ENGINEERING TECHNIQUE FOR SUCCESSFUL ADVANCED CONTROL OF PLANTS USING MULTI-VARIABLE CONTROLLER

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Multi-Variable Control (MVC) allows for improved stability of plant control and significant reductions in operation costs compared with traditional PID control. However, whether or not the introduction of MVC is successful depends on the identification of an accurate process model and the selection of appropriate control, manipulation and disturbance variables. In order to create an accurate model, it is necessary to carry out sufficient process testing and evaluation based on the deep insight gained through chemical engineering.

The identification of a model that fulfils only the aim of minimizing model prediction errors is incorrect. Great care must therefore be taken when evaluating the model, especially, when insufficient step response data or feedback control data has been used. An inappropriate selection of controlled, manipulated and disturbance variables will result in unstable control, even if the model fits the process very well. Non-correlated process variables should be selected as controlled variables, and independent process variables should be selected as manipulated or disturbance variables. In this paper, an MVC engineering technique which focuses on model identification, and the evaluation of model controllability through the 'condition number' of its gain matrix are described.

INTRODUCTION

Almost 20 years have passed since MVC came into use commercially. At first, MVC was only used in large-scale petroleum and petrochemical plants, because at that time computers were expensive and incapable of the performance required to execute an MVC package. However, due to dramatic improvements in the performance and reductions in the costs of computers, implementation of MVC has become viable and it is now possible to implement MVC in small-scale plants. It has been proven that MVC is better at stabilizing plants in the event of disturbances and operation costs are much lower than conventional PID control.

Actual process dynamics is represented by the step response model or Laplus transfer function. With MVC, the model predicts future changes in controlled variables and determines past changes in manipulated and disturbance variables. Then, in order to ensure that targets for controlled variables are reached, MVC calculates future changes in manipulated variables. Analysis of the control principle of MVC shows that the process model is very important for obtaining excellent control performance with MVC.

CONTROL PRINCIPLE OF MVC

MVC uses the following three kinds of process variables.

MV: Manipulate Variable
CV: Controlled Variable
DV: Measured Disturbance Variable

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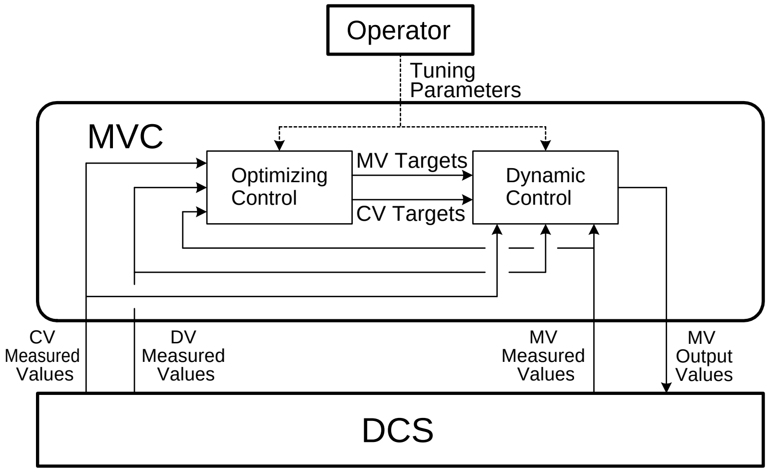

Figure 1 Functions of MVC

MVC has two kinds of optimizing functions as shown in Figure 1. One is the steady optimizing function, which calculates the steady optimal values of a CV and MV. These optimal values are target values for dynamic optimizing. The other is the dynamic optimizing function, which calculates the optimal future path of an MV using the following equation.

ENGINEERING METHOD OF MVC

The process of the engineering method used in MVC is described below.

(1) Deciding Coverage of MVC
The scope of coverage of MVC is selected. If coverage is too wide, model identification becomes difficult. A control loop whose response time is shorter than 5 minutes, should be controlled by PID controller not MVC, because MVC's control interval is normally 1 minute and MVC cannot adequately control such a fast control loop. Parts that have strong non-linearity should not be included in the scope of MVC, since ordinary MVC cannot control the non-linear process properly.

