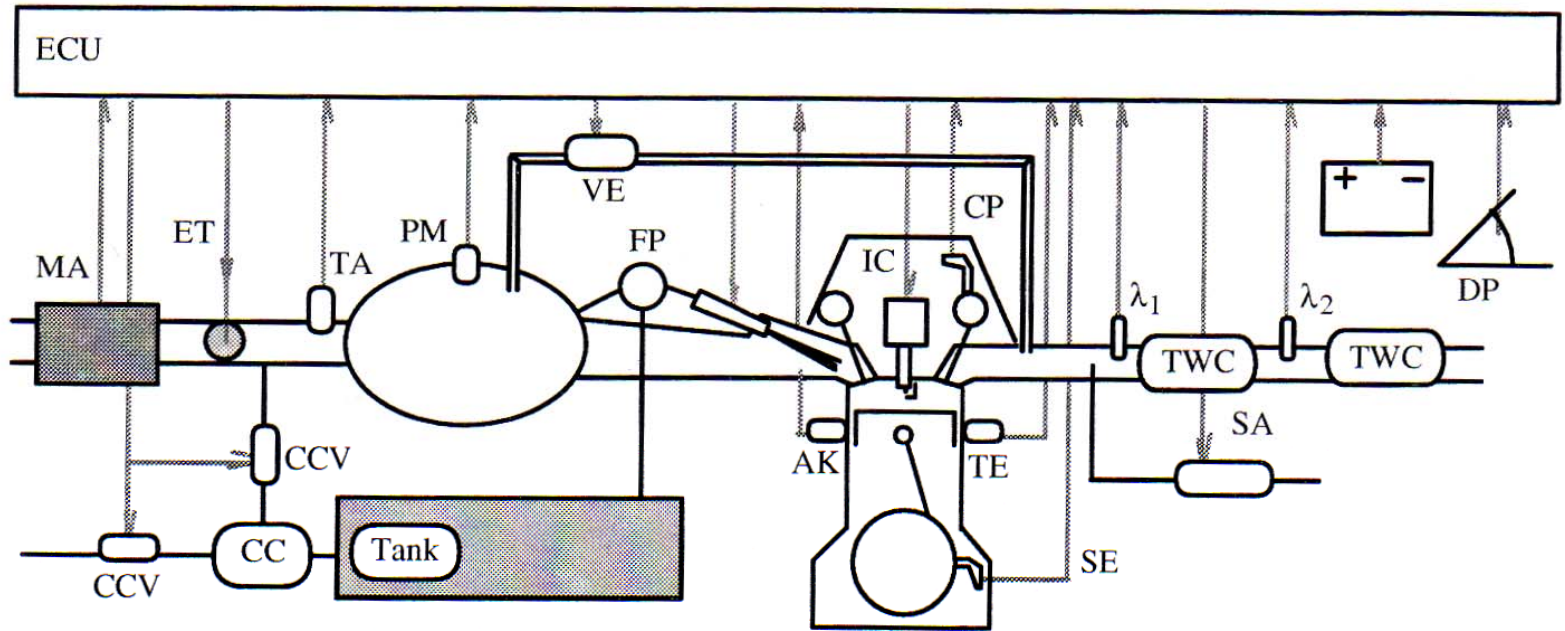




ECU structure

TPU – time processing unit which synchronizes the control commands with the reciprocating action of IC engine

