Chemical Process Control: Present Status and Future Needs – The View from European Industry

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Abstract

Not only in Europe, chemical process control is characterized by a broad invasion of distributed control systems into chemical plants. The information integration from process control up to business management is a great challenge of today which follows from the overall computerization of production. Most of the recent progress in process automation results from the application of computer science paradigms to control systems, and of advanced developments in field instrumentation. Despite these advances and the considerable progress made in process control theory, there is only limited acceptance and application of modern advanced process control methodologies in industrial practice. This paper is an attempt to summarize the European discussion on the reasons for these facts.

Keywords: Chemical process control, computer integrated production, advanced control, quality control, distributed control systems.

1 Introduction

With respect to chemical process control, the last decade, the eighties, can be characterized by the broad invasion of distributed control systems (DCS) into chemical plants. For illustration, Fig. 1 shows exemplary the number of installed DCS in BASF AG, Ludwigshafen. The Ludwigshafen complex of BASF contains about 360 chemical production plants with sales of about 22 Billion DM per year. The extended functionality of computerized process control equipment led to an increasing importance of process automation especially in newly installed plants. As an example, Fig. 2 shows the electrical and control equipment costs related to the costs of machinery and plants over the last years, at BASF AG. This graph expresses the strong trend to install important plant functions in the automation part of equipment. This trend will probably continue due to rapidly increasing computer power and storage capacities, as well as the improving possibilities of computer integration at all functional levels of process control and plant management.

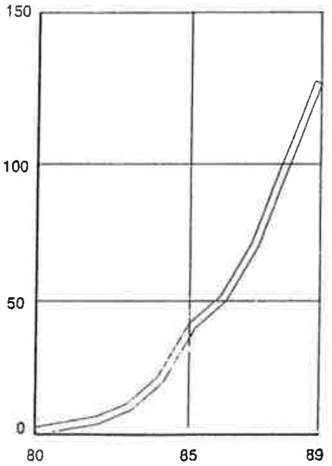

Figure 1: Number of installed DCS, at BASF Ludwigshafen

This rapid technical evolution is not only a consequence of the exponential growth of microelectronics and of digital computers. It is stimulated by strong trends in chemical engineering and plant operation as well:

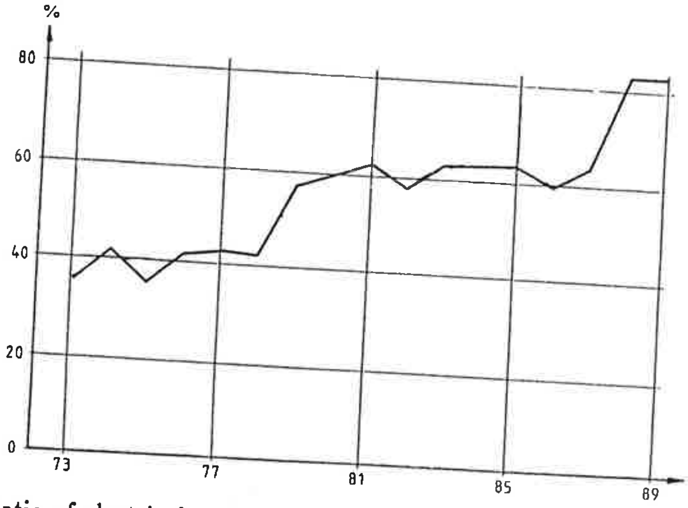

Figure 2: Ratio of electrical and control equipment costs to those of machinery and plants, at BASF Ludwigshafen

- Plants are designed to be highly integrated in the mass, energy and information flows.
- Plants should allow a flexible production of different products at different throughputs.
- Production must be tracked to market demands without delays, just in time.
- Information becomes an important production factor.
- Product quality is superior to mass production. Quality requires transparent and reproducible plant operation.
- Safety and environmental requirements give new constraints to plant design and operation.
- Administrative regulations require an exhaustive documentation of plant operation principles and production runs.
- The global competition requires an increase of productivity, and thus a continuous cost reduction of production and of maintenance.