(2) Performance check of regulatory control
A regulatory controller such as a PID controller must be properly tuned. Normally MVC's output is the set point of a flow controller or temperature controller. If the regulatory controller is not properly tuned, the control performance of MVC is not effective. The regulatory controller should respond smoothly without overshooting against the set point change. If disturbance response is fast, it is better to perform feed forward control at a DCS level than with MVC.

(3) Provisional selection of CV, MV and DV
CV, MV and DV are provisionally selected on the basis of the current operation method and experience of the operator.

(4) Step response test and model identification
To identify the process model, MVs and DVs are changed step by step during the response test. Step changes of each MV and DV are implemented at least 5 times, and to obtain an accurate process model the special pattern of step changes shown in Figure 2 is recommended. This is described in detail latter. Also, it is preferable that each MV and DV be changed separately during the step test. More than two MV or DV should not be changed simultaneously. If more than two MV or DV are changed at the same time, each response cannot be distinguished.

(5) Final selection of CV, MV and DV
CVs, MVs and DVs are finally decided based on the results of the step response test. If some relationship between CV and MV or DV is not identified, the provisional selection of CV, MV or DV is removed from MVC.

(6) Modification of DCS control loop
Some DCS interface functions for both DCS and MVC are required. The interface functions of DCS are as follows.
(a) Sequence control, which changes the control mode from regulatory control mode to MVC mode or from MVC mode to regulatory control mode.
(b) Watch dog sequence control, which changes the MVC mode to regulatory control mode when MVC fails.
(c) DCS graphical display for MVC operation.

(7) Controller design
Using the exclusive MVC building tool, MVC is easily designed from the previously identified process model. The main tasks are to match DCS tag names with MVC variables and provisional controller tuning.

(8) Performance check by off line simulation
Offline simulation for MVC is done with the exclusive MVC simulation tool. The purpose of this engineering step is to obtain the desired control performance by tuning the various parameters of MVC. The control performance is evaluated from the following aspects.
(a) CV's target change
(b) Disturbances change
(c) Mismatch between process model and actual process

(9) Test run
First, MVC is connected to DCS while MVC is still in Prediction or Standby mode which means MVC is running, but does not write MVC output to DCS. The values of MVC output and MVC prediction are checked too see whether or not they are appropriate. Next, if the values of MVC output

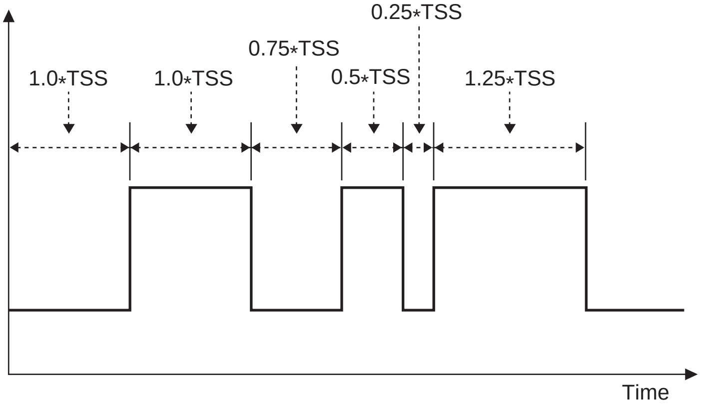

Figure 2 Recommended Test Signal Pattern

and MVC prediction are appropriate, Run or Control mode is set for MVC, which writes MVC output to DCS. Finally, MVC's parameters are tuned to obtain the desired control performance.

(10)Commissioning

This is the final step of MVC engineering. It is required that Control mode be set for a continuous amount of time for MVC at least once a week. Generally, MVC can reduce the CV's standard deviation by half, compared with regulatory control. If this reduction is not achieved, it is assumed that there is a considerable mismatch between the process model and actual process. If worst comes to worst, additional step response testing and model identification is required.

APPROPRIATE STEP RESPONSE TEST METHOD FOR OBTAINING ACCURATE PROCESS MODEL

To obtain an accurate process model the following are important:

(1) MVs and DVs should be changed one by one for the step response test. If more than two MVs or DVs are changed at the same time, each response cannot be distinguished.

(2) The step test signal should have enough magnitude to sufficiently excite the process. At least, change implemented to the CV by the test signal should be greater than that implemented by unmeasured disturbances at a steady state. If the test signal is too small, the process model will not be identified. On the other hand, if the test signal is too big, it might causes quality deterioration. Moreover, process model might be incorrect under the influenceces by process non-linearity.

