SPEEDUP Applications in Control and Optimization of Process Plant

D A Mushin, P S Ward — Prosys Technology Limited, Cambridge, UK
C C Pantelides, S Macchietto — Imperial College, London, UK

Prosys Technology Limited
Sheraton House, Castle Park
Cambridge CB3 0AX, UK

Aspects of modelling, performance monitoring, control and optimisation are discussed, with particular reference to the application of SPEEDUP. A new facility is described which allows SPEEDUP to operate in conjunction with other systems and several examples are briefly given of its power and flexibility. In particular, its use in on-line applications alongside plant management and distributed control systems is described and how it can be used in scheduling/sequencing problems in investigating batch and cyclic problems.

1. Introduction

Within the chemical and process industries, process engineers and control engineers are involved in a wide variety of tasks, including:

- unit process modelling
- process development and selection
- process design and optimisation
- operability, flexibility and resilience analysis
- hazard, relief and blowdown studies
- reliability and maintainability analysis
- retrofit design and optimisation
- control system design and analysis
- online performance monitoring, fault detection and optimisation
- operator training

With current technology, these tasks must be approached in a piecemeal and fragmented fashion—each task typically uses a different technology and requires that a new model must be built from scratch. This, inevitably, leads to duplicated effort and inefficiency and results in many of these tasks not being carried out with the rigour which they require. The consequence is lost opportunity and, ultimately, lost profit.

Imperial College and PROSYS Technology are engaged in the development of an Integrated Modelling Environment whose purpose will be to support ***all*** the above activities and to enable models to grow and evolve within an integrated framework, so that each activity can build upon and enhance all that has gone before, rather than having to start again. Further, the common interface and underlying technology will mean that users will be relieved of the burden of remembering the many different systems and so can become markedly more proficient in a shorter time.

The new Environment will enable that long-sought objective of the integrated design of the Process and its Control System and will make a significant contribution to the development of safer and more efficient plants. This will be especially important in the case of highly integrated plants with the much livelier response characteristics now being demanded to introduce the concepts of "just-in-time" production into the process industries.

The major components of this new Environment are SPEEDUP /1, 4/ and PRODABAS /2, 5/. This paper concentrates on the use of SPEEDUP in the control and optimisation of plant performance.

The accurate calculation of optimal operating conditions is critically dependent on:

- the availability and accuracy of plant model(s)
- the availability and accuracy of measured plant data
- robust, flexible and fast optimisation software
- the effective integration of the above

Each of these areas is discussed in turn and a number of examples are given of the power of the technology and the diversity of its application.

2.1 The Value of Accurate Plant Models and Dynamics

The principal requirements placed upon models for use in online optimisation are:

- the ability to predict plant behaviour both at the "normal operating point" and far away from it, for example during start-up, shut-down, upset conditions or product changeover. The plant model used must therefore be valid over a wide region, so that plant behaviour during transients can be guaranteed safe.

- good accuracy. Process changes during local optimisation are often very small (often significantly less than 1%) but may nonetheless result in very substantial economic benefits.

These requirements call for accurate and realistic nonlinear models, and for rigorous thermophysical property models. Linear models based on transfer functions are very unlikely to be adequate and may lead to significant loss of potential profit.

The plant model(s) must also be easy to modify in order to accommodate, for example, changes in equipment configurations, other plant modifications, and new operating constraints.

The use solely of steady-state models does, however, have a number of limitations:

- In steady state optimisation the plant signals used for either parameter updating or optimisation are assumed to be static. Under transient conditions, therefore, the results may be misleading. Transients must, therefore, be allowed to settle after a change and the minimum interval between optimisations should be larger than the dominant time constant in the plant.

- A steady state model does not contain information about dynamics. Steady state optimisation will therefore give no indication of how long it will take to reach the new optimum, by which path it should be reached or, in fact, whether it can be reached at all!

These deficiencies can only be overcome by the use of dynamic models.

Such requirements are, of course, essentially the same as those for models to be used during the Process and Control Design phases. One of the principal objectives of SPEEDUP, and indeed of the new Environment, is to enable models to grow and evolve. In this way models created at great cost during the design phase can be further exploited during plant operations so that further value can be obtained from the initial investment.

2.2 Performance Monitoring and Obtaining Accurate Plant Data

Ensuring accuracy of measured plant data involves two steps. Firstly to diagnose any plant faults, malfunctions or gross measurement errors and secondly to reconcile the raw data against a suitable model of the plant to ensure consistent energy, material and equilibrium balances and to check such parameters as fouling and separation efficiencies.

Techniques for both these areas are briefly described by Macchietto and co-workers /3/.

SPEEDUP has been equipped with parameter estimation and data reconciliation capabilities which can be used to tackle this problem in a very flexible way.

It is interesting to note that as SPEEDUP also solves dynamic problems, it could, in principle also be applied to data reconciliation in the absence of a steady-state.

2.3. Optimisation Software

An optimisation problem can be formulated easily in the engineering level SPEEDUP language and solved using the standard optimisation methods provided /4/. These include a successive quadratic programming (SQP) method with solution of the equality constraints at every iteration and the MINOS infeasible-path routines from Stanford.