It is a common opinion that advanced control techniques will help to follow these trends.

In the following, the present industrial state of the increasingly important discipline of process control will be analysed. Especially the impact of advanced process control theory on the present state will be dealt with in detail.

2 Present status of industrial process control applications

The Hierarchical Layer Model of Plant Management and Control

The organization of the following statements will be oriented to the hierarchical structure of plant management and control functions. This layer model is depicted in Fig. 3. It helps to classify the tasks of plant management and control functions due to the number of specified operational details, and due to the horizon of operative planning. The specific functions of the layers will be discussed in the following with respect to their present state in chemical industry. The degree of computerized information processing differs substantially in the different layers. There are deficiencies in the plant

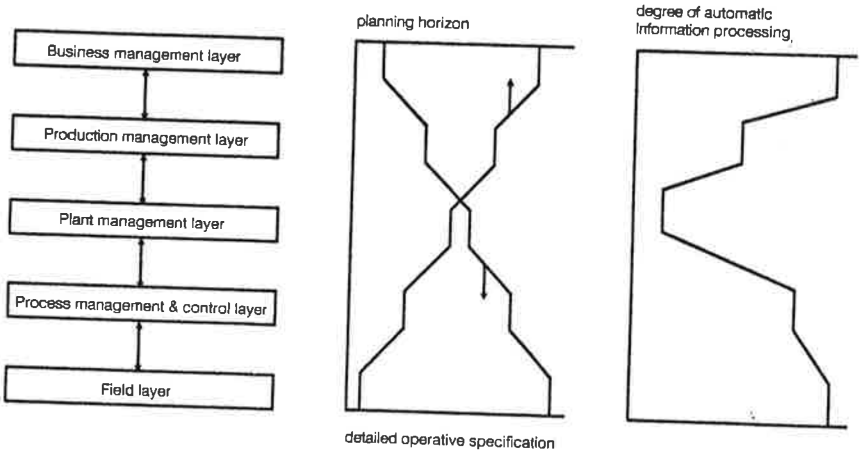

Figure 3: Hierarchical layer model of plant management and control functions

management layer, whereas business administration and process control make use of almost complete information processing capabilities.

The Field Layer: Sensors and Actuators

Standardized measurement instrumentation in chemical process industries is mostly restricted to a limited number of important process variables, like temperature, pressure, flow, level, etc. . The field instrumentation for these variables is designed to be robust and highly reliable. With respect to measurement range sensitivity and absolute accuracy it is normally not as precise, as required in most of advanced process control concepts.

Many other process variables, especially those representing product properties and product quality, are measured continuously only in rare cases. That means that only a small part of the plant state vector is available as sensorial information. When process or product properties are measured, the signals represent not the state variables separately, but, in general, a nonlinear interference of many states. A typical example of these indirect measurements is the density which is a function of temperature, pressure and composition of the process mixture.

On-line-measurements of composition and quality are provided (e.g. by chromatographs) in discrete times, and are normally corrupted by significant time lags. These instruments often need intensive maintenance.

Field instrumentation covers the major part of investments in automation equipment. According to the requirements of quality, operability, environment and safety, the number of measurements still increases continuously in chemical plants. Especially quality control will require additional process-analytical measurements not yet available for production conditions. There is a trend to apply new measurement principles providing additional process variables at least quasi-continuously.

Another trend is the fusion of sensor elements with microcomputer components. These sensors called "smart" or "intelligent" are often based on digital principles. They allow data processing, check of plausibility and functionality, automatic calibration, and other features. These functions of decentralized intelligence provide a qualitative improvement of sensor data quality.

The digital realization supports the mutual communication of individual sensors, and the bidirectional communication with automation systems of the superimposed layer. There are intensive developments and standardization efforts on field bus communication protocols and functionalities. The communication of instruments of different suppliers is mostly impossible at the moment.

Actuators are the second fundament of the field layer. Despite of large progress in instrumentation, the actuator functions are blind spots in control theory interests.

