Faster plant testing and modeling

Automated technology performs both open-loop and closed-loop testing simultaneously

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The Tesoro Mandan refinery has a multivariable predictive control (MPC) application on its crude unit (CDU). The application, which was designed using a commercially available modeling and control package, was originally commissioned in 2001 and ran until process changes in the distillation section resulted in significant changes in the underlying predictive models. These caused most of the MPC controller to be turned off by the console operators. The combination of poor controller models and significant unit performance issues resulted in very low and limited use of the MPC and, thus, poorer operating margins.

Recently, Tesoro decided to reactivate the application by retesting and remodeling the process. However, since the CDU controller is rather large, running conventional plant step tests would have been both time consuming and expensive. This is a common situation in most refineries and it impacts the maintainability of many MPC applications, especially given the limited resource availability of in-house control engineers. Tesoro needed to take a different approach to efficiently regenerate the models and recommission the controller, all while ensuring that the methodology could be leveraged to help maintain future MPC applications. The balance between managing the MPC maintenance workload and ensuring sustained optimal performance of the MPC controllers was the challenge.

Plant/controller description. Tesoro's Mandan CDU processes light North Dakota crude into naphtha, jet, gas oil and reduced crude. The operating and control objectives include keeping the product streams on specification and saving energy when possible. Because the process is effectively divided into two parts: the crude furnace and the distillation section, the multivariable controller is similarly divided into a furnace subcontroller and a distillation subcontroller. Each subcontroller can effectively be considered a separate multivariable control application. The approximate controller structure is shown in Table 1.

Not all MPC controllers exhibit the same level of maintenance and support requirements. This is reflected by the fact that, although the atmospheric tower MPC application was unused for a significant period, the operators were still using the charge heater MPC. The project team felt that, although the charge heater MPC was running, there was still room for improvement in its models. It was, therefore, decided to retest and identify new MPC models for both MPC applications: charge heater and atmospheric tower.

TABLE 1. CDU controller structure

	Charge heater MPC	Atmospheric tower MPC
Number of *MV*s	7	14
Number of *DV*s	2	6
Number of *CV*s	23	29
Approximate models	50	250

Plant testing. Tesoro selected a commercial automated plant testing package and used this to manage running a new set of plant tests, and to rebuild the controller models. The automated plant test software was capable of performing both open- and closed-loop testing simultaneously.[1] Its open-loop testing function is similar to the traditional approach except that all the *MV*s are manipulated simultaneously in a series of uncorrelated step moves. The moves are typically of shorter duration and resemble a series of pseudo-random binary signals (PRBSs). Although this testing approach is only now being widely accepted and utilized in industry, it has been commercially available for several years and has been fully adopted as the standard MPC testing methodology by some of the world's largest refining companies.

The real breakthrough in the field of automated plant step testing for MPC was the introduction of closed-loop testing and model identification. This approach produces similar PRBS-type bias signals that are added to the closed-loop *MV*s signals generated by the MPC controller. Effectively, this dither-type signal introduces a small perturbation onto the *MV* signal allowing the existing MPC controller to remain online during the test period. This adds a level of robustness through unit constraint control by ensuring that the MPC application can continue to provide some level of control performance for the operator. PID loops can similarly remain closed for improved stability during testing, but can later be opened once the MPC controller is recommissioned.

The flexibility in the automated step testing technology's ability to mix open-loop, MPC closed-loop and PID closed-loop variables in a single test was a key requirement and feature. It provided a sound approach for new MPC application development and provided a solid methodology to deal with Tesoro's exiting challenge of MPC maintenance and benefits sustainability.

This article documents Tesoro's experience in using the automated plant tester, with particular focus on how much time the work took and the quality of the results. References 2 and 3

