FCCU advanced control in a DCS

Implementing multivariable constraint control in the distributed control system (DCS) instead of a minicomputer provided a simpler, more reliable control system

W. J. Korchinski and D. B. Black, Treiber Controls Inc., Toronto, Ontario, Canada, and M. C. Li, P. S. Warrington and K. Rasmussen, Petro-Canada Products, Oakville, Ontario, Canada

In 1991 multivariable constraint control was applied to a complete combustion fluid catalytic cracker at Petro-Canada's Oakville refinery. The controls include the reactor, regenerator and the main fractionator in two matrices, both of which reside entirely in the DCS hardware. Extensive use is made of inferential property estimates, wherever analyzers are important control points. This technique exploits simple relationships that can be used to compute compositions from temperatures, pressures and flows. Drift in the estimates is eliminated by analyzer feedback.

The application was split into two smaller controllers to improve operator understanding and ease of operator training. The reactor/regenerator controller has four manipulated variables, two feedforward variables, and 15 controlled and constraint variables. The main fractionator controller has five manipulated variables, two feedforward variables, and nine controlled and constraint variables.

The reactor/regenerator control objectives include the ability to maximize feed rate until constraints are reached in the slide valves, air blower, wet gas compressors or gas plant. The main fractionator control objectives include maintaining all products on specification and keeping the tower in heat balance.

Inferential property estimates, corrected by analyzer feedback, are used in place of raw analyzer measurements. In this way, applications continue to run even though an analyzer is taken out of service for maintenance, or during analyzer failure.

Process description. The Petro-Canada Lake Ontario #1 fluid catalytic cracker is a riser cracker with stacked design, in which the reactor is positioned above the regenerator (Fig. 1). Fresh feed and catalyst combine in the riser where the reaction takes place. Overhead vapor product from the reactor flows to the main fractionator. Catalyst disengages in the reactor vessel then flows through the spent catalyst slide valve into the regenerator where the coke is burned off. The regenerated catalyst then returns to the riser through the regenerated catalyst slide valve, thus completing the cycle. Air is delivered to the regenerator by a motor driven blower.

The main fractionator produces raw gasoline overhead, light cycle stock and decant oil, which in this refinery is a saleable product. There are three pumparounds, two of which are below the light cycle draw. Very little heavy material is recycled to the reactor.

The wet gas compressor consists of three reciprocating machines in parallel, each of which is electrically driven. A spillback from the compressor discharge to the fractionator overhead drum controls suction pressure, which in turn sets reactor operating pressure. A differential pressure is maintained between reactor and regenerator by manipulating the regenerator stack slide valve.

Typically, the unit is run to maximum rates, particularly in the summer. The main operating constraints are related to maximum wet gas suction pressure, and maximum loading of the gas plant, although at times slide valves or blower capacity also may be limiting.

Advanced control project. In April 1991, Petro-Canada decided to install advanced multivariable controls on the #1 fluid catalytic cracker in their Lake Ontario refinery. Motivations for doing this were to increase unit throughput, improve control of gasoline endpoint and control decant oil specific gravity. Plant instrumentation centers around a modern DCS, and includes a link to a minicomputer that is used mainly for refinery information.

By the end of summer, all plant analysis and testing were complete. Modeling of the test data and controller design were complete by September. The main fractionator controller was installed in the DCS hardware and com-
estimating input/output cross correlations and single or multiple parameter fits in the z-domain.\textsuperscript{1} A key component of the analysis software is the graphical and statistical feedback produced, which is used to verify the quality of the models. Without this feedback, there are many pitfalls that can lead to questionable models, which ultimately will seriously degrade the performance of any model-based controller.

An initial screening of the plant tests was done by plotting and visually examining the data. All input/output series that appeared to be related were marked for more detailed analysis. Using the now reduced data set, cross correlations were estimated between input/output variable pairs. In cases where the input/output relationship appeared to be first order, the z-domain parameters were estimated, along with the statistical feedback. (In those occasional cases where response was more complicated than second order, the cross-correlation-based models were retained for use in the controller.)

As an example, the PRBS test shown in Fig. 2 can be used to illustrate the analysis procedure. The cross correlation between wet gas suction pressure (input variable) and wet gas spillback (output variable) is calculated as shown in Fig. 3. A parametric model based on a z-domain parameter fit is also shown. Note the unusual behavior exhibited by the cross-correlation-based model. This was later discarded in favor of the parametric model for use in the controller.

