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Engine Modeling and Control

Modeling and Electronic Management of Internal Combustion Engines

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Preface

The increasing requirements for automotive drives with internal combustion engines on reduced fuel consumption, low emissions and good driveability need continuous improvement of combustion and exhaust treatment processes and their control. This can be reached by a higher variability with an increase of actuators and sensors in addition to thermodynamic, mechanical and structural improvements. Modern engines have therefore an increasing number of manipulation variables and sensors and a complex electronic management. The design of the many control function requires good physical understanding and model-based methods taking into account mechatronic engineering principles.

The book treats as well physical-based as experimental gained engine models for gasoline (spark ignition) and diesel (compression ignition) engines and uses them for the design of the different control systems. The procedure and the workflow from theoretical and experimental modeling over simulations to calibration with test benches is systematically described and demonstrated by many examples. Not only the stationary but also the dynamic nonlinear behavior of engines is taken into account. The combustion engine models include the intake system, fuel supply and injection, combustion cycles, mechanical system, turbochargers, exhaust and cooling system and are mainly generated for real-time computation. Engine control structures and engine control development with different digital feedforward and feedback control methods, calibration, optimization and simulation tools are considered in detail. Various control systems are developed for gasoline and diesel engines with both, conventional and alternative combustion processes, based on nonlinear static and dynamic multivariable engine models and demonstrated by experiments on test benches.

The book is an introduction into the electronic engine management with many examples for engine control and it is oriented to advanced students working in control, electrical, mechanical and mechatronic engineering and will also be useful for practicing engineers in the field of engine and automotive engineering.

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Darmstadt, May 2014 Rolf Isermann

Contents

Part II Engine Models

List of Symbols

Only frequently used symbols and abbreviations are given:

1. General letter symbols

a	parameters of differential or difference equations
b	parameters of differential or difference equations
c	spring constant, constant, concentration, stiffness
d	damping coefficient
e	equation error, control deviation $e = w - y$, number $e = 2.71828\dots$
f	fault, frequency ($f = 1/T_{\mathrm{p}}$, T_{p} period), function $f(\dots)$
g	gravitational acceleration, function $g(\dots)$, impulse response
i	integer, gear ratio, index, $\sqrt{-1}$ (imaginary unit)
j	integer, index
k	discrete number, discrete time $k = t/T_0 = 0, 1, 2, \dots$ (T_0: sampling time)
l	index, length
m	mass, order number
n	rotational speed, order number, disturbance signal
p	pressure, index, controller parameter, probability density function, process parameter
q	controller parameter
r	index, radius, reference variable, residual
s	Laplace variable $s = \delta + i\omega$, symptom, actuator position
t	continuous time
u	input signal change ΔU
v	specific volume, disturbance signal
w	speed, reference value, setpoint
x	space coordinate, state variable, concentration
y	output signal change ΔY, space coordinate, control variable change ΔY, signal

z	space coordinate, disturbance variable change ΔZ, z-transform variable $z = \exp T_0 s$
$\hat{x}$	estimated or observed variable
$\tilde{x}$	estimation error
$\bar{x}$	average, steady-state value
x_0	amplitude
x_{00}	value in steady state (identification methods)
x_d	desired value
A	area
B	magnetic flux density
C	capacitance
D	damping ratio, diameter
E	module of elasticity, energy, potential, bulk modulus
F	filter transfer function, force
G	weight, transfer function
H	magnetic field strength, height
I	electrical current, mechanical momentum, torsion, second moment of area
J	moment of inertia, loss function
K	constant, gain
L	inductance
M	torque
N	discrete number, windings number
P	power, probability
Q	generalized force, heat
R	electrical resistance, covariance or correlation function
S	spectral density, sum, performance criterion
T	absolute temperature, time constant
T_0	sampling time
U	input variable, manipulated variable (control input), voltage
V	volume
X	space coordinate
Y	output variable, space coordinate, control variable
Z	space coordinate, disturbance variable
$\mathbf{a}$	vector
$\mathbf{A}$	matrix
$\mathbf{A}^\mathrm{T}$	transposed matrix
$\mathbf{I}$	identity matrix
$\boldsymbol{\theta}$	parameter vector
$\mathbf{P}$	covariance matrix
$\boldsymbol{\psi}$	data vector
α	coefficient, angle