EVALUATION METHOD AND WORKBENCH FOR APC STRATEGIES

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Abstract: The large number of various advanced control strategies (e.g. Model Predictive Control, Neural Networks or Fuzzy Control) and the lack of a practically usable selection methodology make it very difficult to choose an appropriate strategy for a given plant. In order to support the selection of proper control strategies and products a set of relevant evaluation criteria is developed. A flexible and expandable test environment (workbench) is created aiming at a controller evaluation considering these criteria. The evaluation approach and workbench are demonstrated for PID based and commercial Model Predictive Controllers at some typical process units and plants.

Keywords: Advanced Process Control, Model Predictive Control, Evaluation, Simulation

1. INTRODUCTION

In the last decade, in the area of process control more sophisticated control strategies have been developed (e.g. Model Predictive Control, Neural Networks or Fuzzy Control). With the number of advanced control algorithms increasing a sound selection of the control strategy and product became a challenging task.

The main objective of this project was to develop a methodology and tools to evaluate / compare different control approaches from the viewpoint of industrial application.

To obtain practical relevance all important aspects of the controller application should be considered. Therefore the standard criteria describing the controlled variable performance (i.e. set point and disturbance responses, IAE, ISE) are extended by such practical issues as:

- Engineering and operational aspects
- Robustness and integrity
- Ability to explicitly consider constraints.

Based on literature (Harris, 1996; Joshi, 1997; Le Page, 1998; Schuler, 1998; Seborg, 1999), interviews of control engineers and personal experience a criteria catalogue was accomplished (details in section 4.).

A set of answers to all the criteria is thought as valued guideline for the selection of most appropriate control strategies or products. Considering the diversity of all the criteria, the processes, the enterprises and the control tasks no attempt is undertaken to provide a single selection, instead the user is supported in his multiobjective decision.

The initial idea of the project was to create only exemplary evaluations of important control strategies for typical process units which should represent entire classes of equipment and to obtain generic evaluations. However, a retrospective result is the usefulness of the proposed approach for any specific process assumed its detailed dynamic model is available.

While some of the criteria can be evaluated using documentation / literature others need

measurements in a real plant or - as chosen in this project - in a suitable simulation environment.
This simulation environment (referred to as Workbench) is the platform for the detailed dynamic process simulation, for the basic control functions, and can be connected to commercial Advanced Control Algorithms. It is utilized to “experimentally” obtain the controller design models as well as to implement and evaluate the controllers.
To achieve an industrially relevant assessment of the above mentioned criteria a commercial distributed control system (DCS) is used and representative commercial advanced controller software packages can be included. The emulated controller of the DCS performs the basic controls of the simulated units or plants, and provides the interface between the emulated DCS controllers and the advanced controller (Figure 1).
In addition it provides the function blocks for some conventional advanced control strategies (e.g. PID based, and decoupling control).

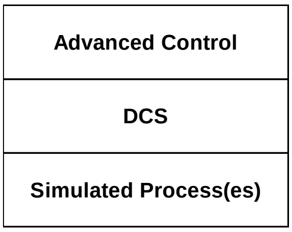

Fig. 1 Workbench Structure

2. TECHNICAL REQUIREMENTS FOR THE WORKBENCH

A complete controller evaluation is not possible in a sole offline-simulation environment such as Matlab/Simulink since the actual commercial control products are available only as self-contained applications without source code. This and the intended use of the workbench lead to the following demands:

- evaluation of strategies and products
- evaluation of commercial and user programmed controller
- fast simulation
- high reproducibility
- availability of appropriate interfaces
- implementation on heterogeneous distributed computers / DCS systems
- assessment of engineering effort
- flexible choice of controller or process models, respectively.

The selected workbench structure is depicted in figure 2 and contains the following levels:
<u>APC-Strategies / Products</u>: Commercial as well as user-specified APC-strategies, which are relevant for the process industry and hence will be assessed.
<u>Distributed Control System (DCS)</u>: The DCS is utilized as Operator-Station, data transfer unit and watchdog. In addition, PID-controllers can be realized in the DCS. The control units (process connected devices) can be emulated on the PC.