2.4 The External Data Interface

SPEEDUP dynamic simulations solve the continuous behaviour of a process subject to discrete events whether externally imposed or implicit within the plant model. Repetitive discrete events can be imposed upon the simulation using an External Data Interface (EDI). EDI can therefore be used in a number of ways to control the execution of the dynamic simulation and a number of effects can be achieved. Three examples are given below, but first the basic capabilities of EDI are described. The four primary functions of EDI are:

- the association of SPEEDUP variables with external information, using the EXTERNAL section of the data input. This "tags" those variables which are to be RECEIVEd from the external source and those which are to be TRANSMITted to it.

- synchronisation of the simulation with time-sensitive aspects of the external information

- the ability of the simulation to handle externally-generated interrupts

- message passing between the simulation and the external system

These facilities are implemented using FORTRAN CALLs to standard subroutines /6/. The actual communication of the data is performed in terms of tag names so that the external system need not know about the internal conventions of the SPEEDUP system itself.

2.4.1 EDI Example 1 - Pressure-Swing Adsorption

PSA processes have significant advantages as they can achieve extremely low concentrations and, at the same time, have an inherently low energy consumption. Their wider exploitation, however, has been held up because they are difficult to design due to their cyclic/dynamic nature. SPEEDUP has been equipped with a new library of models especially designed to handle such complications as reversible flow and which enable the simulation of PSA and other gas adsorption processes. The cyclic behaviour of the process model is controlled by a Cycle Manager using EDI which also accumulates information on the TRANSMIT variables for special-purpose reporting.

The Cycle Manager handles the valve and heater sequencing aspect of the simulation by setting values periodically in the SPEEDUP RECEIVE list according to a cycle definition given by the user. Hence it can be seen to mirror the effect of the control system while the simulation program represents the physical plant. *Figure 1* illustrates the result of a dynamic simulation where inlet and outlet valves to a unit operation are switched in different stages of a series of cycles. The response indicates that the process is at a "cyclic steady-state".

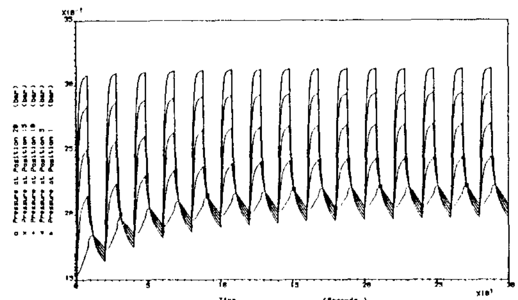

Figure 1: Variation of Bed Pressures with Time

2.4.2 EDI Example 2 - Optimisation using a SPEEDUP/RPMS Interface

An interface to IBM's Real-time Plant Monitoring System (RPMS, earlier versions were known as ACS /7/) has been implemented using EDI. This has been used to add a general purpose on-line optimisation capability to RPMS which controls the pilot plants in the Chemical Engineering Laboratory at Imperial College. RPMS maintains a real-time database of the plant measurements. Selected variables are RECEIVEd by SPEEDUP, an optimisation is performed and the results TRANSMITted back into the database. The control system is configured so that the new values can be used automatically as set points for the lower level control or, alternatively, they can be displayed to the operator.

2.4.3 EDI Example 3 - Batch Plant Simulation

Using EDI, SPEEDUP has been interfaced to a supervisory batch management system /8/. This schedules, initiates and monitors the operation of discontinuous processes. All sequence control aspects, scheduling algorithms and operating logic were implemented through the external programs. The plant configuration, product recipes and operating procedures are specified by means of a new, high-level procedural language /9/. It is then possible to simulate the processing of any number of batches, each being processed in a number of stages, such as weighing, reactor charging, reaction with cooling and reactor discharge.

All of the time dependent controls could have been implemented directly within SPEEDUP without the use of EDI. However, a much greater degree of flexibility was obtained through the external interface (much as in 2.4.1).

3. Conclusions

The External Data Interface opens up a multitude of opportunities in the wider application of SPEEDUP. In particular, it presents exciting applications in conjunction with plant management and distributed control systems. Two particular areas of interest are on/off-line optimisation and operating training. At the same time the facility offers a natural route to enable the dynamic simulation of scheduling/sequencing problems.

4. References

/1/ C C Pantelides, "SpeedUp - Recent Advances in Process Simulation", AIChE Annual Meeting, Miami, USA, Nov 2-7 (1986).

/2/ P Winter, C J Angus, "An Integrated Approach to Process Engineering", Paper to EFCE Conference "CACHI '89", Erlangen, West Germany, April 1989.

/3/ S Macchietto, G Stuart, F A Perris, G R Dissinger, "Monitoring and Online Optimisation of Processes Using SPEEDUP". Paper to EFCE Conference "CHEMDATA '88", Goteborg, Sweden, June 1988.

/4/ SpeedUp V5.0 User Manual, PROSYS Technology Ltd., Cambridge, England.

/5/ PRODABAS User Manual, PROSYS Technology Ltd., Cambridge, England.

/6/ SPEEDUP V5.0 Systems Manual, PROSYS Technology Ltd., Cambridge, England.

/7/ B A Bradbury, R W Brooks, "The Advanced Control System", IChemE Symposium Series No. 79, 220 (1983)

/8/ B J Cott, S Macchietto, "An Integrated Approach to Computer Aided Operation of Batch Chemical Plants", Paper to Conference PSE'88, Sydney, Australia, August 1988.

/9/ B J Cott, S Macchietto, "A Procedural Definition Language for Discontinuous Process Operations", Paper to EFCE Conference "CACHI '89", Erlangen, West Germany, April 1989.