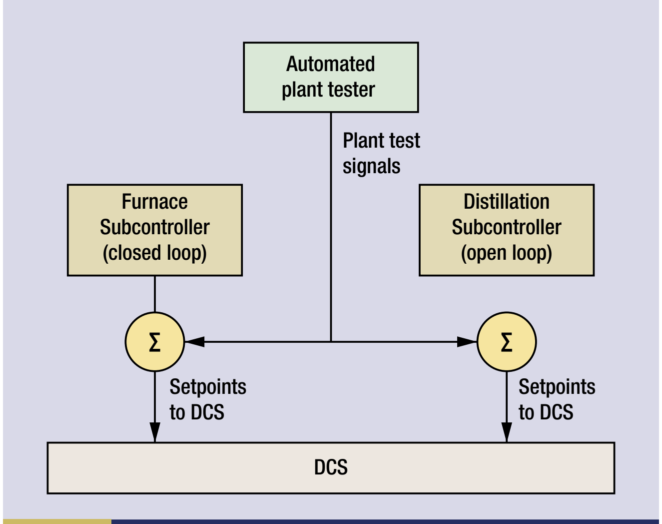

FIG. 1 The automated tester generates plant test signals and sends them to the DCS.

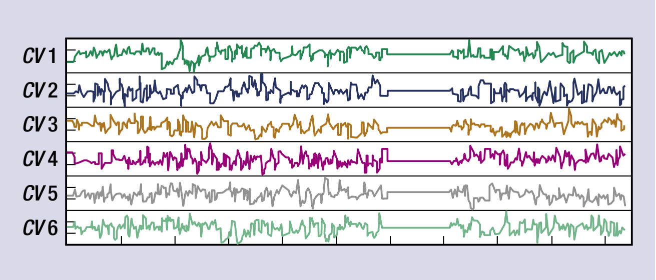

FIG. 2 Example furnace *MVs* during test (furnace controller in closed loop).

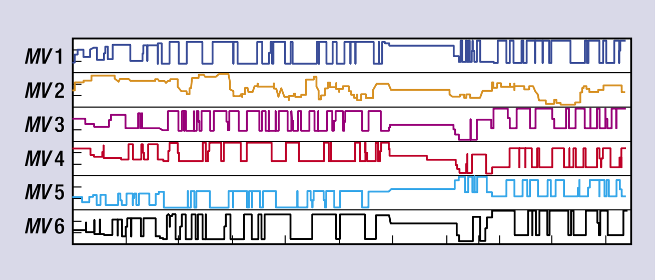

FIG. 3 Example distillation *MVs* during test (distillation controller in open loop).

TABLE 2. Modeling and analysis time required

	Original tests, days	Automated tests, days
Plant testing time	21	4
Model analysis time	5	1
Total time	26	5

provide a more technical review of the automated step testing algorithms.

With the automated testing technology allowing combined open- and closed-loop variables in a single test, it was decided to leave the existing furnace MPC subcontroller active and running in closed loop. Due to serious performance issues and model degradation, the crude tower subcontroller was turned off during the testing period. Also, a few select PID controllers were tested in closed loop, since it was still undecided if these loops would be opened and controlled with the new MPC controller design.

The plant testing setup is shown in Fig. 1. The automated tester generates plant test signals and sends them to the DCS. Since the furnace subcontroller application was running during the plant test, the test signals were added together with the multivariable controller *MVs* (illustrated by the summation block on the left in the diagram). The distillation controller was not active during the tests, so the automated tester signals were sent directly to the DCS controller setpoints. This is an important point—during the automated testing, part of the plant was being controlled by a multivariable controller, while the other part of the plant was not.

During the testing, 21 manipulated variables were moved automatically. The automated tester generated a unique test signal pattern for each *MV* using a few simple rules:

- Each *MV* move size is set by plant operations.
- The *MV* move durations vary, depending on the estimated time to steady state for the process.
- *MV* move patterns are largely uncorrelated.

Because all variables are tested for the entire testing cycle, there are a significant number of perturbations in each variable, producing a set of very “information-rich” signals. This allows the perturbations to remain small, having little impact on the process or operators, while yielding high-quality test data and a much shorter time period as compared to the traditional single-variable testing approach.

The tests took a total of four days. Model identification took one day. When the multivariable application was first installed in 2001, it was built using conventional single-variable plant tests and analyses. These original plant tests took a total of 21 days, and model analysis took approximately one week. These results are summarized in Table 2.

Fig. 2 shows the *MV* test pattern used. Unlike conventional single-variable plant tests, the *MVs* are moved simultaneously. The complex *MV* behavior is partly due to the action of the multivariable controller as it controls the furnace process, and partly due to the test signals superimposed by the automated tester.