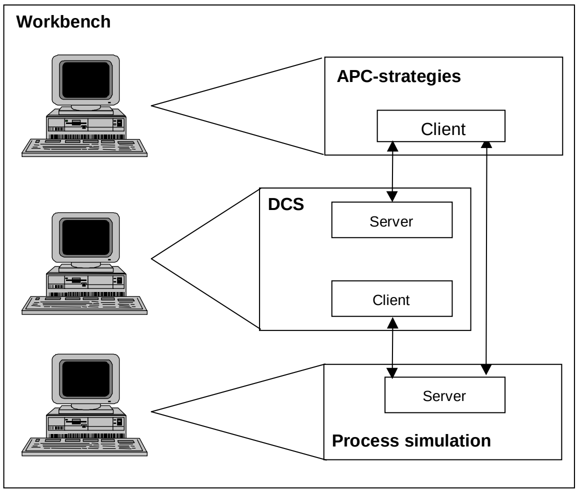

Fig.2 Client-Server-Concept of the Workbench

<u>Process simulation</u>: The existing plant is replaced by a dynamic typically non-linear, first principles process model. The demand of a flexible and easily usable workbench requires a well-defined connection from the APC to the simulation process via the DCS (Figure 2). The desired flexibility and short training period to get familiar with the workbench is attained by using Microsoft Windows NT operating system which provides several (industrial) standard interfaces like Dynamic Data Exchange (DDE) and OLE for process control (OPC). Because of the performance advantage of the OPC versus the DDE and its popularity in process automation the OPC-interface is selected as standard interface in the workbench.
Most of the actual APC products provide an OPC-interface, therefore they can easily be implemented in the workbench. However, the products of the simulation level (i.e. MatLab or Gproms) do not provide this interface as standard feature. Therefore several simulation products were extended with the OPC interface. OPC is based on the Client-Server-Concept, and the APC-strategies usually provide the OPC-Client functionality only. Thus the selected DCS needs to have an OPC Server and an OPC Client in order to accomplish the depicted connections. The OPC code of WinTECH Software Design was used to add these functions to Matlab/Simulink and stand-alone simulations (WinTECH, 2001). The different workbench levels can be implemented on a single PC or two / three PCs communicating via TCP/IP.
Due to the real time character of some workbench components (e.g. DCS, MPC) their calculations are normally triggered by the computer’s real time clocks. The interactions of the process model and the controller must be synchronized. The achievement of a significant acceleration of the simulation time compared with real time (up to the factor of 100 on standard PC) was a challenge and at the same time a prerequisite to cope with the many simulations necessary for the evaluation. One simple option is to “shrink” the controller’s time scale by the ratio “necessary computation time for

integrating the model about a given real time interval / real time interval". Another option is using the "external trigger" mode of the APC-strategies. In this mode (often hidden for end user) the controller calculations can be triggered by an external program.

3. PROCESS MODELLS AND CONTROLLERS IMPLEMENTED

The four process models used in the workbench hitherto are:

- A Binary distillation column: A simple distillation process, enabling initial experience in controller implementation and evaluation
- A Distillation Operator Training simulator: A detailed rigorous dynamic plant model which can be used not only for normal operation but also for the simulation of start-up, shut down transients and several process / equipment malfunctions.
- A Divided Wall Column (DWC): A DWC can efficiently be used for the separation of three products. Since a dynamic model was developed for a DWC pilot plant the evaluation approach could be accomplished on the model and on the pilot plant. This provided the opportunity to validate the simulation based evaluation approach by real process data.
- The Tennessee Eastman process: A complex academically well acknowledged control benchmark process

All models contain unit operations relevant and typical for process industry. With the exception of the first model they all comprise not only the main equipment components but also the auxiliary ones, e.g. separators, pumps heat exchangers.
The commercial DCS and controllers which were offered to participate at the evaluation are:

- DCS PlantScape, Honeywell
- RMPCT, Honeywell
- DMC, Aspen
- INCA, Ipcos
- 3dMPC, ABB .

4. APPLICATION OF THE EVALUATION CRITERIA

The evaluation approach is divided into five groups containing qualitative or numerical ratings. The tables 1 to 5 list the criteria concerning:

- identification and tuning
- implementation of the controller
- control performance
- control system robustness and integrity
- usability

The application of the evaluation criteria is exemplarily demonstrated here for the binary distillation column.