ECU for SI engine system

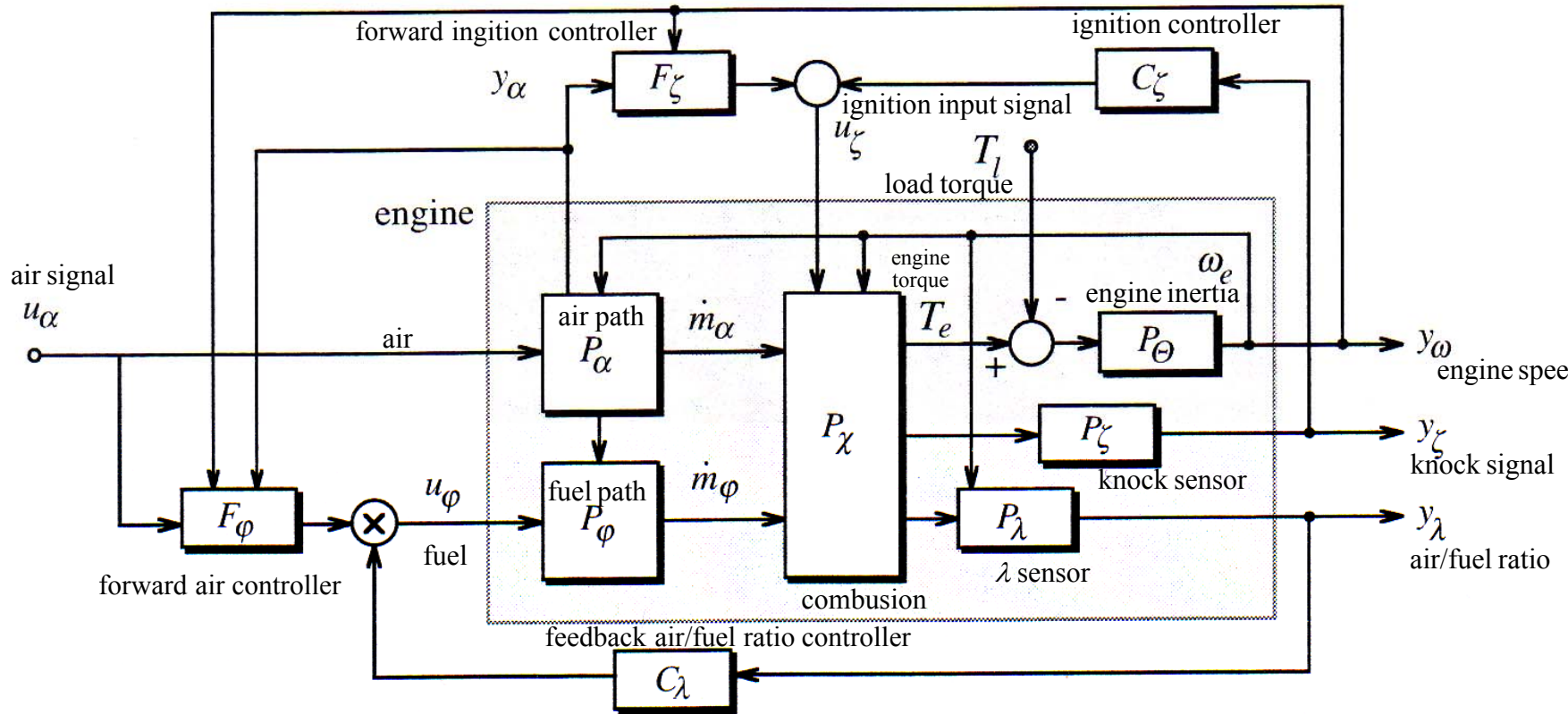


AK knock sensor
 CP camshaft sensor
 IC ignition command
 MA air mass-flow sensor
 SE engine speed sensor
 FP fuel pressure control

PM manifold pressure sensor
 ET electronic throttle
 TA intake air temperature sensor
 TE cooling water temperature sensor
 CC active carbon canister
 $\lambda_{1,2}$ air/fuel ratio sensors

VE EGR valve
 SA secondary air valve
 TWC 3-way catalyst
 ECU controller
 CCV CC control valves
 DP driver pedal

