Extruder Automation with Learning Control

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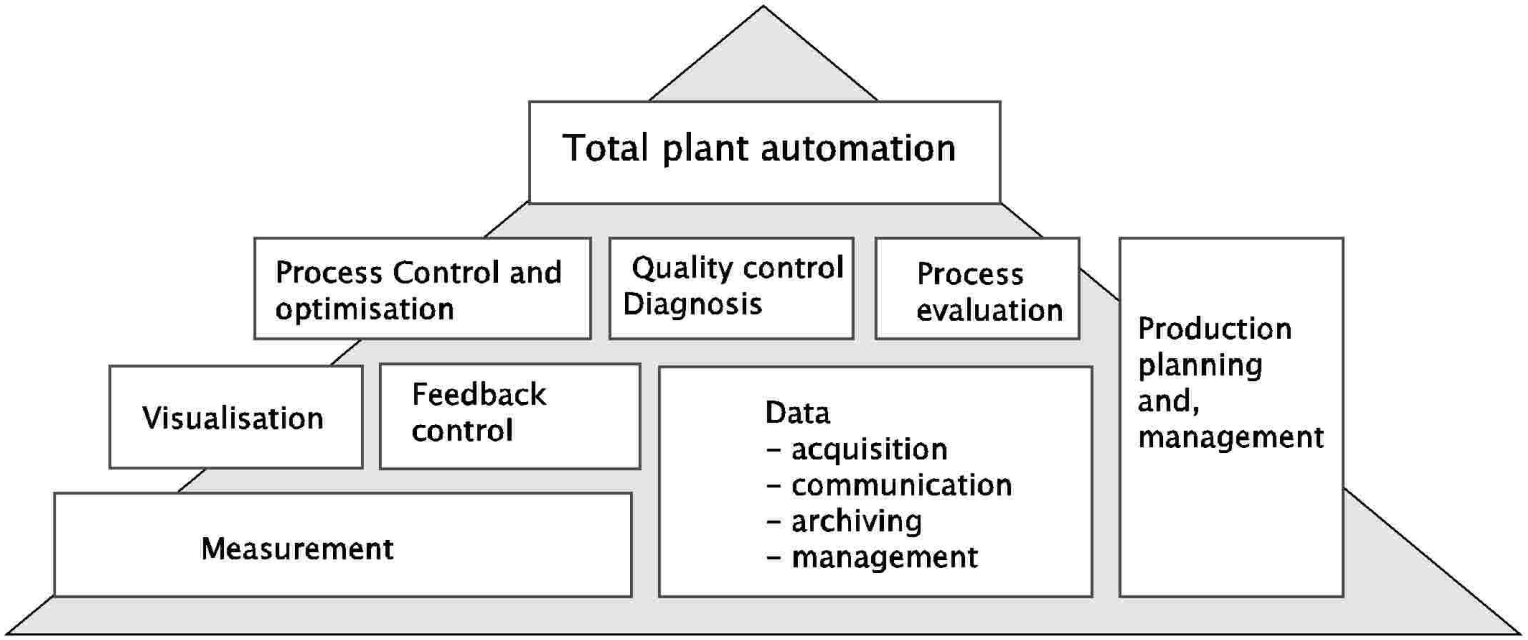
AUTOMATION TASKS TO BE PERFORMED in EXTRUSION



AUTOMATION TASKS - General -

Goal

Raise quality, increase productivity

Tasks involved

Control of motion, temperature, force etc.

Archiving and data evaluation

Monitoring Visualisation of Process variables
Alarms and Interlocks

Means available

Sensors
Methods and Algorithms for control
Hardware and Methods for signal processing and communication

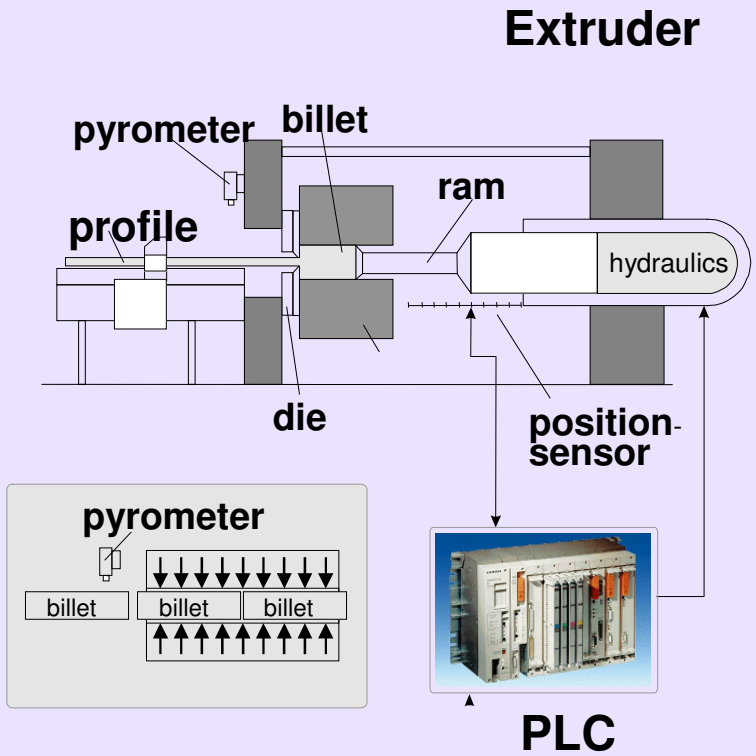
AUTOMATION TASKS in EXTRUDERS

Goal: **Increase productivity, enhance product quality**

For productivity:
Maximise extrusion rate

For product quality:
Extrude under prescribed conditions e.g. extrusion temperature and rate