The binary distillation column (Figure 3) comprises 41 stages and separates a binary mixture. The model is based on the following assumptions:

- Constant relative volatility
- Constant hold-up
- Perfect level control.

The model of the distillation column considers the material balance and the phase equilibrium on each stage.
As both the bottom and the top condenser levels are assumed as perfectly controlled, the remaining manipulated variables reflux flow and heating steam flow are utilized to adjust the concentrations of the light component x_T and x_B.
The control objective is to ensure tight control of x_T and x_B during operating point transition and in the presence of disturbances (feed flow and composition changes).

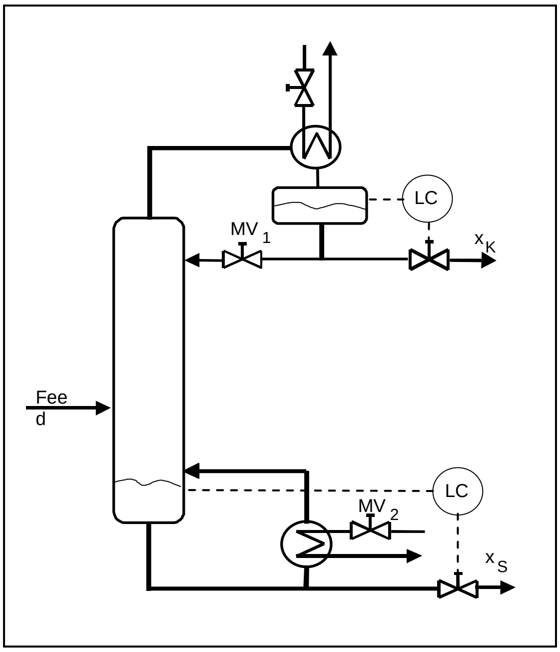

Fig.3 Distillation column

The model of the column is a non-linear Multi Input Multi Output (MIMO) system. Although the process has only two manipulated and two controlled variables, it represents some typical features of distillation units.
The comparative evaluation study includes the following controllers:

- Decentralized PID controller
- PID controller with steady state decoupling
- Commercial Linear model predictive controllers (MPC #1, MPC #2).

Both PID based control structures are implemented on the DCS, the MPCs are installed on top of the DCS.
The evaluation method comprises the assessment of the controller design steps and of the controller performance:

- Controller design:

- Identification to obtain the controller design model (e.g. step tests at the rigorous model)
- Tuning of the controller
- Offline simulation using the design model

- Implementation of the controller on the non-linear simulation model of the plant.
- Investigation of controller performance
  - Controlled variable performance
  - Stability
- Applicability

Example:
The first step of the controller design is the model identification to obtain a design model (figure 4).

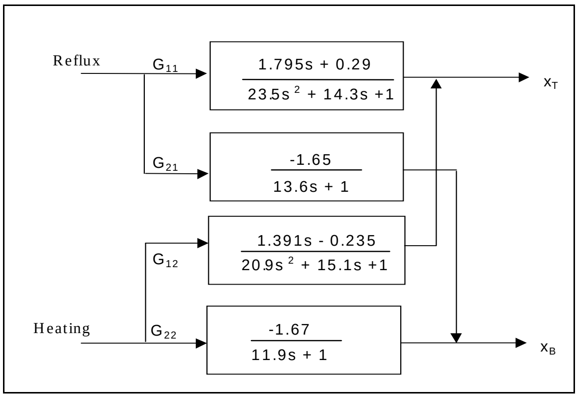

Fig.4 Linear model of the column

At the next step the controllers are to be configured and tuned. To achieve an equal performance specification for all controllers, the tuning parameters are adjusted to obtain the same closed loop settling time (figure 5) with minimum manipulated variables activity.
This indirect "unification" was necessary because the optimisation criteria of the commercial MPCs differ widely and are not documented in detail.