The Process Management and Control Layer

Process controls installed in production environment have a number of specific characteristics:

- Controllers are operated using predefined blocks in DCS-software. This technique results in a user-friendly interface to operators and to maintenance.
- A characteristic feature of DCS-implementation is the great flexibility to make structural variations in the automation strategy.
- The implementation of controls is mostly restricted to the capabilities of predefined DCS-software. An implementation of advanced control concepts is difficult when special information processing structures are required which are not available in the DCS toolbox.
- Some DCS offer integrated specialized computer modules, or programmable software modules, in order to allow the user to do process-specific calculations.
- Single-loop controls are used in the vast majority of applications. Loop-pairing is based on physical, intuitive principles, and on trial and error during plant startup. Controller design packages are used only in exceptional cases.
- Simple loop nestling strategies like cascading etc. are frequently used in DCS-realizations. The same holds true for different forms of structure-selective controls.
- Multivariable control is done sometimes in the form of decoupling control (e.g. for distillation columns (Trilling and Kaibel, 1980)). Another multivariable struc-

ture sometimes used is sensor data fusion to calculate control variables which are controlled in single-loop.

- Controllers based on transfer function models are used for deadtime compensation.
- Controllers based on physicochemical models are used in few applications.
- Adaptive controllers often work satisfactorily when based on heuristic principles (Krahl et al., 1986).
- Predictive control schemes are implemented at some plants (Froisy and Richalet, 1986).
- Knowledge-based controls are far away from industrial acceptance. Only a few research-based applications are known (Soltysiak, 1989), many attempts failed in the past years (Ahrens, 1990).
- Neural network approaches are in the state of academic research. No industrial application to chemical processes is known to the authors.
- Maintenance of advanced controls is normally done by special groups of highly qualified control experts. Personal continuity is not always provided in these groups.
- In the past, unreliable computer hardware (e.g. micro-computers) in conventionally instrumented plants led to loss of credibility of advanced methods in general.

The predominance of continuous control in control theory should not divert from the fact that logic control is very important even in chemical process control. The application of programmable logic controllers (PLC) in the process industries is in the same order as that of DCS. Especially in batch process control, there are broad applications including logic, sequential and recipe control in a variety of instrumentation types. Each potent vendor of DCS offers such batch control packages. The academic control community has ignored this development substantially. There are fundamental questions of hierarchical structuring of these logic controls, and the inclusion of continuous controls with switching modes. These questions are treated in practice heuristically, on an intuitive level.

The process control level does not only contain functions of automatic process control. Other specific functions are also included, that provide better insight into the actual process behaviour, and will help to operate processes in a smart way ("smart operating"). Some of these functions will be quoted in the following.

Display functions. The representation of process variables on screen displays has changed the operator monitoring and control interfaces totally during the last years. These displays offer new opportunities to man-machine-interfaces. There is a tendency to use not only displays of recorder-like trends for process visualization, but also additional displays, like profiles, phase plots, etc. Further improvements of display functionality is required for situations with abnormal plant behaviour, in which screen displays are not as flexible as is required in plant operation.

Sensor data processing. These functions are usually located in the sensor systems of the field layer. They include data compression from multi-sensor systems, the use of sensor models to provide more evident process information (Schuler, 1990), and others. More ambitious applications, like Kalman-filters, require more computer power, and are therefore implemented in the DCS environment.

Model-based measurement tools. The application of Kalman-filters and Luenberger-observers solves many practical problems even in industrial-scale plants (Schuler, 1986; Bachmann and vom Felde, 1988). These methods provide sensor data interpretation by process models and allow a reconstruction of unmeasured process variables from these models. By doing that, they solve a basic problem of chemical process control: they improve the insight to the actual process behaviour. The application of these model-based measurement tools is limited by the lack of adequate process models.

Plant diagnosis. Diagnosis is normally done by checking measured variables to predefined constant alarm limits. There are a few approaches to shift these alarm limits depending on operating conditions, e.g. during plant startup and shutdown. Other approaches use characteristic variables (calculated due to mathematical principles, or to models) as a basis of diagnosis. The use of knowledge-based systems is far away from industrial acceptance.