SI engine control system



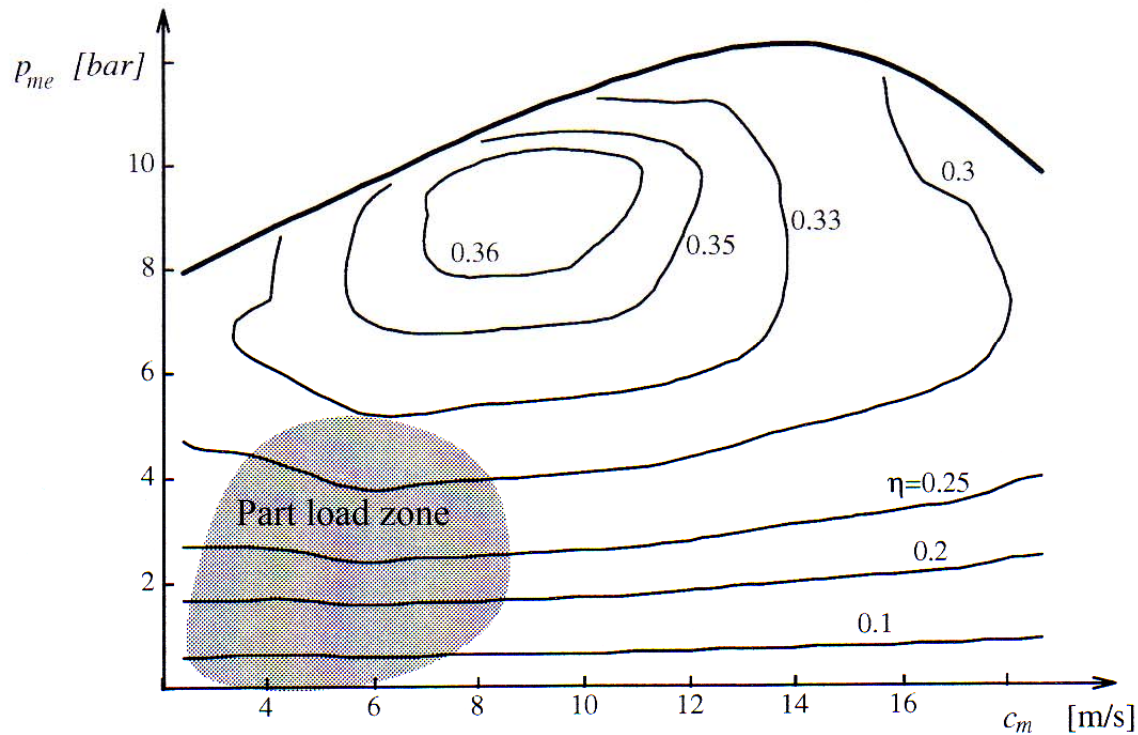
C : Feedback Controller
 F : Feedforward Controller
 Θ : Inertia