Fig. 4 reinforces the importance of statistical feedback on model quality. Note that final parameter values fall within 95\% confidence limits. Without such checks, one is forced to resort to cross-correlation-based models, many of which contain anomalous or incorrect behavior.

The final step in the data modeling is to produce an ASCII file containing the discrete step weights for each of the input/output relationships (Fig. 5). These step weights, shown graphically, are stored in the file as a simple list of numbers (30 in this case).

**Controller design and tuning.** Once all the models are available as ASCII files, the next step is to decide on a controller structure which makes sense. This decision centers around the number of controller matrices required to implement the application. One option is to build a separate matrix for each piece of equipment. In this case, the result would be three controllers: one each for the reactor, the regenerator and the main fractionator. The other obvious extreme is to condense the entire application into one large matrix. Factors which influence this decision involve considerations such as degree of interaction between various equipment, speed of response of the different processes, project schedule, ease of operator training and complexity of the operator interface.

In our case, the decision was made to divide the application into two control matrices: one for the reactor/regenerator and one for the main fractionator. The primary reason for this split is that the main fractionator has process dynamics which are considerably longer than those associated with the reactor/regenerator. A secondary reason relates to operator interface design. Computer displays for a single large control matrix would consume several screens and unnecessarily complicate operator interaction.

Once the decision on controller structure was made, the controller design was carried out on a PC. The ASCII
model files obtained earlier were automatically assembled into the desired matrix structures, and tuned using commercially available software. The software has the ability to simulate plant responses and combine these with the effects of the multivariable controller being tuned. In this way, controller tuning parameters are adjusted until the desired process response is obtained. The end result of the controller design phase is a final ASCII file which can be transported to the on-line machine. This file contains all the information necessary to drive the on-line controller including controller tuning and plant models. Table 1 shows the reactor/regenerator matrix, and Table 2 shows the main fractionator matrix as implemented in the on-line hardware.

**Commissioning.** Because this refinery has both a modern DCS and an on-line minicomputer, we had to decide on which hardware to run the application. In the end, the decision was based on issues of reliability and operator interface. It was felt that if implementation was done in the DCS hardware, it would be simpler, more reliable, and the operator interfaces would be cleaner than if the application resided in the minicomputer. This conclusion was based on previous experience with FCCU control implemented in computers.²

The on-line ASCII file generated on the PC was copied over to the DCS database. Operator displays were built and the application turned on about a week after the control design was completed.

During commissioning, setpoint changes were made to each controlled variable in turn, and the controller was forced to run against each of the individual constraints. This was done to verify that the in-plant controller performance conformed to the design done on the PC.

**On-line performance**

**Light cycle stripper level.** An important feature of the main fractionator controller is its ability to maintain light cycle stripper level above its minimum limit during heat and mass balance disturbances. Before commissioning, the LCS draw tray was frequently pulled dry which resulted in the loss of the light cycle stripper level. To correct this situation, the operator was forced to cut LCS flow significantly, which resulted in large amounts of light cycle being downgraded to decant oil. Fig. 6 is a comparison of
Although great strides have been made recently in improving reliability, these devices are prone to failure, and require frequent calibration. The traditional method of handling these events is to flag the measurement as bad, and turn the controller off.

Our approach is to estimate those properties we want to control using a simple model, and correct for model drift with feedback from the on-line analyzer, when it is available.

This technique has several advantages. First, the estimator will continue to run, even though the analyzer is not available. Second, the estimator produces a continuous result, even in cases where the analyzer is running at discrete intervals (e.g., a chromatograph running once every 20 minutes). This allows the controller to be run faster than the chromatograph cycle times. Third, when the analyzer is out of service for extended periods, the estimator can get its feedback from laboratory analyses. Combined, these factors produced a control application with extremely high uptime, despite several analyzer failures of long duration.

**Flue gas \( O_2 \) example.** In the reactor/regenerator application, the most important controlled variable is regenerator flue gas \( O_2 \). In a complete combustion FCCU, the amount of \( O_2 \) determines how far the unit is from reversion to partial burn. This is a dangerous situation that can lead to a flow reversal in a very short period. It is crucial that the flue gas \( O_2 \) is maintained at a safe level by the controller.