To achieve both simultaneously:
Employ tight control of extrusion rate and temperature



Isothermal – Isorate Extrusion

Contents

2. AUTOMATION TASKS TO BE PERFORMED in EXTRUSION

Billet Handling

Billet transport
Billet loading
Billet heating *Control*

Extrusion

Ram movement *Control*

Profile Handling

Assess profile properties *Image processing*
Cool profile
Puller movement *Control*

2. AUTOMATION TASKS TO BE PERFORMED in EXTRUSION

For optimal production:

Prescribe values of relevant process variables appropriately

Extrude such that the variables take on the prescribed values

Process variables:

Billet temperature,

Extrusion force, Ram speed, Profile speed

Profile exit temperature,

Cooling of Profile

2. AUTOMATION TASKS TO BE PERFORMED in EXTRUSION

For choosing values appropriately

- *Use experience*
- *Gather data, analyse it and store optimal values in a data-bank and retrieve when required*

Data Acquisition Task

To extrude such that values of the variables are held in prescribed ranges

- *Display process variables and let the operator control inputs manually*
- *Use automatic control*
- *Use a combination of both*

Visualisation Task

Control Task

3 IMPLEMENTATION: Measurement and Control …

Extrusion Control Task

Adjust billet temperature and ram speed such that the process variables

Billet temperature,
Profile exit temperature,
Profile speed
Max. extrusion force
Cooling rate

lie within the prescribed ranges and extrusion speed is maximum

… 3 IMPLEMENTATION: Measurement and Control

Methods of performing the Extrusion Control Task

1. Simulated extrusion:

Make calculations using simulation studies and calculate billet temperature and ram speed (Profile temperature not measured during extrusion)

2. Feed-back controlled extrusion:

Measure process variables and adjust the input variables such that the desired runs are obtained.

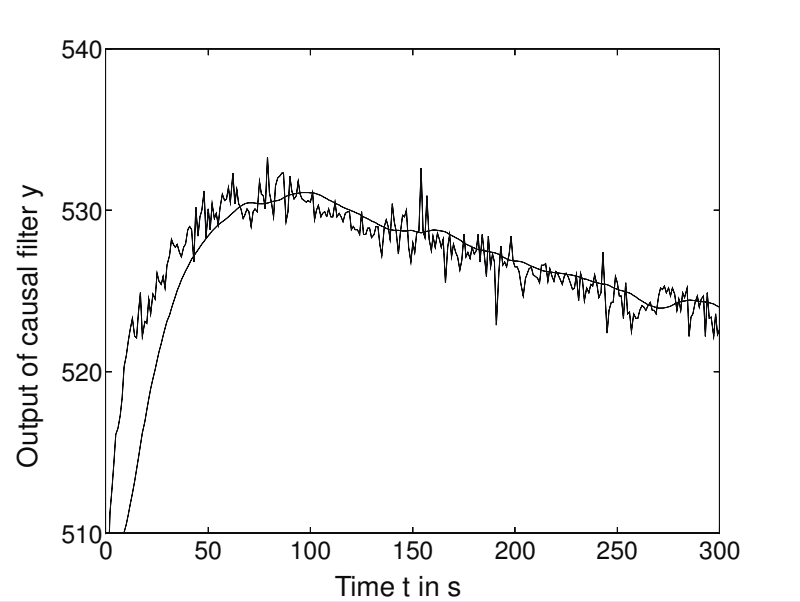
Direct Feed-back

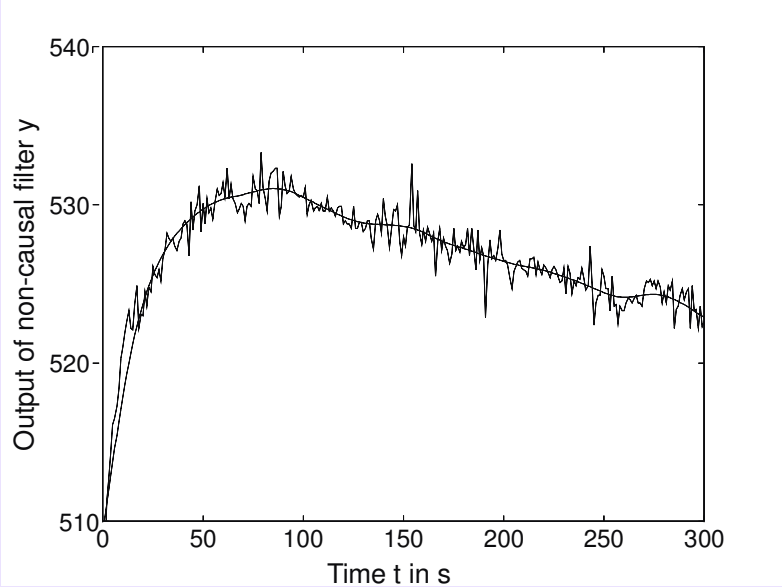
Feed- back over the cycles

… 3 IMPLEMENTATION: Measurement and Control

Non- contact temperature measurement

- for measurement and control systems for temperature of billet and profile exit with non- contact radiation pyrometers