α : Air
 φ : Fuel
 χ : Thermodynamics

λ : Air/Fuel Ratio
 ζ : Ignition
 ω : Engine Speed

u : Signal Input
 y : Signal Output
 T_l : Load Torque

mean effective pressure



mean piston speed

SI Engine (efficiency) Map

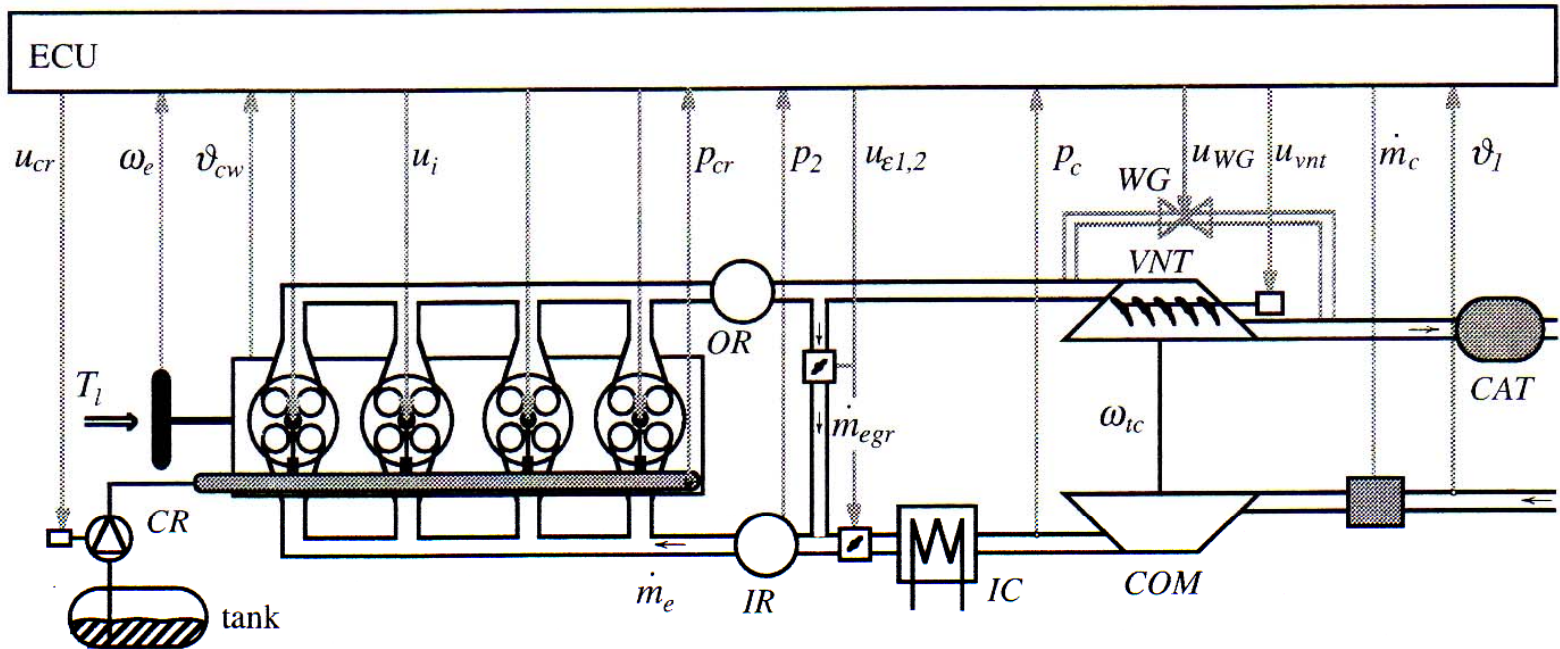
Part-load operating condition: in-efficient.

Most passenger cars on the average uses only 10% of the maximum engine power.

Control to improve the fuel economy

- Part-load efficiency is to be improved
- Use variable valve timing systems (VVT)
Allows the lift or duration or timing (some or all) of the intake or exhaust valves (or both) to be changed while the engine is in operation.
- Downsizing and super-charging system
- Homogenous and stratified lean combustion SI engine
Stratification: e.g two different fuels or fuel components are admitted through two separate inlets and stratified into two regions laterally by strong tumble flows. Each region has a spark plug to control the ignition
- Variable compression ratio engines
-

ECU for CI engine system



CAT	oxidation catalytic converter	$u_{\epsilon 1,2}$	EGR valve(s) command	p_c	pressure after COM
COM	compressor	u_{cr}	CR pump command	p_2	intake pressure
CR	common-rail system	u_i	injection command	p_{cr}	CR injection pressure
IR	intake receiver	u_{vnt}	turbine nozzle command	\dot{m}_c	intake air mass flow
OR	outlet receiver	u_{WG}	WG command	ϑ_1	intake air temperature
IC	intercooler	T_l	load torque at the flywheel	ϑ_{cw}	cooling water temperature
VNT	variable nozzle turbine	ω_{tc}	turbocharger speed	ω_e	engine speed
WG	waste-gate (alternative to VNT)	\dot{m}_e	total engine-in mass flow	\dot{m}_{egr}	exhaust gas recirculation