(3) The recommended test signal is shown in Figure 2. A different width for step signals is recommended. TSS is an abbreviation for Time to Steady State, which means the time that CV reaches a steady state. To identify the correct process gain it is important to have a step signal width that is longer than the TSS. On the other hand, to identify the correct process dead time and time constant it is important to have a step signal width that is shorter than the TSS.

(4) The regulatory control loop that indirectly controls CV should be open. If the control loop is closed, there is the possibility that a model strongly affected by process conditions will be obtained.

(5) Generally, it is difficult to identify a model for DV. This is because with most of the process we cannot change DV at our discretion for identification. In this case, there is another way to identify the process model. It is possible to identify the process model from the long-term normal operation data. The DV probably changes many times during those periods. The process model is identified from the correlation between DV and CV. The required term for identification from the data is normally 1 or 2 months.

EVALUATION OF PROCESS MODEL

The key to the success of MVC depends on the selection of CV, MV and DV, and the accuracy of the process model. As for the selection of CVs, MVs and DVs, each CV should not have a correlation to each other and MVs and DVs should be independent variables. If CVs, MVs and DVs do not satisfy those conditions, MVC will fall into an unstable condition even when there is only a slight mismatch between the process model and the actual process, or MVC will calculate extremely large values for control output when the CV's target is changed. This bad process model is called an ill-conditioned model. As for the accuracy of the process model, model prediction error should be checked against another set of data that has not been used for model identification. If a correlation between a model prediction value and measured value is calculated, the model prediction error is evaluated objectively. If there is a long delay between them, the process model should be modified.

There is the possibility that the process model is an ill-conditioned model, even though the model prediction value matches the measured process value well. This situation often occurs when insufficient response data is used for model identification. When there is insufficient data the change of MV or DV is too small to identify the process model correctly.

The condition number of the model gain matrix is used to check whether the model is ill conditioned or not. The condition number of the matrix is defined as the ratio of the maximum singular value to the minimum singular value. If the condition number of the model gain matrix is over 100, it is considered to be an ill-conditioned model.

The following gives an example of a well-conditioned model and an ill-conditioned model. Both models are identified from the same two component distillation towers. The ill-conditioned