… 3 IMPLEMENTATION: Measurement and Control

Strategy for Extrusion Control

Objectives:

Isothermal Extrusion Control
Isothermal Isorate Extrusion Control
Robustness of control

Control inputs:

Extrusion velocity
Billet temperature / - taper
Valve position of hydraulics
Velocity of billet/quench ring

hitherto: Feedforward control (simulated extrusion)
Feedback control (on-line)

now: Employ control from cycle to cycle

→ *Iterative Learning Control (ILR)*

4 CONTROL: Modelling and Iterative Learning Control …

Learning algorithm(Predictive feed- forward adaptive feed- back) :

$u_{k+1}(l) = u_k(l) + \Delta u_{k+1}(l)$ (Optimal ram speed / billet temp.)

$\Delta u_{k+1}(l) = F[\vartheta_d(l), \vartheta_k(l), \vartheta_{k+1}(l), \vartheta_{B\,k}(l), \vartheta_{B\,k+1}(l), p_{k+1}(l), v_k(l), v_{k+1}(l), \Delta\vartheta_{k+1}]$

with:

$\vartheta_d(l)$	:	Desired run of exit temperature
$u_k(l)$	:	Input as a function of extruded length of cycle k
$v_k(l)$	:	Ram velocity in current cycle k
$\vartheta_k(l)$	:	Run of exit temperature in previous cycle k
$\Delta u_{k+1}(l)$	:	Increment of input calculated for cycle k+1
$\vartheta_{B\,k}(l)$	:	Billet temperature in cycle k
$p_{k+1}(l)$	:	Extrusion force in current cycle

F[…] to be chosen (based on model) for fast convergence.

With exact model convergence to optimal input in 1 cycle !

… 4 CONTROL: Modelling

Notation

x : position of ram with respect to its starting point ,

t : time elapsed since the beginning of extrusion

$v(x,t)$: velocity of the ram when it is at position x

$\vartheta_B(x,t)$: billet temperature

$\vartheta_P(x,t)$: profile temperature

$F(x,t)$: extrusion force

$\vartheta_R(t)$: temperature of the container

$\vartheta_{die}(t)$: temperature of the die

… 4 CONTROL: Modelling

Modelling Approaches

- *Model based on exact physical laws (structure and parameters)*
  - *exact analysis leads to partial differential equations (p.d.e.) (unsuitable for control)*

- *Lumpend parameter approximations (suitable for control)*
- *Model from physics nonlinear o.d.e.*
- *Model with formal structure from input output data ('black box model')*
  - *Artificial Neural Network (ANN)*
  - *Nonlinear-Regression, fuzzy sets etc.*
- *Model with structure derived from physics + parameters obtained using measurements – ('grey box' model) our choice !*

… 4 CONTROL: Modelling

Relations between variables based on physical laws

The profile temperature $\vartheta_P(t)$ depends on

- initial temperature in the deformation zone $\vartheta_I(t)$
- the temperature rise $\Delta\vartheta_D(t)$:

$$d\vartheta_P(t)/dt = -(1/T_2).\ \vartheta_P(t) + (K_2/T_2).(\vartheta_I(t) + \Delta\vartheta_D(t)$$