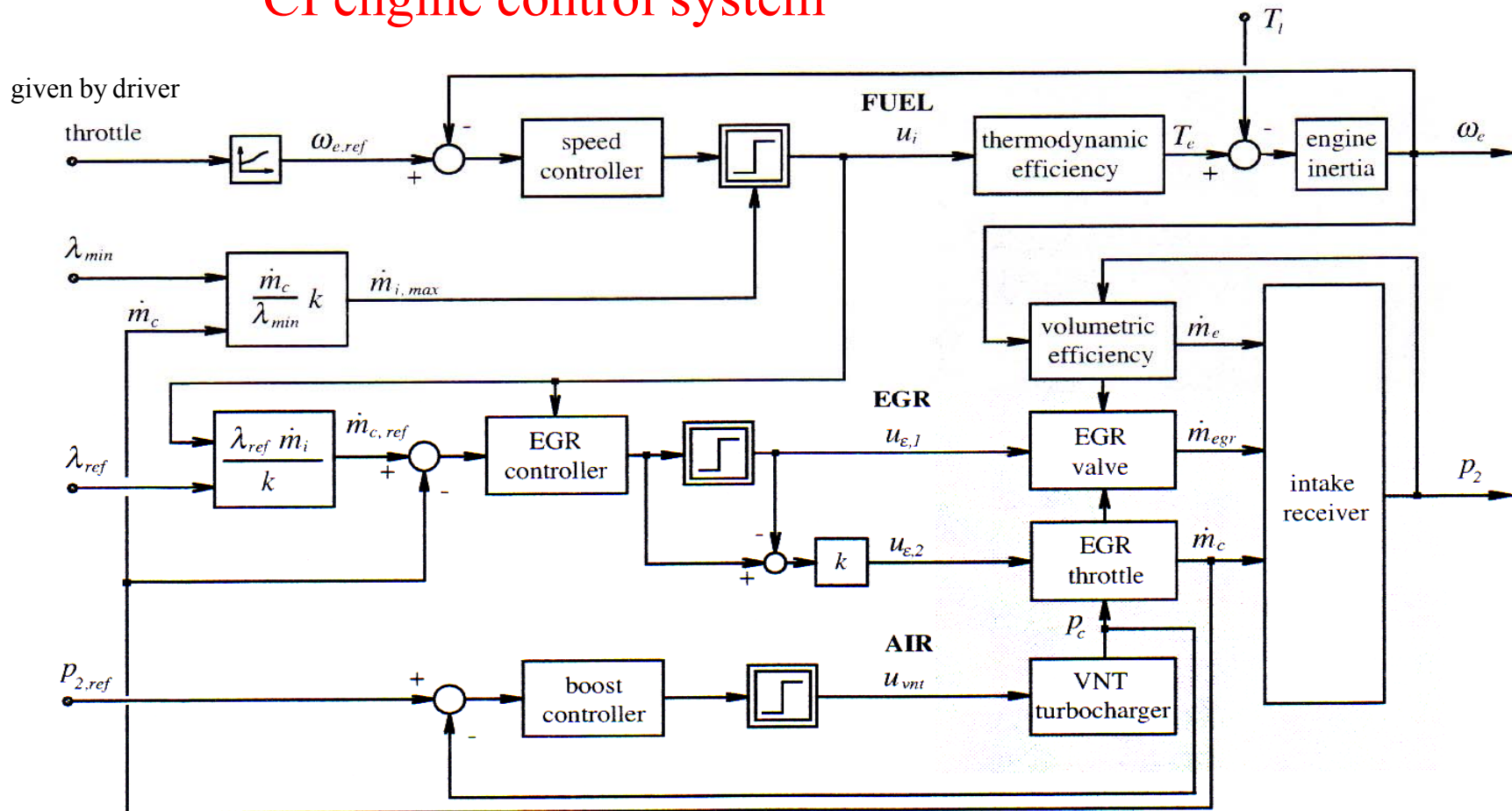
Diesel engine control

- Diesels are more fuel efficient
- The torque output is controlled by changing air/fuel ratio. (This is not compatible with TWC for exhaust treatment)
- Air flow can keep unchanged, fuel injection can change instead in order to meet load change.
- Improve fuel injection patterns: common rail injectors (several pre-, main and post-injections) or integrated pump-injectors.
- Control is to provide required torque with minimal fuel and meeting the given exhaust gas and noise emission regulations.

