

Reihe 8

Mess-,
Steuerungs- und
Regelungstechnik

Nr. 1253

Dipl.-Math. techn. Maxim Stuckert,
Ludwigsburg

Theory and Application of the Lang-Gilles Ob- server for Distillation Processes

Berichte aus der
Aachener Verfahrenstechnik - Prozesstechnik

RWTH Aachen University



Theory and Application of the Lang-Gilles Observer for Distillation Processes

Theorie und Anwendung des Lang-Gilles Beobachters für Destillationsprozesse

Von der Fakultät für Maschinenwesen der Rheinisch-Westfälischen
Technischen Hochschule Aachen zur Erlangung des akademischen Grades
eines Doktors der Ingenieurwissenschaften genehmigte Dissertation

vorgelegt von
Maxim Stuckert

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Univ.-Prof. Dr.-Ing. Achim Kienle

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This thesis deals with the nonlinear full state observer for distillation processes first introduced by Lang and Gilles in 1990. The observer is very attractive in practice as it requires only few temperature measurements in each section of a distillation column and only few observer parameters need to be tuned. We provide conditions under which this observer converges and derive a simple rule for the tuning of the observer parameters. We also give a method for the on-line estimation of the Murphree tray efficiency. Such on-line methods are rarely found in literature. In a sequence of simulation studies, we investigate the capabilities of the observer for the estimation of the tray efficiency and for model-predictive control. The simulation studies are based on distillation processes for separation of multicomponent mixtures and one of the studies introduces a plant-model mismatch.

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Vorwort

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Maxim Stuckert

Contents

1	Introduction	1
1.1	Distillation, distillation state observers and distillation control	1
1.2	Scope of the thesis	3
1.2.1	A distillation process for the separation of the mixture of acetone, chloroform, benzene and toluene	4
1.2.2	Convergence of the Lang-Gilles observer	5
1.2.3	Separation efficiency estimation in conjunction with the Lang-Gilles observer	5
1.2.4	Model-predictive control in conjunction with the Lang-Gilles observer	6
1.3	Structure of the thesis	6
2	Dynamic distillation modeling	8
2.1	Introduction	8
2.2	Classification of distillation models	10
2.2.1	Fundamental models	10
2.2.2	Empirical models	20
2.2.3	Hybrid models	21
2.3	Distillation efficiency models	22
2.3.1	Murphree point efficiency	22
2.3.2	Murphree tray efficiency	23
2.3.3	Multi-component Murphree tray efficiency	23
2.3.4	Multi-component Murphree tray efficiency in parametric form	24
2.4	Distillation column models for simulation and theoretical analysis	28
2.4.1	Plant-replacement model	30
2.4.2	Controller/Observer model	33
2.4.3	Comparison of plant-replacement and controller/observer models	36
2.4.4	Controller model in a compact form for theoretical analysis	38
2.4.5	Determination of model parameters	45
2.5	Dynamics and basic control of the ACBT process	46
2.5.1	ACBT process dynamics at the nominal state	46
2.5.2	Regulatory control of the ACBT process	49

2.6	Chapter summary	50
3	Analysis of the Lang-Gilles observer	52
3.1	Introduction	52
3.2	Lang-Gilles observer	56
3.2.1	Problem statement and initial data	56
3.2.2	Observer correction term	56
3.2.3	Plant observer in a compact form for theoretical analysis	58
3.3	Convergence analysis	61
3.3.1	The state error equation	61
3.3.2	Preliminary results	61
3.3.3	Convergence results	63
3.3.4	A tuning method for Lang-Gilles observer	71
3.3.5	An effect of internal flows on the observer convergence time	74
3.4	Chapter summary	79
4	Efficiency estimation in distillation columns	82
4.1	Introduction	82
4.2	Sequential state and parameter estimation	87
4.2.1	Estimation of the state variables	87
4.2.2	Estimation of the Murphree efficiency matrix	88
4.2.3	Periodic estimation of the Murphree efficiency matrix and observer states	88
4.3	Case study: methanol-ethanol-water separation	89
4.3.1	One single constant C_l^{true}	90
4.3.2	One single drifting C_l^{true}	90
4.3.3	Multiple drifting C_l^{true}	91
4.4	Chapter summary	95
5	Application of the Lang-Gilles observer in distillation control	97
5.1	Introduction	97
5.2	Plantwide control	99
5.3	Control design	100
5.3.1	Control problem statement	100
5.3.2	Design of regulatory and supervisory controllers	102
5.4	Case study: output feedback control of ACBT separation	110
5.4.1	The PID regulatory layer is turned off (open-loop process)	111
5.4.2	The PID regulatory layer is turned on	112