K2 depends on $\vartheta_{die}(t)$, the ram velocity v(t) force F(t),

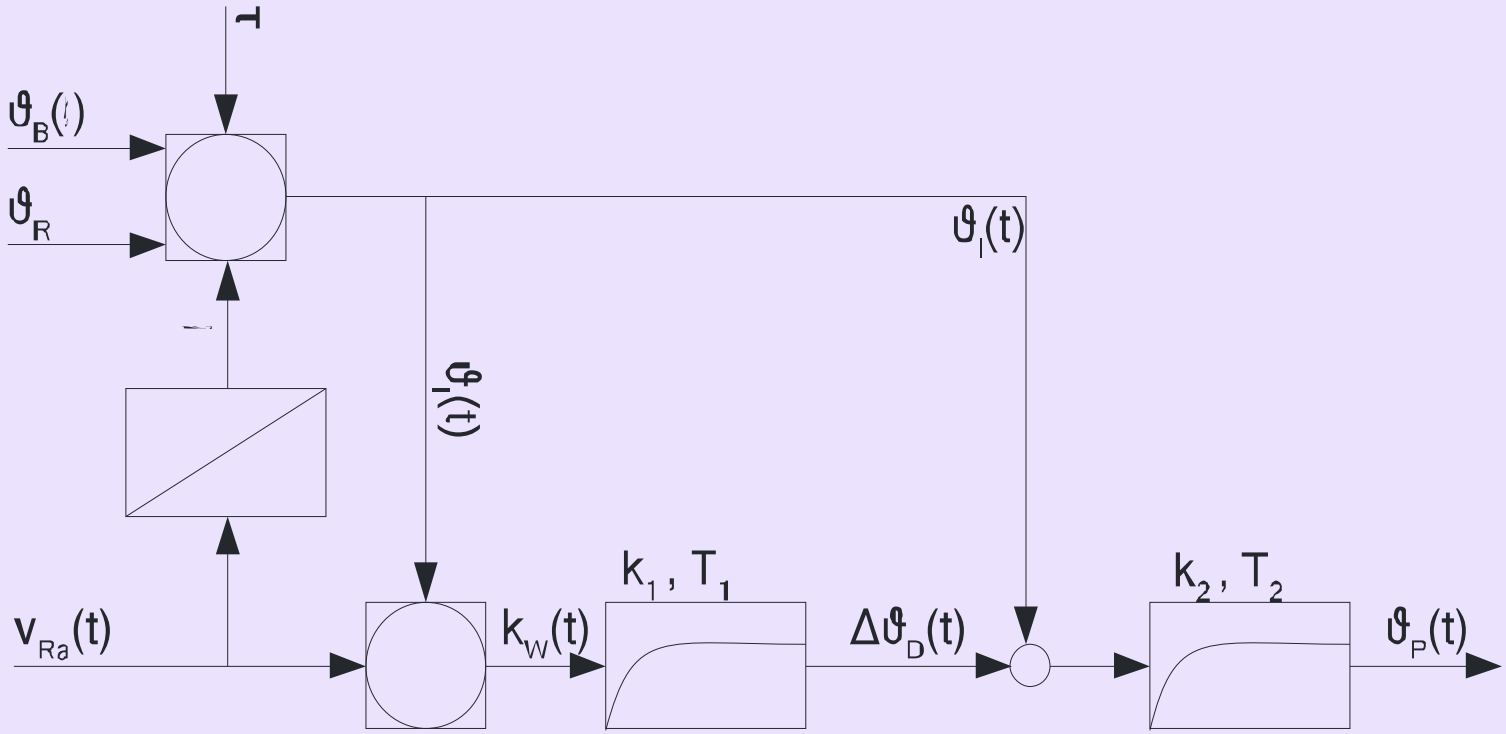
$\vartheta_I(t)$ on temperature of billet $\vartheta_B(t)$, of receptacle $\vartheta_R(t)$ and v (t)

$$\vartheta_I(t) = \vartheta_B(t) + c_1 \int v_{Ra}(\tau)\, d\tau + c_2(\vartheta_B(t) - \vartheta_R).\sqrt{t}.$$

$\Delta\vartheta_D(t)$ in the deformation zone

$$d\Delta\vartheta_D(t)/dt = -(1/T_1).\ \Delta\vartheta_D(t) + (K_1/T_1)(c_3.v^k(t).\exp(c_4 .\vartheta_I(t)).$$

… 4 CONTROL: Modelling



Block diagramme of the model

Non-linear models with Hammerstein structure

Simplifying approximations for discretised model

a. The temperature change in the deformation zone is constant.

b. The recipient temperature ϑ_R is nearly equal to the billet temperature ϑ_B .

c. The temperature of the profile ϑ_P follows changes of heat input instantaneously without lag.

d. A term is introduced to weight the influence of a ram speed change $v(n)$ depending on the billet temperature ϑ_B and ram position $L_B(n)$.

… 4 CONTROL: Modelling

Equations depicting the relationships in discrete form

$$\vartheta_P(n) = k_B.\vartheta_B(n) + k_l.L_B(n) + k_v \cdot \left(\frac{\vartheta_B(0)}{\vartheta_B(n) - k_l L_B(n)} \right)^3 \cdot v_{Ra(}n)$$

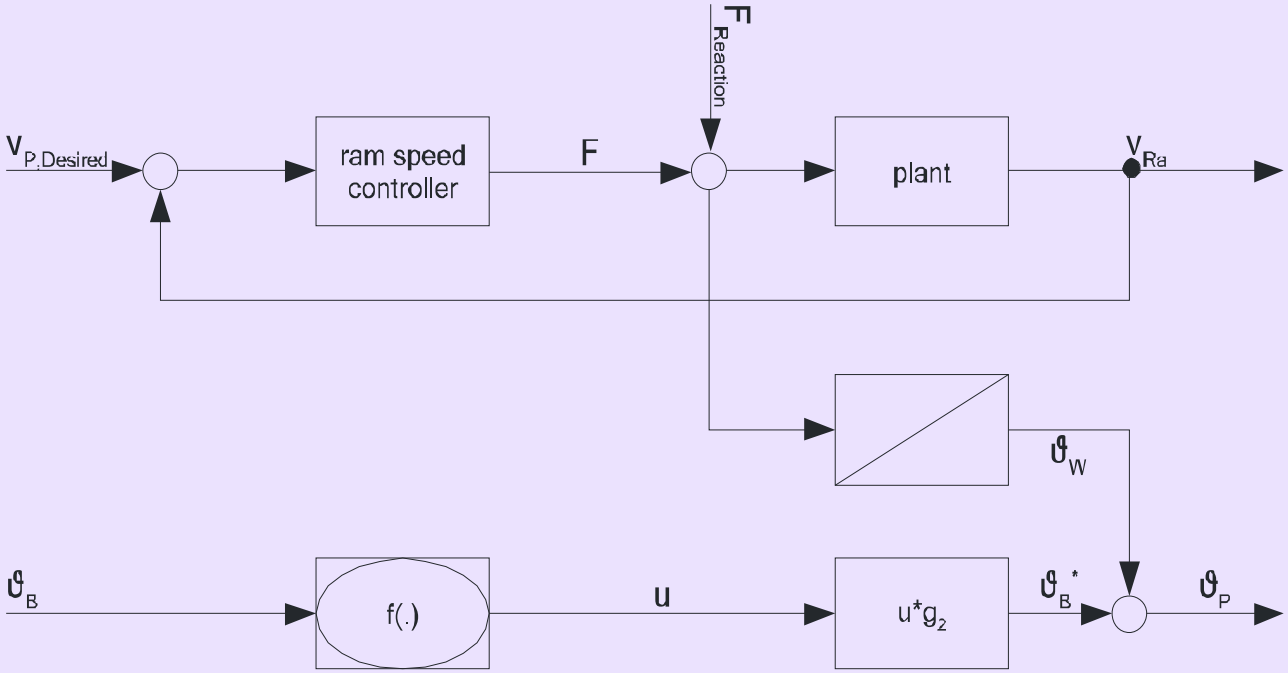
$$\vartheta_P(k) = \vartheta_B(k) + \vartheta_B^*(k)$$