Diesel engine control

- Control need: Coordinate injection, turbocharger and exhaust gas recirculation in engine stationary and dynamic operating conditions.
- 3 paths need to be controlled
 - Fuel path
 - Air path
 - EGR path to reduce NO_x

CI engine control system



CAT oxidation catalytic converter

COM compressor

CR common-rail system

IR intake receiver

OR outlet receiver

IC intercooler

VNT variable nozzle turbine

WG waste-gate (alternative to VNT)

$u_{e1,2}$ EGR valve(s) command

u_{cr} CR pump command

u_i injection command

u_{vnt} turbine nozzle command

u_{WG} WG command

T_l load torque at the flywheel

ω_{tc} turbocharger speed

\dot{m}_c total engine-in mass flow

p_c pressure after COM

P_2 intake pressure

p_{cr} CR injection pressure

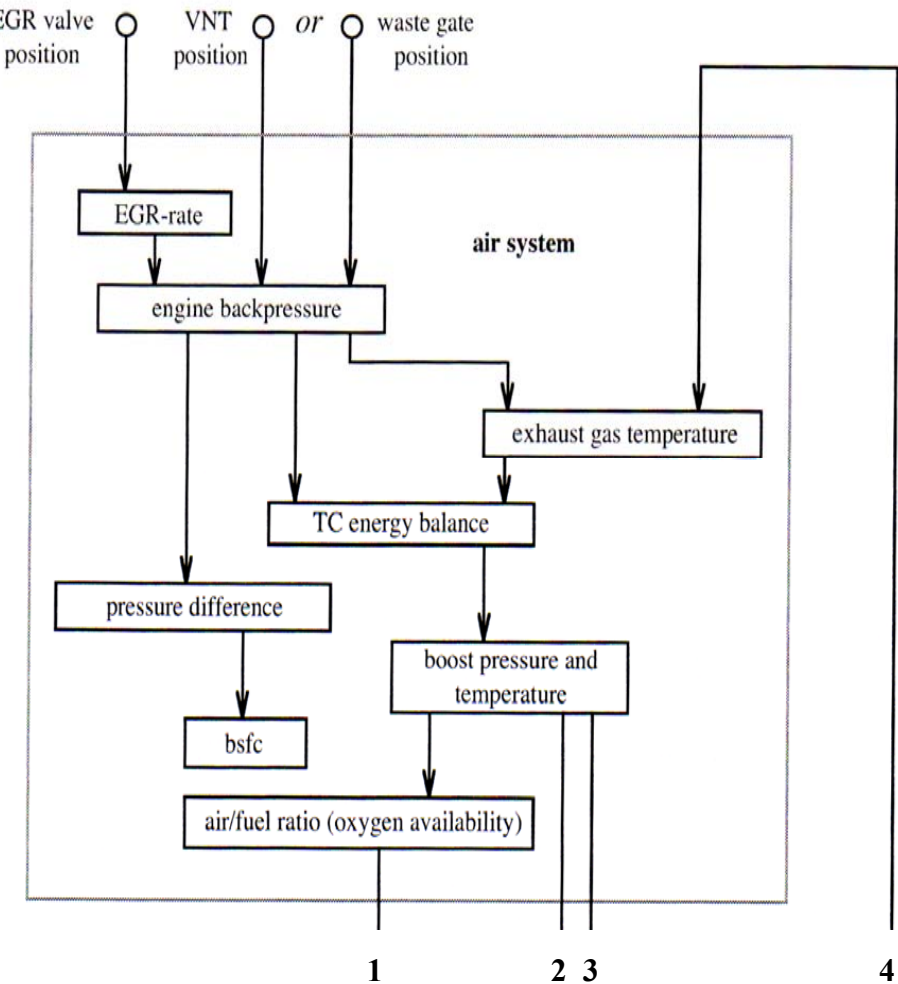