Plant safety. Safety functions are not allowed to be realized in software, but in highly reliable hardware. Advanced diagnostic methods may be applied only for monitoring and supervision functions.

Statistical process control, statistical quality control. Initiated by buyers of chemical products from other industries, statistical methods of process and quality control command considerable attention in chemical industry. These statistical methods originally developed in manufacturing industries are not always adequate in chemical process control: when process variables are provided by sensors continuously and in real-time, and when process behaviour can be controlled by suitable manipulated variables, conventional process control of variables influencing product quality is obvious. Elementary statistics in on-line process control will introduce dead-time and threshold-type nonlinearities to the control loop, and its design does not consider process dynamics. We believe that classical statistical process control (SPC) is restricted to a very small part of process control. Statistical quality control (SQC), as a method of monitoring control product properties, is of great importance for process improvement, and for documentation of production results.

Robotics. Chemical process automation covers applications which are similar to the automation of manufacturing processes. Some of these applications are: the charge of sacks or barrels on palettes, the handling of samples in analytical laboratories, the cleaning of vessels containing aggressive atmospheres, the filling of multi-tubular fixed bed reactors with catalysts, etc. . In such applications, robots are applied with great success. Robots will continue to invade chemical industries in some few special applications. There is no need for new types of robots, but a creative look to corresponding problems of plant operation and management.

The Plant Management Layer

The degree of information processing in the plant management layer is relatively low compared to the adjoining layers of process control and production management. The plant management functions are considered by many vendors of application software as an increasing market of the upcoming years. There is a strong trend to introduce computerized tools for these functions. Typical functions of the plant management level will be touched upon in the following.

Batch plant management. Batch processes are controlled in a hierarchical sequence of control layers. It is based on the fundamental concept of unit operations. Unit operations are understood in this context as logical operation units needed to describe the implementation of a recipe. The assignment of a recipe to the plant, and of the amounts of reactants to the batch, is an important task of plant management. This task includes batch scheduling and batch sequencing, production logistics, etc. Whereas batch control tends to be fully automated, these functions of plant management are rarely integrated in the DCS-environment. Some functions are still performed manually even in multi-product plants.

Automation of plant startup and shutdown. At present, plant startup and shutdown need a lot of operator intervention and manual action. These operations have to be supervised by the plant manager. Similar procedures are applied to throughput variations and to handling of disturbances. The automation of these operations requires a complex interaction of logic, sequential and continuous controls. The design of these control strategies is so far based on intuitive and physical principles. Theoretical concepts are not used except of simulation studies.

Optimization of large-scale plants. At large-scale plants, advanced control and optimization show sometimes significant economic incentives. These plants (e.g. refineries, ethylene and ammonia plants) are operated using similar principles all over the world. That's why advanced control and optimization techniques have been worked out for these plants by different engineering companies. In most applications, advanced controls work satisfactorily, whereas the on-line optimization tools are often at standstill. The optimization packages need often a lot of economic data not entered automatically to the systems. Rigorous process models are used, and optimization is typically constrained by economical and technical limits.

Operator training. The high degree of automation, and the advanced state of process design, lead often to a very constant operation of many plants. In this situation, operators are not always familiar with plant operation in the case of sporadic disturbances. In order to train operators to abnormal situations, simulators are operated using the same operator interface as the real process, and the simulation is run in real-time. There are some very successful applications of simulators mainly for distillation columns (Gilles et al., 1990; Schuler et al., 1990).

Documentation of plant data. Administrative regulations and customer needs require an exhaustive documentation of plant data. The databases of plant runs are used for administrative purposes in quality and environmental management. It should be stimulated to use these data also for operational purposes, e.g. as a pattern store of plant situations, for plant optimization, diagnosis and model fitting.

The Production Management Layer

When coming up from process control to production management, the number of administrative functions increases substantially. These administrative functions shall not be treated in this context. We will restrict to those functions which are directly connected to the plant management and process control layer.

Production planning. Production planning systems are sometimes used in practice and are implemented on digital computers. Data integration to plant management, with connections to batch scheduling and recipe control, is only realized in very few examples. These interfaces are needed with high priority. This deficiency is not only a question of computer communication, but also a basic problem of control system structuring.