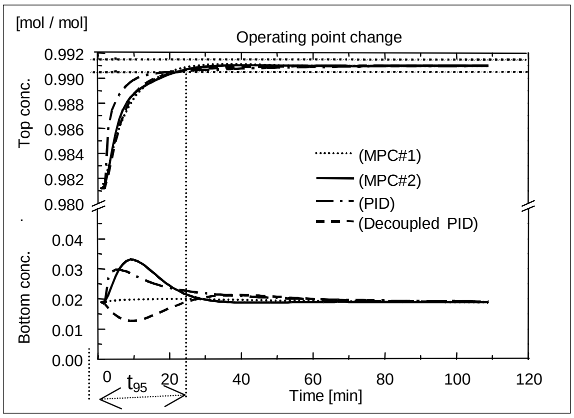

Fig. 5 Closed loop settling time t_{95} specification (linear model)

For the PID controllers the IMC tuning was applied whereby the two λ were determined by a non-linear optimisation according to the above objective.
The evaluation criteria concerning identification are shown in (table 1).

After being tuned the controllers can be implemented and used to control the non-linear simulation process. The assessment of the implementation procedure is given in table 2.
The controlled variable performance can be evaluated analysing figure 6.

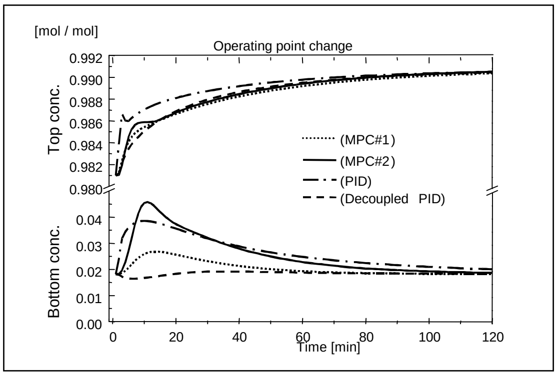

Fig.6 Closed loop control (non-linear model)

It shows the transients of the non-linear plant with the different controllers for a given change of the operating point (x_T).
Further quantitative evaluation criteria values are given in table 3 to assess the controlled variable performance.
As analytical considerations of the stability margins are hardly possible many of the considered controllers they are determined here by an empirical simulation approach. To do this gain or dead time blocks are placed between model outputs and controller inputs. Either the gain or the dead time is increased until the closed loop stability threshold is reached. The obtained gain and delay represent some kind of of the phase and gain margins. The robustness is considered as criteria in the table 4 below, see also (Subawalla, 1996; Le Page, 1998).
Last but not least some features describing the practical usability are investigated (table 5).
From these evaluation criteria it gets evident that the selection of a control strategy and product for a given plant type and control objective is a multi-objective task. However, the proposed criteria give a clear guideline, which allows to give the choice a reasonable foundation. Besides the proposed evaluation criteria, the final decision is also influenced by "external" and partially soft factors as companies policy.
For the given simple binary distillation with relatively "control-friendly" steady state and dynamic behaviour and no explicit constraints on controlled and manipulated variables the best choice is obviously a pair of PID controllers with steady state decoupling.
Similar investigations were performed also for the other processes mentioned above and for an additional commercial MPC. The evaluation results are published in (Mahn, 2003).

5. SUMMARY

The proposed approach to evaluate control strategies and products (incl. their tools) in a close-to-reality simulation environment has been tested on several processes from a relatively simple binary distillation column up to the difficult to control Tennessee Eastman Challenge benchmark process. The approach was successfully validated applying the evaluation criteria for both a real pilot plant DWC with DCS and for a simulated DWC in the workbench.

Until now PID based control structures and several linear MPC controllers were analysed.

The major findings for the time being are:

- The evaluation of advanced control strategies using a simulation environment and rigorous models of typical units is feasible (and affordable).
- While the evaluation results of the workbench regarding the controllers inspire confidence the assessment methods / tools seems to be less significant due to the variety of disturbances and operating limitations in real plant experiments.
- Practically relevant evaluations comprise more than just controlled variable performance only.
- The evaluation results can be significantly biased / influenced by the evaluator's experience. This issue is worsened due to the lack of good product manuals / documentation.
- The maturity of the evaluated APC products regarding the engineering by external users is still low.
- Besides the use as evaluation tool the developed workbench turned out to be a useful medium to acquaint oneself with the identification / design and operation of control products and to try out control system designs.