\dot{m}_c intake air mass flow

ϑ_l intake air temperature

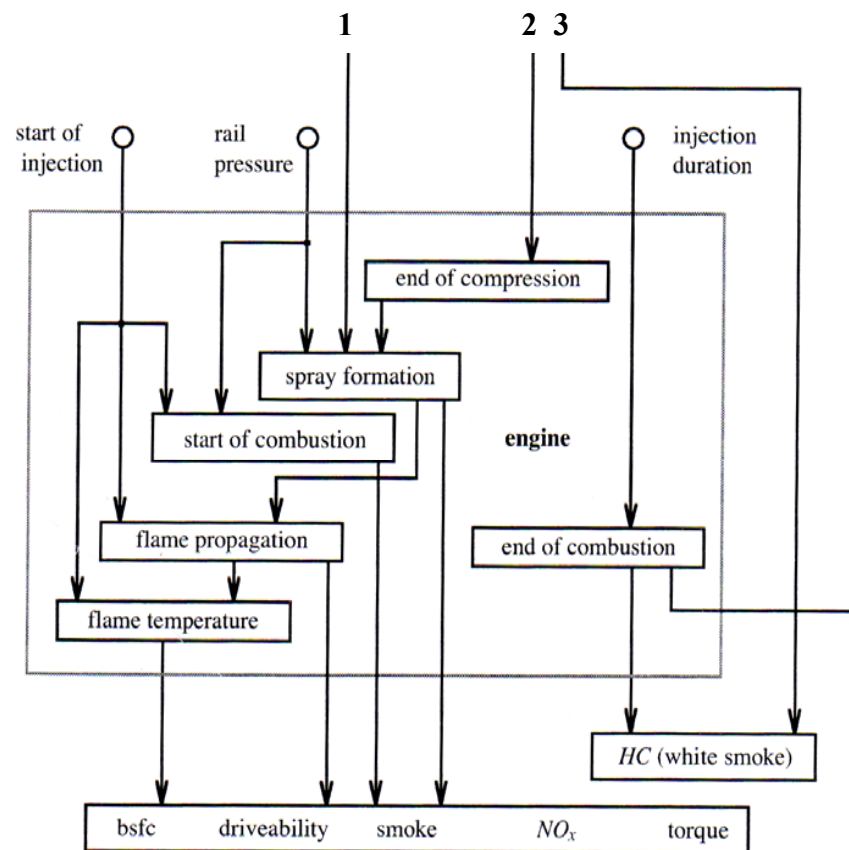
ϑ_{cw} cooling water temperature

ω_e engine speed

\dot{m}_{egr} exhaust gas recirculation



Input-out relations in a diesel engine



Key issues in diesel emission control

- Thermal efficiency of a combustion process

$$\eta_{\text{carnot}} = 1 - \frac{\mathcal{G}_{\text{exh}}}{\mathcal{G}_{\text{com}}}$$

where \mathcal{G}_{exh} – mean exhaust temperature, \mathcal{G}_{com} – mean combustion temperature.
The higher the \mathcal{G}_{com} , the better the thermal efficiency and bsfc.

- *NO* formation

$$NO = \int \frac{6 \cdot 10^{16}}{\sqrt{\mathcal{G}}} e^{-\frac{69090}{\mathcal{G}}} |O_2|^{0.5} \cdot |N_2| dt \quad \text{– higher temperature form more } NO.$$