3 Present status of process control research in Europe

To make general statements about specific European research interests and trends is a very difficult task if one wants to generalize for the whole of what is geographically called Europe. The diversity from Poland to England, from Greece to Norway is probably more striking than anything which might be in common. Therefore what follows can not be considered *the* status of European process control research or *the* European view. Most probably it is influenced by the fact that all authors stem from Germany. Nevertheless, there are some differences between European and non-European process control research orientation. These differences shall be pointed out in the following.

Looking into the academic process control literature reveals some areas of research where most effort is put in worldwide at the moment. This is in particular the huge

area of predictive control, nonlinear control with its various directions, robust linear multivariable control, and AI control, learning systems, fuzzy control and the like.
Looking only at Europe and what is published by European researchers, all the above areas are also present, but much less distinct. In addition there is a strong interest in adaptive control and in the development of control strategies for specific processes and problems. Generalizing, European process control research is closer to the process, while e.g. American control research is mostly more abstract and closer to control theory. This is also expressed in the fact, that in Europe departmental laboratories are usually very good equipped. A reason for this orientation of European process control research can be seen in the different education for chemical engineers, and also in the difference in who is doing process control research: if we look at the background of graduate chemical engineers (equivalent to Master or Ph.D.), then the amount of formal mathematical training is much less stressed in many parts of Europe than e.g. in the USA. There is also a greater emphasis on thermodynamical fundamentals in European student education and less effort is put into the special properties of various units.

From a operational view, processes can be divided into two main groups: continuous processes and batch processes. A third area, the control of entire plants, also reveals different operational properties. In difference to the problems seen by industry, academic research is mostly concerned with control of continuous processes and only little research is conducted on batch and plant-wide control.

It is widely recognized, that there is a very close relationship between design and control of chemical processes. There is no doubt that control strongly depends on design, but the specific needs and requirements of control should also be embodied in the design step. Nevertheless, organization of science in Europe usually separates design and control to a great extend, disregarding this strong interference. This seems to be different to other regions, as e.g. the US, where design and control are very often represented by the same people within chemical engineering departments.
On the other hand, there are very few research groups in European chemical engineering, that only work on controller design. In order to be able to practically apply new and advanced control strategies, suitable process models have to be available. Most probably out of this need, there are strong research efforts within process control groups

towards modelling, identification and dynamic simulation of chemical processes (Holl et al., 1988; Perkins and Sargent, 1982; Marquardt, 1991). Also control related areas like estimation, observer design or fault detection play an important role.
Research efforts that concern the management layers can be observed, but do not play by far the same central role as in industrial practice.

It is also interesting to note, that the total number of people being involved in process control research is much smaller than the comparable number e.g. in the US. This is not only true for universities, but also for research laboratories, whether they are sponsored by industry or by the respective government. There are even few research labs outside universities concerned with process control in Europe.
On the other hand there is quite a number of people outside chemical engineering departments who use chemical engineering control problems to test their theories.

Altogether it is interesting to note that European research orientation in process control differs from other regions, although not tremendously. This is most likely due to a different research organization and student education.

4 Discrepancy between the status of industrial application and of process control research

Modern control theory has been applied very successfully in aerospace, mechanical and electrical industries. This successful development is still lasting, remember the trends in robotics, mechatronics, and others. The use of control theory has never been as spectacular in chemical process applications. Early expectations to transfer available methods to this discipline could not be completely fulfilled. Nevertheless, there is a broad academic literature on methods and on possible applications in chemical industries. At present, a considerable discrepancy can be observed between the research interests of academia and the implemented control concepts in industry. More importantly, industry sees the most urgent needs in fields other than the design of specific control algorithms. But it should be noted at this point, that the discrepancy in Europe has never been unbridgeably big. A considerable number of European research groups is working on many of the problems stressed by industry. The questions remain:

Why is there not more use of advanced control concepts in industrial practice? Why is there not more research in directions where industry sees the most urgent problems? The following two subsections will summarize this longterm discussion in the view of the present European situation.