Tab. 1 Criteria concerning identification and tuning

Criteria group	Criteria	PID	PID with decoupling	MPC #1	MPC #2
Identification	Identification tool available	No[1]	No[1]	Yes	Yes
Tuning	Model accuracy	Normal	Normal	Normal	High
	Number of tuning parameters	1[2]	1[2]	1	5 (many)
	Tuning rules available	Yes	Yes	Yes	No
	Off Line simulation possible	No	No	Yes	Yes
	Adaptation of parameters possible	Yes	Yes	No	No
	PV transformation possible	Yes	Yes	Yes	Yes

[1] several identification tools available [2]due to IMC-tuning

Tab. 2 Criteria concerning the implementation of the controller

		DCS			
Criteria group	Criteria	PID	PID with decoupling	MPC #1	MPC #2
Implementation	Transfer of tuning parameters from offline to online possible	No	No	No	Yes
	Minimal execution period	50 ms	50 ms	5 sec	5 sec
	Connection controller to DCS	Browser	Browser	Manual	Manual
	Special requirements for the tags	No	No	Yes	Yes

Tab. 3 Criteria concerning the control variable performance

		DCS			
Criteria group	Criteria	PID	PID with decoupling	MPC #1	MPC #2
Controller Performance	$J_{11} = [\ \Sigma e(x_T)^2 \mid \Sigma \Delta u_1^2\ ]$ $J_{22} = [\ \Sigma e(x_B)^2 \mid \Sigma \Delta u_2^2\ ]$ $RPI = \frac{J_{ij}(Actual\,Controller)}{J_{ij}(Dec.PID\,Controller)}$	Top conc. [1 | 1] [1 | 1] Bottom conc. [1 | 1] [1 | 1]	Top conc. [2.0 | 0.5] [0.005 | 1.0] Bottom conc. [0.2 | 0.9] [2.1 | 0.32]	Top conc. [2.0 | 0.3] [0.1 | 0.6] Bottom conc. [0.8 | 0.1] [2.3 | 0.06]	Top conc. [1.9 | 0.2] [1.0 | 0.5] Bottom conc. [0.8 | 0.06] [2.3 | 0.02]

e = set point-controlled variable Δu =manipulated variable J = controller performance criteria

Tab. 4 Criteria concerning the control system robustness

		DCS			
Criteria group	Criteria	PID	PID with decoupling	MPC #1	MPC #2
Stability margin*	Robust design possible	Yes	Yes	No	No
	$RRI_{KP} = \frac{\Delta KP}{\Delta KP_{PID}}$ (1)	$RPI_{KP}(x_T)=1$ $RPI_{KP}(x_B)=1$	$RPI_{KP}(x_T)=18$ $RPI_{KP}(x_B)=4$	$RPI_{KP}(x_T)=3.0$ $RPI_{KP}(x_B)=1.2$	$RPI_{KP}(x_T)=3.0$ $RPI_{KP}(x_B)=1.5$
	$RRI_{TP} = \frac{\Delta TP}{\Delta TP_{PID}}$ (2)	$RPI_{TP}(x_T)=1$ $RPI_{TP}(x_B)=1$	$RPI_{TP}(x_T)=4.5$ $RPI_{TP}(x_B)=1.2$	$RPI_{TP}(x_T)=5.0$ $RPI_{TP}(x_B)=2.4$	$RPI_{TP}(x_T)=5.0$ $RPI_{TP}(x_B)=3.2$

(*): Used as measure of the control system robustness

(1): ΔKP is the minimal change of the process gain, which induces unstable operation for the controller.

(2): ΔTP is the minimal change of the process dead time, which induces unstable operation of the system.

ΔKP_{PID}, ΔKT_{PID} are the values of the stability thresholds of the PID controllers used as reference.

Tab. 5 Criteria concerning the usability

		DCS			
Group of criteria	Criteria	PID	PID with decoupling	MPC #1	MPC #2
Usability	Separately usable subsystems supported	Yes	No	Yes	Yes
	Anti-reset windup supported	Yes	No	Yes	Yes
	User interface available / customized possible	Yes / Yes	Yes / Yes	Yes / No	Yes / No
	Quality of human-machine-interface (poor, normal, excellent)	Normal	Normal	Normal	Poor
	Quality of user guide (poor, normal, excellent)	Normal	Normal	Poor	Poor

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