For control of flue gas \( O_2 \), an estimator was built whose form is:

\[
O_2 = K_1 \text{Feed} + K_2 \text{Air} + O_{2\text{feedbk}}
\]

where

- \( O_2 \) = Estimated \( O_2 \)
- \( K_1 \) = Model gain
- \( \Delta \text{feed to unit} \)
- \( K_2 \) = Model gain
- \( \Delta \text{air to unit} \)
- \( O_{2\text{feedbk}} \) = Analyzer feedback

The design procedure for this oxygen estimation was also carried out on a PC using commercial software. Long-term plant data were used to tune the calculation gains, which were then used in the on-line \( O_2 \) estimator.

Sample tuning results are illustrated in Fig. 8. The \( O_2 \) analyzer signal is shown on the same scale as the prediction, but is offset for clarity. Note that when the feedback is turned off, the prediction correctly mimics behavior of the analyzer. When feedback is reinstated, there is no shift in the estimated \( O_2 \), which again is corrected for long-term drift. The strength of this type of estimator design is that it avoids having to spend weeks or months of tuning in the plant.

Throughout the plant testing phase of the project, the \( O_2 \) analyzer worked well, allowing accurate modeling of flue gas oxygen. But by the time of the commissioning phase, the analyzer had stopped functioning completely due to a problem with the sample probe. For commissioning, the on-line oxygen estimator was modified to accept feedback from a lab analysis of flue gas (once per shift), instead of from the nonfunctioning analyzer. This has formed the basis for the oxygen control for a few months, until the probe could be repaired.

Fig. 9 shows the response of the estimated regenera-
It doesn't have to cost a fortune to comply with NESHAP.

Prevention is Better Than Cure: A Case History

A major refinery was faced with a dilemma — clean up or close down. The EPA said their 17 annual tons of Benzene discharge was 7 tons over the allowable limit. A Benzene stripper for their wastewater treatment plant would cost the refinery millions of dollars.

Instead of upgrading the wastewater system, Agar's solution was SOURCE REDUCTION. Agar’s Desalter Control Systems and Tank Dewatering Systems were installed for less than 10% of the cost of the proposed upgraded wastewater treatment system.

Benzene discharge has been reduced 64% and is now only 6 tons per year — well below the NESHAP limit.

Call today to see how Agar's patented technology can help you not only clean-up, but stay in business profitably.

The authors

W. J. Korchniski graduated from McGill University in 1978 with an MS degree in chemical engineering. After working in the pulp and paper and refining industries, he joined Treiber Controls, Toronto, Ontario, Canada, in 1985. His current work includes advanced control and closed loop optimization projects in many areas of refining, petrochemical, plastics and wastewater treatment.

D. Bruce Black joined Treiber Controls, Toronto, Ontario, Canada, in 1990 where he has worked on advanced control systems for fluid catalytic crackers and wastewater treatment plants. He is also responsible for the continuing development of Treiber Control’s Optimum Predictive Control design software. Previously, Mr. Black was a senior process engineer with a major EPCM contractor and held various technical positions at both the refinery and the head office of an integrated oil company. Mr. Black graduated in 1976 from the University of Toronto with an M.A.Sc. degree in chemical engineering.

Peter S. Warrington is a senior applications engineer for Petro-Canada Products, Oakville, Ontario, Canada. He has been involved in process engineering and supervision, distributed control system implementation and advanced process control. He holds a B.Sc. in chemical engineering from the University of Salford (UK).

M. C. Li is a senior applications engineer for Petro-Canada Inc., Oakville, Ontario, Canada. He holds an MS degree in chemical engineering from McMaster University. His experience includes advanced process control, plant information systems and process simulation. He is a member of CSGCE.

Kary Rasmussen is a process operator for Petro-Canada Inc., Oakville, Ontario, Canada. He is currently the operations department's liaison for advanced controls projects. Mr. Rasmussen holds a BA degree in communications and an honors BA degree in English and history.

ACKNOWLEDGMENT

The authors would like to express appreciation to the management of Petro-Canada Products for permission to publish this article.

LITERATURE CITED


Whether you require trays for a new tower or maintenance spares for installed trays, Glitsch Conventional Trays Unconventional Service

trays are always ready for the quickest turnaround in the industry. Our renowned reputation for instant response to emergency situations means you can contact us 24 hours every day of the year.

Glitsch can provide trays in every style, plus bubblecap assemblies, valve units and hardware, assuring you of a tray that suits your exact requirements.

Our conventional trays come with unconventional service.