4.1 Industrial Perspective on Limited Acceptance of Advanced Control Techniques

Advanced control techniques are applied in chemical industry only to a limited degree. The reasons for that situation can be found in the inherent properties of the processes, the practical requirements to process controls, and in the state of available theories as well.

Properties of chemical processes. With respect to process controls, chemical processes are characterized by a number of specific features:

- Plant behaviour is in most cases not perfectly known. Even rigorous models are often not adequate to predict plant behaviour with satisfying accuracy.
- When modelling is based on physicochemical principles, even simple models are nonlinear. Also, differential-algebraic systems, distributed parameter systems, differential-integral equations are very common modelling results.
- When linearizing these equations, a lot of physical information is lost.
- Plants are generally of multivariable nature. The dimension of models is sometimes very high. Together with the nonlinearities, this results in strongly interacting dynamical systems of high complexity.
- Manipulated variables as well as controlled variables are normally constrained.
- A great part of process state variables are not measured continuously. Variables describing product quality are usually not measured, and if, these measurements are interfered by other influences, or are provided in discrete times and with considerable time lags.

- Some of the sensor signals are corrupted by considerable noise. Sources of noise may be fluctuations due to pump movements, and others.
- There is a natural variability in the process due to raw material quality fluctuations, and due to unsteady environmental conditions.
- Dynamics is important in most aspects of chemical process control and operation.
- The occurrence of deadtime is evident as a consequence of transportation lag, and sensor time lags, etc. .
- The time constants of many processes are rather high. Dynamic transients are time consuming and expensive.
- Plant behaviour is often time-variant due to catalyst activity variations, heat transfer decay, etc. .
- The behaviour of a plant can change dramatically during operation. (e.g., when another mixture is separated in the same distillation column, or another reaction is run in the same reactor).
- The localization of disturbance sources in process and model structure is in most cases not trivial.
- The configuration of plants is changed during their lifetime.
- The variety of processes is very high, each process is a unique construction. Only a few processes are operated in a larger number of pieces.

It is obvious from the above, that most chemical processes are very difficult to describe analytically. Nevertheless most of the process control problems that appear in industrial practice can successfully be solved by applying very simple and intuitive control strategies. For these more than 95% of control problems, no significant improvement can be achieved using advanced control strategies.

Practical requirements to chemical process control. Plants are operated under the principles of profitability, transparency, simplicity, maintainability, safety. These principles shall be explained in more detail with respect to process control:

- Control structures must be robust to disturbances, malfunctions, and failures, and should not cause serious maintenance problems.
- Often implementation of highly sophisticated control strategies does not satisfy the requirements to safety, reliability and maintainability.
- Controller structure must be made evident to responsible plant managers not familiar with control theory.
- Plant reconfiguration should be tolerated (or automatically detected and tracked) by the control system.
- Maintenance must be possible by personnel without academic qualification.
- The successful operation of advanced control strategies should not depend on the support of single individual persons.
- Dynamic experiments (e.g. for recording transients and dynamic matrices) are tolerated rarely and only exceptionally in production plants.
- Economic incentives are often found only with difficulties for advanced control strategies. A prerequisite of advanced process control is an investment in analytics, computer hardware and in control system development. These high set-up costs cannot always be compensated by the expected improvements.
- Operator and maintenance interfaces of advanced controls lack of accepted standards.
- Operators need not more, but better information about the state of the process.
- Continuously operated plants need good stationary control and disturbance rejection. Startup and shutdown are very infrequent.
- The startup and shutdown of batch processes is so far a major problem of logic control and sequential control, not of classical optimal control.

Practically available control theory. The inherent deficiencies of theories, or the fact that the theories are not appropriate for solving the problems often prevent the application of control theories. Some reasons are:

- The lack of proven process models prevents the successful application of most theoretical concepts.
- Many common mathematical forms of physicochemical process models can hardly be handled by available control theory.
- Linear theory is sometimes (often?) inadequate. Nonlinear dynamics is not incorporated in process control theory.
- There is no proven theory for the design of robust nonlinear multivariable controllers.
- Some complex control strategies lack of robustness.
- There is no fully developed theory of discrete, logic, sequential control.
- In general, there are practically no sufficiently customized problem-solving methods relying on realistic process models.