$$\vartheta_B^*(k) = \vartheta_0 + \sum g_1(n).f(\vartheta_B(k-n))$$

$f(.)$ is a non-linear function approximated by

$$f(\vartheta_B(k)) = a_1.\vartheta_B(k) + a_2.\vartheta_B^2(k) + a_3.\vartheta_B^3(k)$$

… 4 CONTROL: Modelling



Block diagram with Hammerstein block

… 4 CONTROL: Modelling

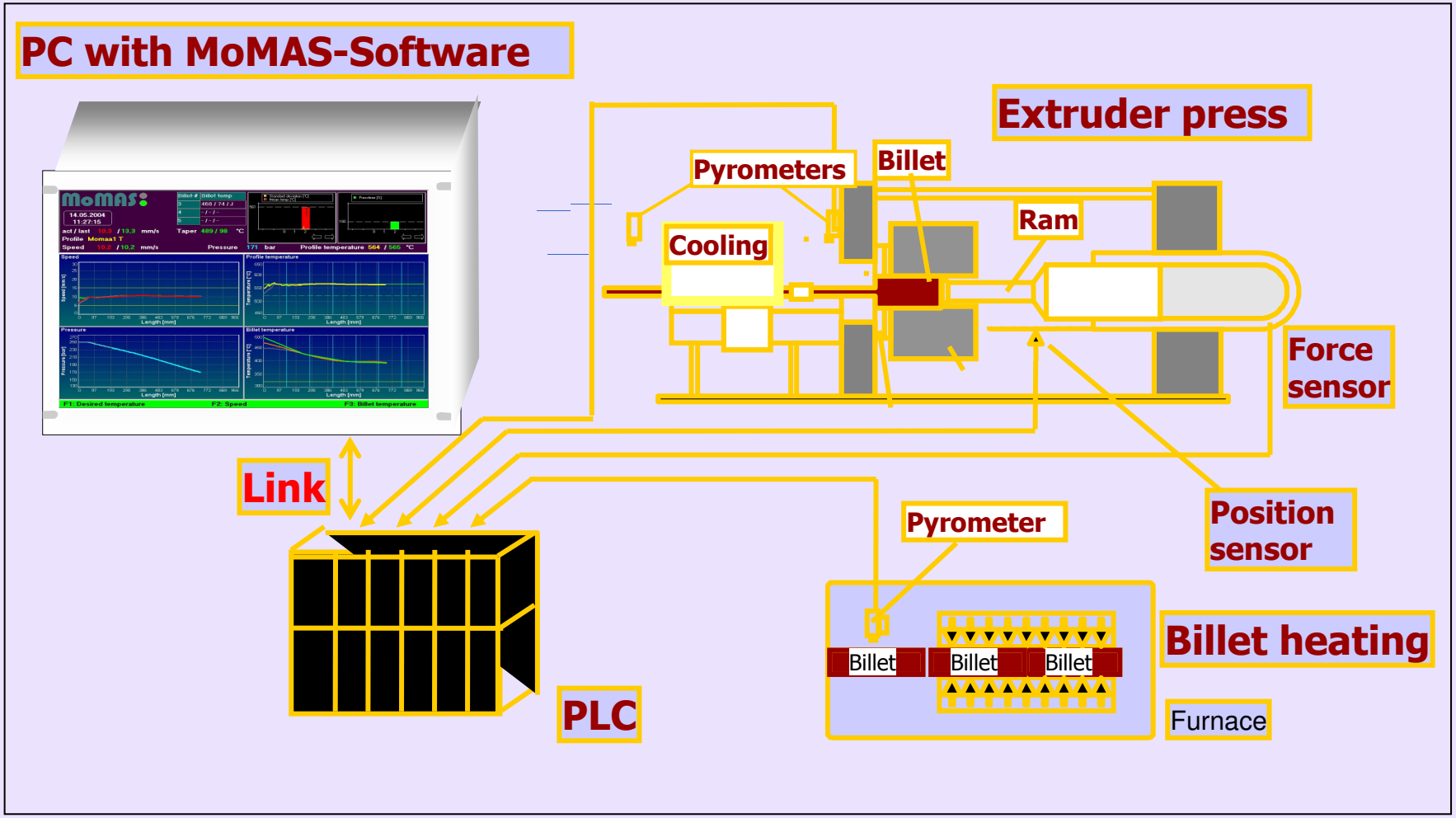
Non-linear model in general state space representation