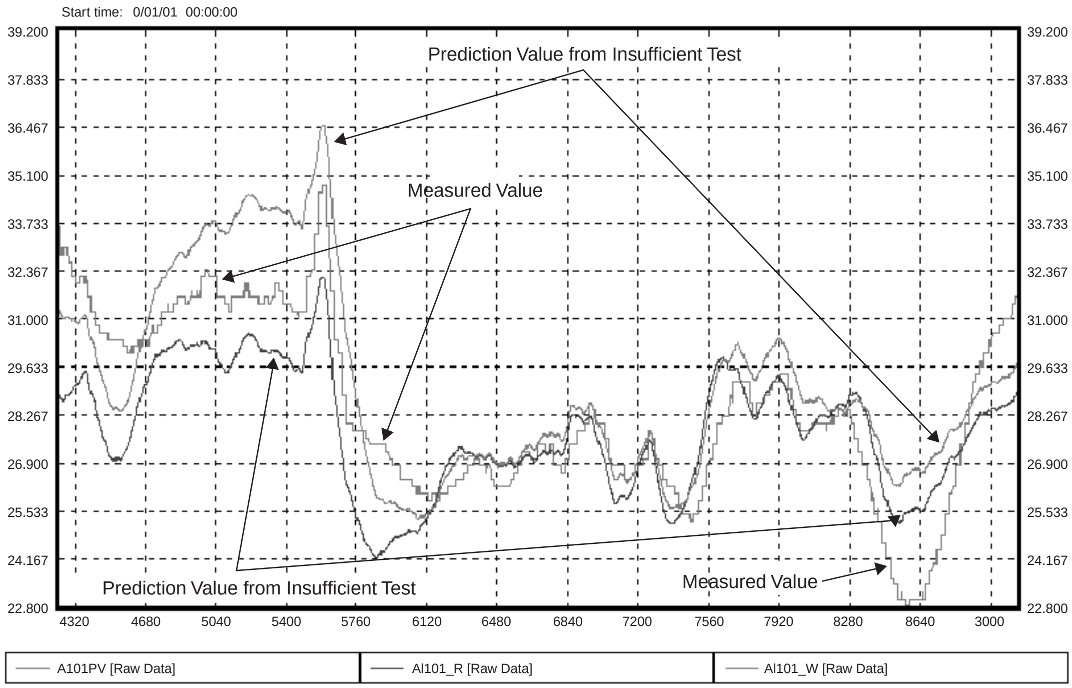

Figure 3 Comparison between Prediction Value and Measured Value for Two Models

model is identified from insufficient response data, which shows that two MVs of the reflux flow and reboiler steam flow are changed almost simultaneously. The well-conditioned model is identified from sufficient response data, which shows reflux flow and reboiler steam flow are not changed simultaneously. Equation 1 and Equation 2 show the gain matrix of the ill-conditioned model and well-conditioned model, respectively.

$$\begin{bmatrix} CV1 \\ CV2 \end{bmatrix} = \begin{bmatrix} -4.0 & 5.1 \\ 2.5 & -3.1 \end{bmatrix} \begin{bmatrix} MV1 \\ MV2 \end{bmatrix} + \begin{bmatrix} 1.6 \\ 6.0 \end{bmatrix} DV1 \quad (1)$$

$$\begin{bmatrix} CV1 \\ CV2 \end{bmatrix} = \begin{bmatrix} -5.1 & 3.9 \\ 1.9 & -4.0 \end{bmatrix} \begin{bmatrix} MV1 \\ MV2 \end{bmatrix} + \begin{bmatrix} 1.6 \\ 7.0 \end{bmatrix} DV1 \quad (2)$$