4.2 Perspective from Research Community on the Discrepancy between Industrial Practice and Academic Research

In the last section it was stated that more than 95% of all control problems that appear in chemical plants are very good-natured, although the underlying process dynamics might be analytically very complex. In many cases the most fundamental knowledge about control suffices for adjusting the tuning parameters in the respective PI- or sometimes PID-controllers. Of course, these control problems are not the ones that make practicing control engineers worry, neither do academic researchers try to find new and advanced solutions for these control problems. The approximately 5% remaining demanding control problems are the ones we will direct our attention on. Considerable improvements in the quality of the products, in the reduction of energy consumption, in the safety and operability of the processes or in the diminution of the environmental impact can in some cases be achieved through application of "better" control algorithms. Despite the relatively small number of such cases, efficiency and

profitability of chemical plants can thereby increased notably.
If better control algorithms would exist, some design practices, that were necessary because of quality requirements, could be changed. E.g. in distillation, a column usually consists of more trays than needed for achieving a desired stationary separation of the ingoing compound. Because of possible disturbances additional trays are included. If those trays are included column design is not optimal, but the control problem is rather simple. If those additional trays are left out, the column is well designed, but difficult to control. This over-dimensioning is common practice in industry.
As stated in Section 2, there is also a tendency to not only look at single units within a chemical plant, but to consider the plant as a whole. By explicit consideration of the interconnections, which are sometimes even material or energy "feedback"-loops, again a much higher efficiency of design and operation can be achieved. Of course this trend creates also new demands on the control concepts needed.
Because of these reasons industry is expected to face a considerably growing number of difficult control problems in the years to come. There is a definite and growing need for a process control theory which is able to handle the nontrivial control problems addressed above.

Because of the specific facts existing about chemical processes, that were explained in more detail in the previous section (like nonlinearity in process dynamics and sensors, uncertain dynamics, distributed parameters, underlying algebraic equations, non-measurable states, high order, ...) it is a very difficult venture to find generally applicable design and analysis methods. It needs no great prophetic gift to foretell that such a complete and perfect theory will not be developed in this millenium.
A fatal conclusion of this realistic insight would be to condemn control theory at all. Not only the last decade has proved, that progress can be made. But of course progress will only be achieved one step after the other. Linear geometric control theory, known for its limited realistic applicability (Shimizu and Matsubara, 1985), was necessary in order to be able to develop nonlinear differential geometric control theory, which is, due to its nonlinear nature, much closer to reality.

There are two fields of activity desirable, where research should be conducted: the first is to provide practical solutions for the control problems that exist at present.

And the second, actually more important area, is the development of a realistic (i.e. nonlinear, robust, ...) and applicable controller analysis and design theory for the future. These two fields are not disjunctive, although the objective is different. For the first field, applicability is a short term objective, for the second, applicability is necessarily a long term objective.

In the preceding we often used the term *process* control theory. It is our strong believe, that special properties of chemical processes, that are usually seen as complications for purposes of control, can at least partially be exploited for a specific *process* control design and analysis theory. Of course a greater expenditure is necessary for understanding the respective process dynamics and for modelling these dynamics appropriately. By means of the insight won about the process, the actual controller design step is then rather straightforward (Retzbach, 1986b). Another advantage of this approach is that control specifications, due to physically motivated quality requirements, can be formulated and considered in a much simpler way.
On the other hand, when applying "general" control theory, much less effort has to be put into modelling the process dynamics, although, here too, better modelling always pays off. The control specifications, motivated from physical quality requirements, have to be "translated" into a suitable form for the controller design methodology to be applied. For example, when designing an H_∞-controller for a distillation column, suitable weighting matrices (frequency domain!) have to be found to reflect the quality requirements on the separation products. There is a lot of practical knowledge and experience to do this, and in many cases this "translation" is possible without causing too much trouble. In many other cases, however, a lot of design iterations with repeated adjustment of design specifications is necessary, sometimes even leading to unnecessarily conservative controllers. The smaller effort for modelling often faces a greater effort for the controller design step. The great advantage of this approach is the general applicability to practically all control problems. A phenomenon-oriented process control design methodology is usually only applicable to the restricted class of processes for which it was developed.