$$\dot{x}_i = f_i\,(x_1, x_2, x_n, u_1, u_2, \ldots u_p, t)\,, \qquad i = 1, 2, \ldots, n$$
$$y_k = g_k\,(x_1, x_2, x_n, u_1, u_2, \ldots u_p, t), \qquad k = 1, 2, \ldots, q$$

Black box model in state space representation

5 A STATE-OF-THE ART AUTOMATION SYSTEM MoMAS®

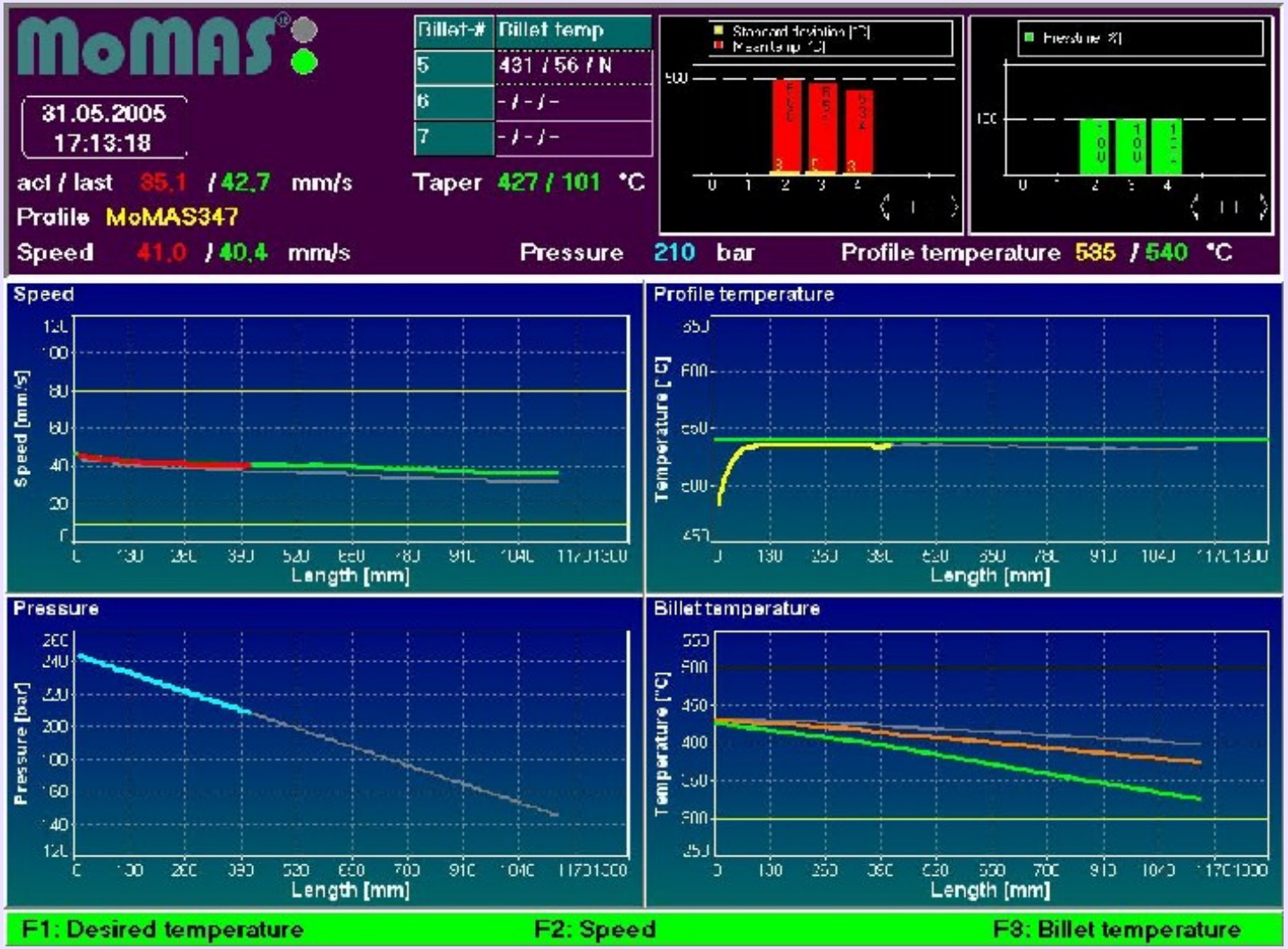
- Modular Measurement and Automation



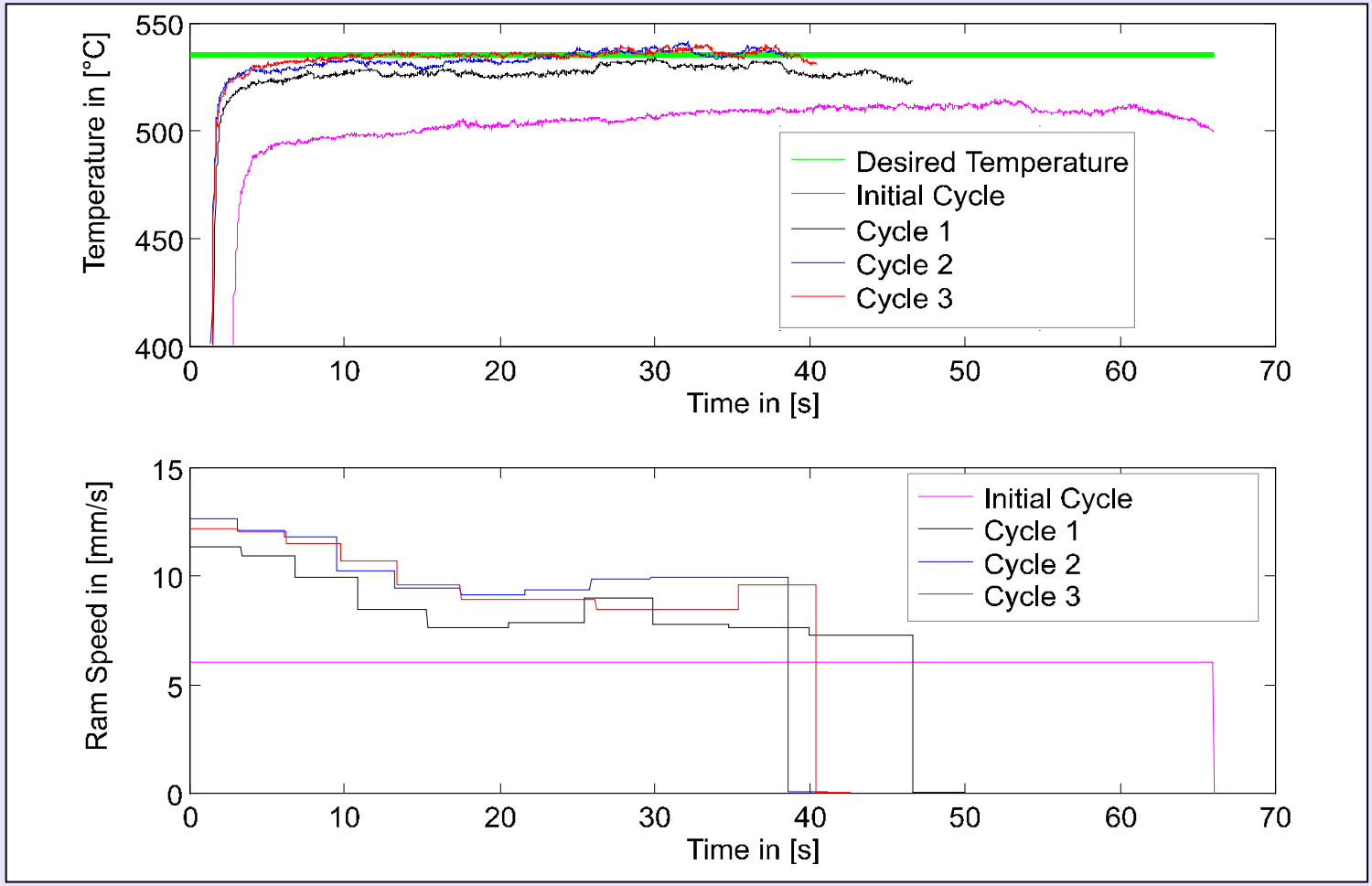
… 5 A STATE-OF-THE ART AUTOMATION SYSTEM MoMAS®

MoMAS®

Display at operator console



Runs of die exit temperature and ram velocity



… 5 *A STATE-OF-THE ART AUTOMATION SYSTEM* MoMAS®

The functions performed hitherto:

- measures and displays process variables profile exit temperature, extrusion force, ram velocity etc. during every cycle *and* extrusion time per billet, idle times and the mean temperature over the cycles
- calculates the optimal process input functions and transfers this to the PLC
- determines best process inputs for an order, stores them and retrieves them **aut**omatically when needed
- provides the extruder managers and engineers with a data data base for monitoring and evaluation a

… 5 A STATE-OF-THE ART AUTOMATION SYSTEM MoMAS®

Hardware and Software required

- Pyrometers for billet and for profile exit
- An Industrial PC with Windows operating system and MoMAS and OPC server software
- A sensor for measuring the position of the ram

Prerequisite for the installation

availability of

- A hydraulically actuated ram
- A PLC (e.g. Siemens S5/S7, Allen Bradley 5/40 etc.)
- An inner velocity control loop and
- *Of advantage:* An induction furnace for controlled taper