5.4.3	The supervisory and regulatory control layers are turned on	113
5.5	Chapter summary	117
6	Summary and conclusions	119
Appendix		123
A	Derivation of particular column assumptions	123
A.1	Derivation of the constant enthalpy assumption	123
A.2	Derivation of the constant molar overflow condition (CMO)	124
A.3	Derivation of a simplified energy balance equation for condensers . .	125
B	Implementation of distillation libraries	128
B.1	Modeling environment	128
B.2	External software	128
B.3	Implementational issues	130
C	Simulation data	133
C.1	Parameters for prediction of activity coefficients and vapor pressures in ACBT mixture	133
C.2	Parameters for prediction of activity coefficients and vapor pressures in MEW mixture	133
C.3	Regulatory control parameters	134
C.4	Supervisory control parameters	135
C.5	Nominal design condition used in Section 3.3.5	137
C.6	Nominal design condition used in Section 5.4	139
D	Auxiliary theorems	142
Bibliography		144

Nomenclature

Abbreviations

ANN	artificial neural network
CMO	constant molar overflow
DMPC	distributed model-predictive control
EQ	equilibrium stage
MPC	model-predictive control
NEQ	nonequilibrium stage
PDE	partial differential equations
PI	proportional-integral controller
PID	proportional-integral-derivative controller
PLS	partial least squares
QP	quadratic programming
RGA	relative gain array
S-DMPC	sensitivity-driven distributed model-predictive control
SP	setpoint
VLE	vapor-liquid equilibrium

Greek letters

α	observer tuning parameter, see Eq. (3.3)
α_i	observer tuning parameter
$\Delta \hat{T}_{k,m}^{pred}$	predicted temperature difference between two trays k and m
$\delta \hat{y}^*$	deviation of the estimated vapor compositions from the estimated equilibrium compositions, see Eq. (3.6)
$\Delta h_{L,0}$	heat of vaporization
δT	vector of temperature differences, see Eq. (3.7)
$\Delta T_{k,m}$	temperature difference between two trays k and m
$\gamma_{i,j}$	activity coefficient of component i

λ_M, λ_V	parameters specifying liquid dynamics with respect to holdup and vapor flow rate changes
ν_i^L	liquid phase molar volume of component i
$\phi_{i,j}^L$	fugacity coefficient of pure component i in the liquid phase
$\phi_{i,j}^V$	fugacity coefficient of pure component i in the vapor phase
Ψ_j	Jacobian of the vapor-liquid equilibrium function
ξ_0, ξ_1	correlation constants in pressure relation

Latin letters

$\bar{f}(\bar{x}, t)$	majorant of $f(x, \hat{x}, t)$, see Eq. (3.14)
\bar{T}	vector of all temperature differences in the plant, see Eq. (3.8)
$\Delta x, \Delta u, \Delta d, \Delta y$	vector deviations in state equation, see Eq. (5.6)
\hat{D}	estimated mass transfer matrix, see Eq. (3.4)
$\mathcal{H}, \mathcal{F}, \mathcal{A}, \mathcal{B}$	matrices in QP formulation, see Eq. (5.22)
$\mathcal{T}_x, \mathcal{T}_d, \mathcal{T}_u$	matrices in prediction equation, see Eq. (5.17)
$f_i^{vap}(\cdot)$	function specifying vapor component i
f^{vle}	vapor-liquid equilibrium function
A, B, C	matrices in state equation of the plant, see Eq. (2.65)
A_c, B_c, C_c, D_c	continuous-time matrices in state equation, see Eq. (5.7)
A_d, B_d, C_d, D_d	discrete-time matrices in state equation, see Eq. (5.12)
a_j	interfacial area between liquid and vapor phases on tray j
$A_{l_1 l_2}, B_{l_1 l_2}, C_{l_1 l_2}$	inner matrices in state equation of the plant, see Eq. (2.66)
$a_{r,s,l}, b_{r,s,l}, c_{r,s,l}, f_{r,l_1,s,l_2}^L, f_{r,l_1,s,l_2}^V$	sub-matrices, see Eq. (2.67)
C_l^V, C_l^L	efficiency factors with resistance on the vapor and liquid side, respectively
C_l	efficiency factor with resistance on the vapor or liquid side
$E_{MV,i,j}$	Murphree tray efficiency for component i on stage j
$E_{MV,j}$	multi-component Murphree tray efficiency on stage j
$E_{OV,i,j}$	Murphree point efficiency for component i on stage j
$E_{OV,j}$	multi-component Murphree point efficiency on stage j
F	flow rate through a valve
$f(x, \hat{x}, t)$	redefinition, see Eq. (3.11)
f^L	function specifying liquid dynamics
F_j^L	feed liquid stream on stage j