But no matter how we approach the control problems, there is always a number of prerequisites that have to be fulfilled in order to be able to develop a practically meaningful control theory:

- For the processes to be controlled, there must be a sufficient understanding of the physical and chemical principles that govern the stationary and dynamic behaviour.
- There must be a good mathematical model for the process. "Good" meaning, for the purpose to use.
- There must be a powerful and comfortably usable dynamic simulation tool for chemical processes for reasons of identification, controller test a.s.o. .
- Finally, there should be the possibility to test controllers at pilot plants and to verify model assumptions made about the process.

Especially this last point plays a very important role.
Our experience shows, that good and meaningful results may be achieved when controller design methodologies are applied with care. Applications to binary and multicomponent distillation, as well as to fixed-bed reactors show that especially nonlinear design philosophies (e.g. exact linearization) (Allgöwer et al., 1989), linear multivariable designs (Allgöwer and Raisch, 1988) (e.g. H_∞- or H_2-optimization) and phenomenon oriented approaches (Retzbach, 1986a) lead to very satisfying performance of the closed loop, with reasonable effort needed to get the respective controllers. Some control schemes were implemented at a distillation column in pilot plant scale, satisfying industrial standards. Due to the very realistic application, the good results achieved there are also meaningful for industry and show that considerable advances can be achieved using the, admittedly incomplete, control theory of today.

A promising field of research for the future, that is stressed by industry, is control of batch processes and startup/shutdown automation. Recent developments in discrete event control theory and related areas show very appealing results. There is for example a rather well developed theory in the framework of state machines and formal languages (Ramadge and Wonham, 1987). Other notable approaches are Petri-Net theory (Peterson, 1981), branching-time temporal logics (Emerson and Srinivasan, 1989), Boolean differential equations (Bochmann and Posthoff, 1981), and several approaches using algebras of concurrent processes (Heyman, 1990; de Bakker et al., 1989; Brooks et al., 1984).

For all the important advancements, that we can expect for the following years and decades, especially academia has to be cautious not to let a second gap open, a gap in information, knowledge and interests between universities and industry.

5 Conclusions

Presenting an European view on the status of process control in industry and its relations to the research community is a difficult venture due to the diversity that makes Europe what it is. In 1992 there will be the start of the European Common Market which might lead to a more homogeneous picture for the future. Despite this diversity practically all regions have one thing in common: the different view from industry and from research community on the relevant topics in process control. Industry is interested in easy-to-handle support for improving process operation and plant management. Academia is mostly concerned with theories for control system analysis and design. Short-term goals are different, but many long-term goals are very similar:

- Process design and process control should be treated as an entirety. This is a very important perspective of both industry and academia.
- Integrated software tools for modelling, simulation and control system analysis and design are needed.
- Control system design methods are required for special types of model equations (large-scale, nonlinear, differential-algebraic, differential-integral, distributed parameter systems). Design methods for discrete event and logic controls are of great interest.
- Design principles should refer to physical principles. Practical aspects, like maintenance, simplicity, transparency, should be included in the design process.
- Problems like quality control, plant safety, flexibility and operability need theoretical concepts that can be applied in industrial applications.
- New results should always be tested under realistic conditions, e.g. at pilot plants.

In the last years, advances in industrial process control were mostly determined by application of informatics principles and less by the introduction of new advanced control concepts. From this, a definite gap between academic research and industrial practice can be seen. Often this discrepancy is considered unwanted. But there are also positive effects: the gap acts as a driving force for progress in academic research as well as advances in industrial application. Some methods, that are developed today, will be applied in industrial practice in the future, and some practical problems of today will be significant topics of research in the years to come.

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