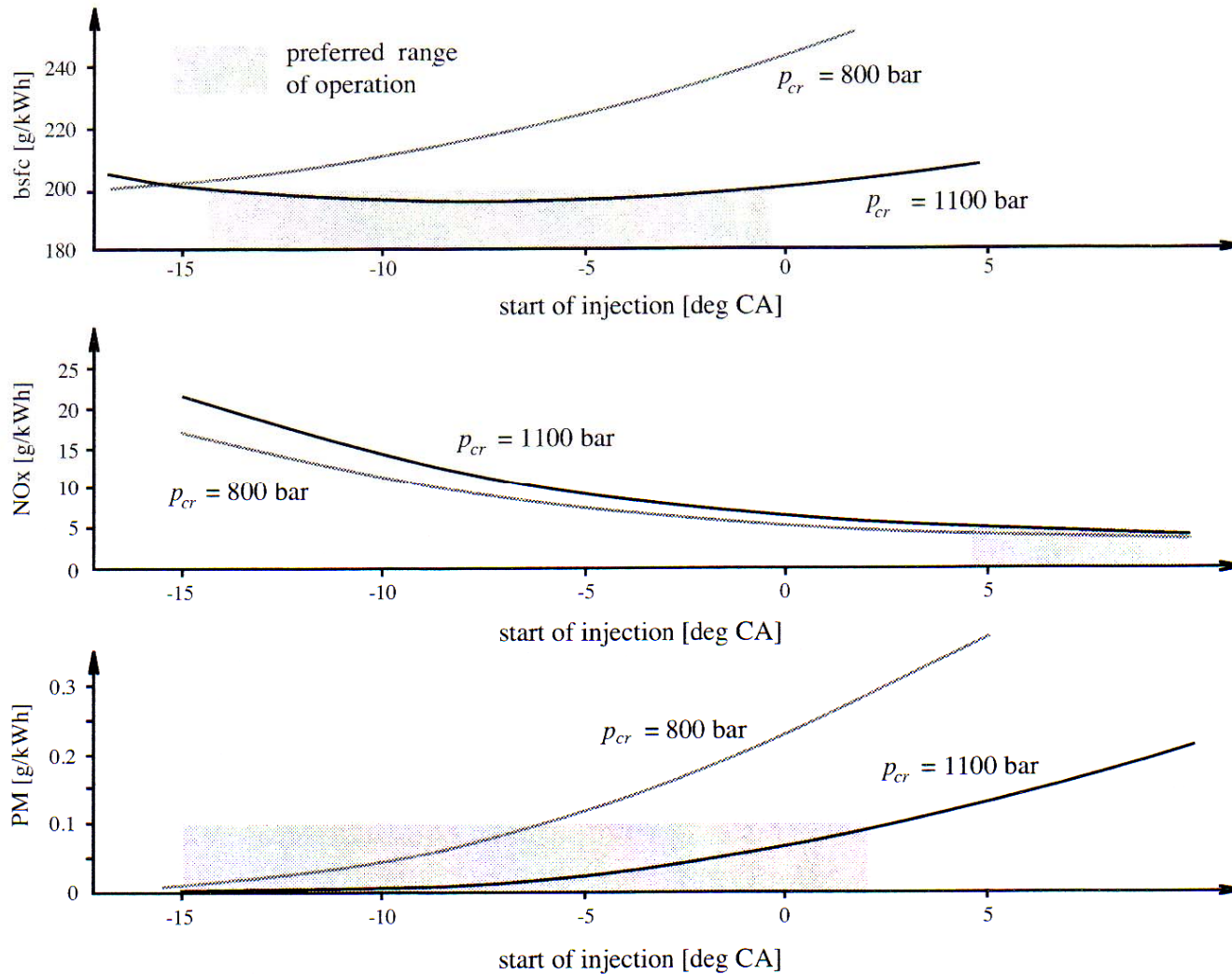
- Particulate matter depends on oxygen, spray formation and oxidation condition

Key issues in diesel emission control – Influence of control inputs

- bsfc improvement : with a given injection rate, start point of injection
- NO formation reduction : a later start of injection plus EGR reduce the peak temperature
- Particulate matter : an early start of injection reduces the particulate matter.

Control Input	Result
early start of injection	good bsfc low particulate matter high NO_x
high rail pressure	increased NO_x low PM slightly improved bsfc
pilot injection(s)	low noise
smaller VNT area	improved bsfc lower particulate higher NO_x
increased EGR	lower NO_x danger of higher PM improved noise equal or slightly increased bsfc

Key issues in diesel emission control –start of injection



Reference

Guzzella, L. et al: Introduction to Modelling and Control of IC Engine Systems