Fig. 3 shows the *MV* test pattern for the distillation section of the plant. Note that, like the furnace, all *MVs* are moved simultaneously. The distillation *MV* behavior is simpler than the furnace *MVs* (Fig. 2) because the distillation controller was not running and adding its own *MV* moves to the plant test.

Fig. 4 shows the behavior of the *CVs* during the plant testing. Unlike with conventional single-variable plant tests, it is difficult to see the correlations between individual *CVs* and individual *MVs*. However, because the *MV* test patterns are largely uncorrelated with each other and with the multivariable controller actions (furnace controller only), the model analysis software was able to extract good relationships.

Selecting the step size is an important parameter in developing the test. This is selected by reviewing the original open-loop step tests along with discussions with the console operators. The automated step testing application then slowly ramps the process up to this maximum value, ensuring that no specified *CV* limits are violated. As the test progresses, the process control engineers

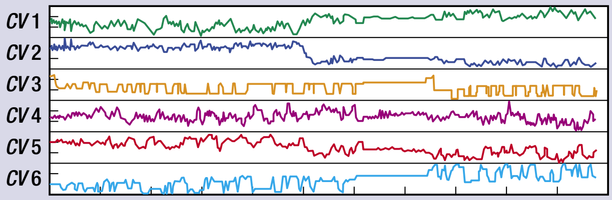

FIG. 4 Example *CV*s during test.

use the integrated modeling environment to generate models and review statistics on the quality of the models. These qualities are used as a guide to either make a decision to reduce step sizes for those variables already generating high-quality models, or conversely to increase step sizes for variables requiring a higher signal-to-noise ratio. This iterative modeling/testing approach is a key element in ensuring that the quality of the models being generated is being monitored in real time. It allows the process control engineer to quickly intervene if the designed test is not producing the desired results, and minimizes risk of a poorly executed plant test.

Results. The automated plant testing package used by Tesoro has a fully integrated model identification package. Models were generated and reviewed during the test period and, upon completing the plant tests, this modeling package was used to derive the final new controller models. Like the plant testing, the entire modeling phase is automated, requiring little input from the user.

Predictions were made for each *CV* for the plant test period. These predictions were compared to the measured *CV*s. An example for four *CV* predictions is shown in Fig. 5. This example is typical—in almost all cases, the predicted *CV*s closely matched the measured *CV*s, indicating that the models accurately represent the process.

One of the most interesting results of this work is that, because we had an existing controller original matrix from 2001, we were able to compare the results from the automated testing and modeling with the original manually derived results. The original controller matrix from 2001 had 250 models, as did the newly analyzed matrix from 2005. In all cases, the models were in the same locations in the matrix (same *MV/CV* locations), and the model gains were the same sign in all cases. This technology is able to extract good models, while simultaneously providing structural information on the required controller design. It identifies both the strong and weak gain relationships in the controller matrix.

Essentially, the automated plant testing and modeling package had identified exactly the same controller structure as did the original manual testing and modeling, but was able to achieve this in five days instead of 26. This amounts to a savings of 21 days of engineering time, a conservative estimate, given the fact that more than one engineer is normally present for plant testing and modeling.

Next steps. Now that the refinery has seen the benefits of the automated step testing approach for maintaining MPC controller development, the refinery personnel will be developing a

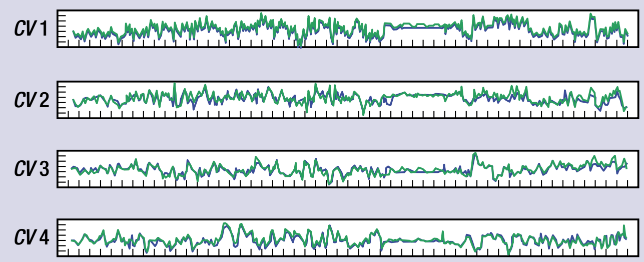

FIG. 5 Example *CV* predictions.

"best practices" methodology on the use and deployment of this technology. Some areas for further advancement include:

- Integrating online, real-time MPC performance monitoring such that MPC model quality can be tracked over time, measuring the need for plant retesting
- Integrating MPC model-quality KPIs, generated from automated step testing data, as benchmarks to measure the degree of MPC model degradation
- Implementing PID, soft sensor and MPC online monitoring such that MPC controller issues can be extended and fully managed beyond simply model degradation. **HP**

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