f^V	function specifying vapor dynamics
F_j^V	feed vapor stream on stage j
F_0	distillate flow rate
F_j	side stream on stage j
F_{m+1}	bottom flow rate
F_{max}	maximum flow rate through a valve
h_j^{tot}	total height of the liquid on tray j
h_F	enthalpy of feed stream F
h_L	enthalpy of liquid stream L
h_{SL}	enthalpy of stream S^L
h_{SV}	enthalpy of stream S^V
h_V	enthalpy of vapor stream L
J_j	interphase stream on stage j
K_j^L	matrix of mass transfer coefficients in the liquid phase on tray j
K_j^V	matrix of mass transfer coefficients in the vapor phase on tray j
L_j	liquid stream leaving stage j
M_j^L	liquid holdup on stage j
M_j^V	vapor holdup on stage j
m_l	number of stages in column l in-/excluding feed stages/condenser and reboiler
$M_{i,j}$	holdup of component i on stage j
m_{sec}	number of stages in a distillation column section
$N_{i,j}$	molar flux between the vapor and liquid phases of component i on stage j
$NTU_{L,j}$	matrix of numbers of transfer units for the liquid phase
$NTU_{OV,j}$	matrix of overall number of transfer units on tray j
p_i^{sat}	vapor pressure of component i
p_j	pressure on stage j
q	number of components in the mixture
Q_C	heat flow out of condenser
Q_R	heat flow into reboiler
$q_{L,0}$	thermal condition of the reflux flow
R	ideal gas constant
S_j^L	side liquid stream on stage j
S_j^V	side vapor stream on stage j
S_j	side stream on stage j

S_{actual}	current valve stem position
T_j	boiling temperature on stage j
U_j	internal energy of both phases on stage j
V_j	vapor stream leaving stage j
x, y, z	vectors of all liquid and vapor compositions in the plant, see Eq. (2.64)
x_l, y_l, z_l	vectors of all liquid and vapor compositions in column l , see Eq. (2.63)
$x_{i,j}, y_{i,j}, z_{i,j}$	molar liquid, vapor or feed fraction of component i on stage j , page 12
$x_{j,l}, y_{j,l}, z_{j,l}$	vectors of all liquid and vapor compositions in column l on stage j , see Eq. (2.62)
y^*	vapor compositions in equilibrium with liquid

Mathematical symbols

\circ	Hadamard product
$(\dot{\cdot})$	time derivative
\mathbb{R}^n	vector space over \mathbb{R}
$\mathbb{R}^{n \times m}$	$n \times m$ matrix space over \mathbb{R}
$L(\cdot)$	linear function
$N(\cdot)$	nonlinear function

Subscripts, superscripts, accents

$(\cdot)^{nom}$	nominal value
$(\cdot)^{rec}, (\cdot)^{str}$	refers to a quantity in the rectifying or stripping distillation sections
$(\cdot)^{true}$	refers to a quantity in the plant replacement model
$(\cdot)_{j_i}$	stage number selected from all stages in the distillation column
$(\bar{\cdot})$	difference between estimated and measured quantities
$(\check{\cdot})$	nominal value of the variable
$(\hat{\cdot})$	an observer variable