Production Statistics of Extruder equiped with MoMAS ® at SAPA Offenburg

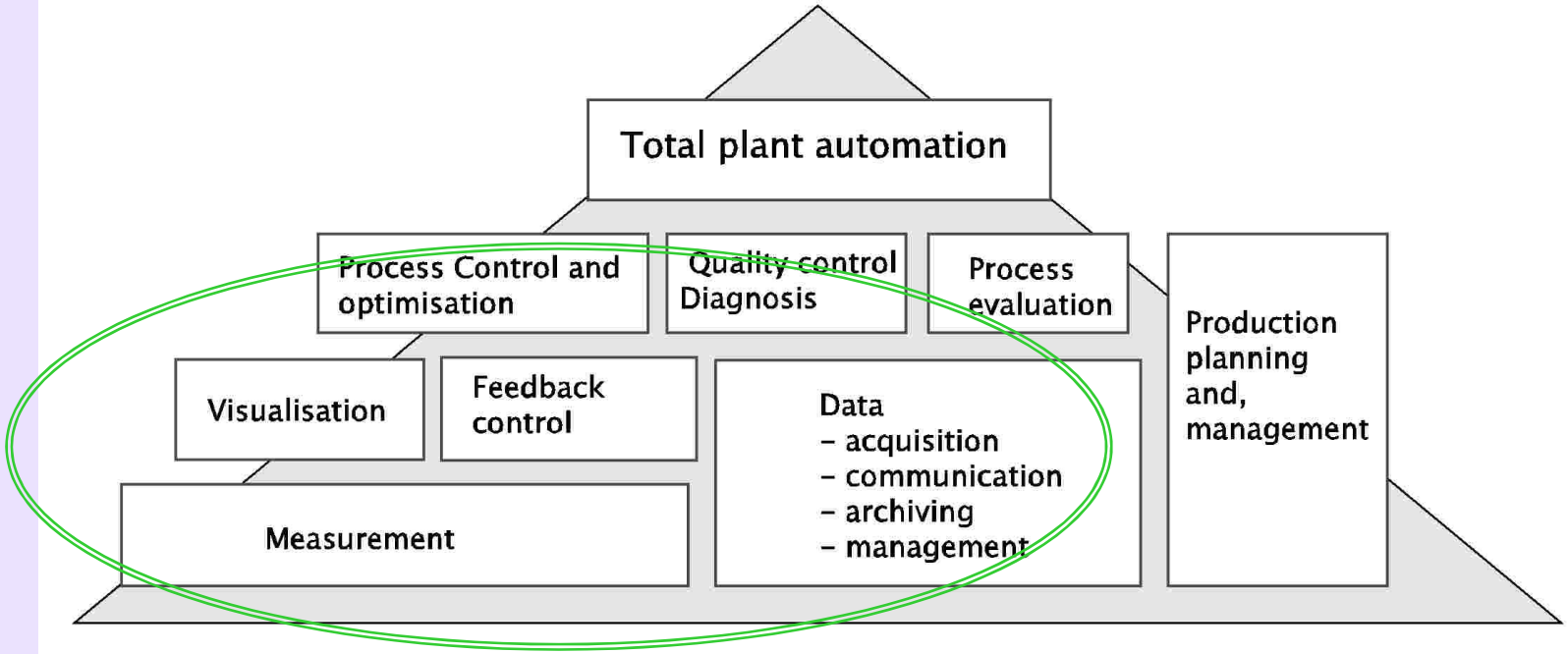
	No. of billets extruded	Mean extrusion rate	RMS error of exit temp. ϑ	Standard deviation of ϑ
With MoMAS	30 381	10,02 mm/s	12,1 °C	3.89 °C
Without MoMAS	26 180	9,29 mm/s	(28,8 °C)	4,21 °C

Actual production statistics for the period May – September 2001 of an extruder in Offenburg

Note increased mean extrusion rate of > 6%

6 CONCLUSIONS AND PERSPECTIVES …

How far are we with total automation ???



Achieved !!!

… 6 CONCLUSIONS AND PERSPECTIVES

Commercial viability

Is extruder plant working at its full capacity ?
Is there a demand for increased product output ?
Is a new market sector being envisaged ?

Technical feasibility

Are the hydraulics and ram position / speed control adequate ?
Is the billet furnace temperature control in order ?
Is the puller control adequate ?
Is the PLC capable of handling the data traffic ?

Acceptance by the crew

Is the crew capable of coping with the new system ?

… 6 CONCLUSIONS AND PERSPECTIVES

Conclusions

- Contactless temperature measurement of extruded aluminium with high accuracy is feasible
- Advanced extruder control based on exit temperature monitoring offers an useful tool for total automation
- *Isothermal extrusion at constant extrusion rate* has been implemented employing MoMAS to achieve gains in productivity and quality
- Improved models yield faster convergence

Perspectives

- Fault detection and technical diagnosis using process model

Whether automation based on temperature measurement and control is expedient seems to be a dogma…

If you think it is not necessary, you may be right….

or
- more likely -
you may be left behind

INSTALLED SYSTEMS

Presses which run with MoMAS ®

- 3 presses in Germany (SAPA , ALCAN and Research Centre for Extrusions, Berlin)
- 1 press in Sweden (SAPA)
- 2 presses in Italy (ALEX and COMETAL)
- 2 presses in USA (SAPA)
- 4 presses in Australia (CAPRAL)
- 2 presses in Russia (Minsk)