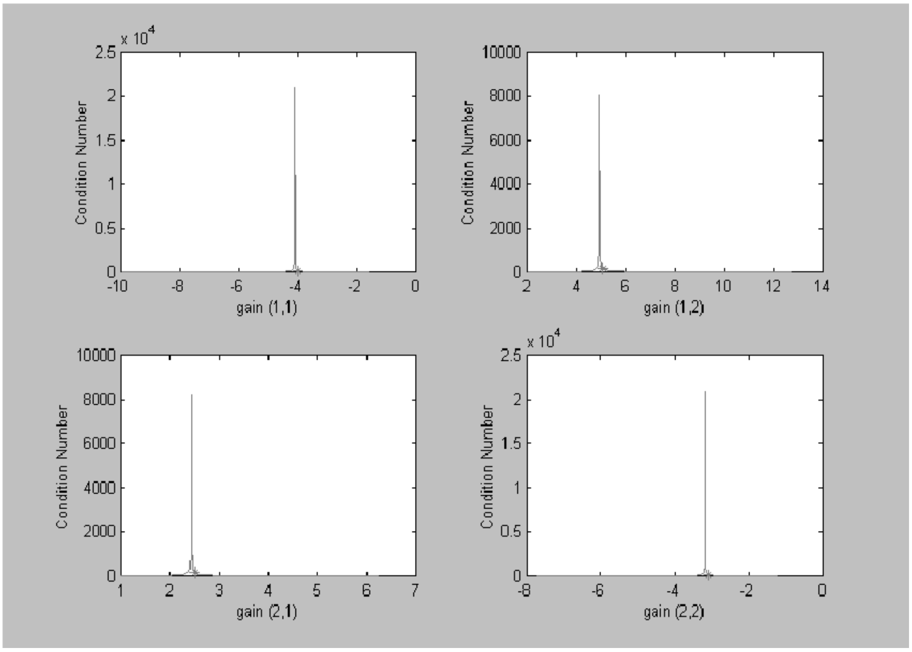

Figure 4 Condition Number Variation in Response to Gain from Insufficient Test

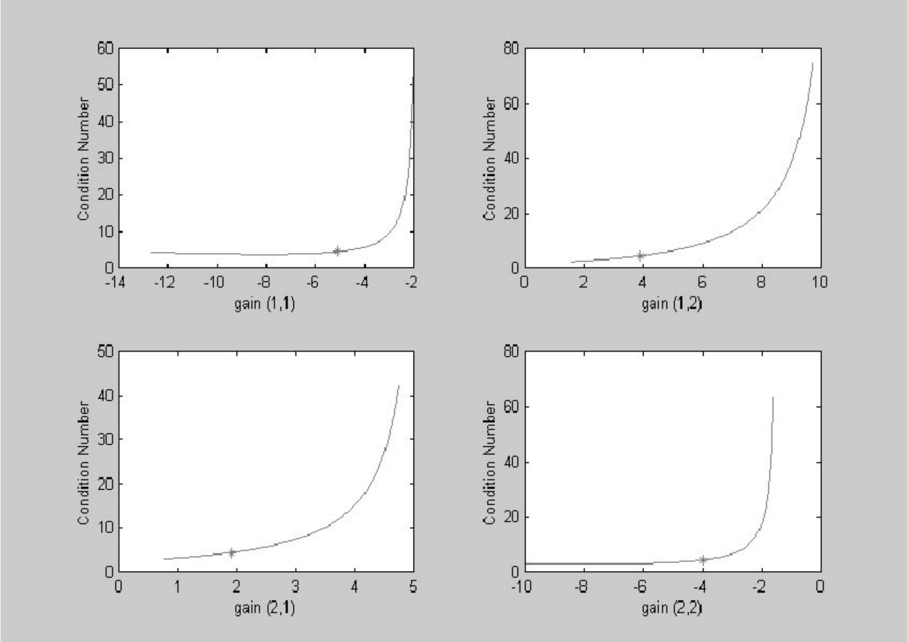

Figure 5 Condition Number Variation in Response to Gain from Sufficient Test

Here, CV1 represents the top component, CV2 the bottom component, MV1 the reflux flow, MV2 the reboiler steam flow and DV1 the feed flow. A comparison between prediction values and measured value for these two models are shown in Figure 3. Although it is difficult to say which model is better from just a comparison of prediction values, the condition number of the model gain matrix allows us to determine which model is better. In this example, the condition number of the ill-conditioned model is 165.3, while the one of the well-conditioned model is 4.5.

Figure 4 and Figure 5 show how the condition number changes response to the change of the model gain from 2.5 to 1/2.5 times for the ill-conditioned model and well-conditioned model respectively. The position of the "∗" mark shows the original model gain and the condition number of its gain matrix. If the model is ill conditioned, the condition number is not only

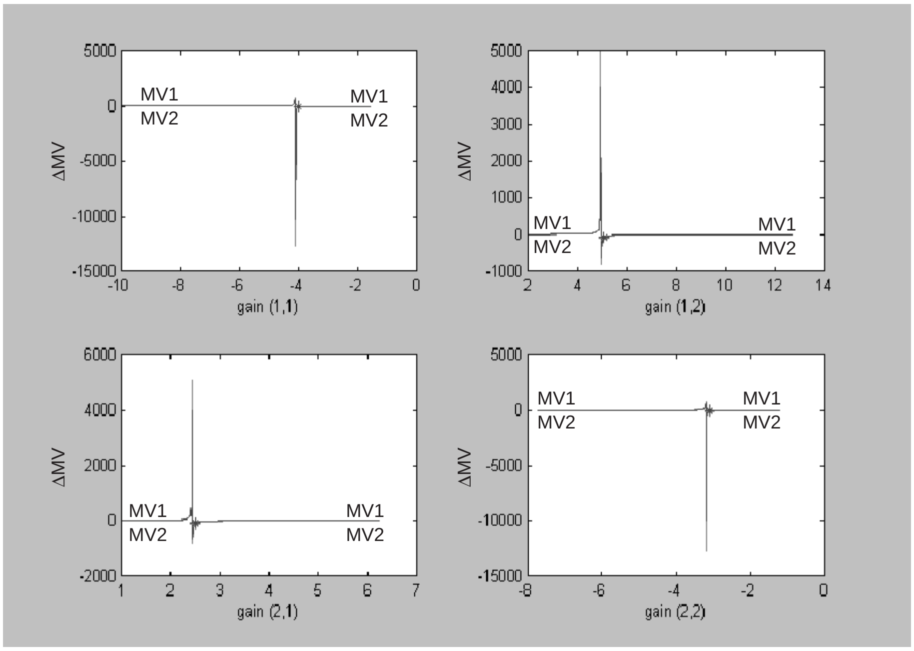

Figure 6 Required MV against Process Disturbance in Response to Gain from Insufficient Test

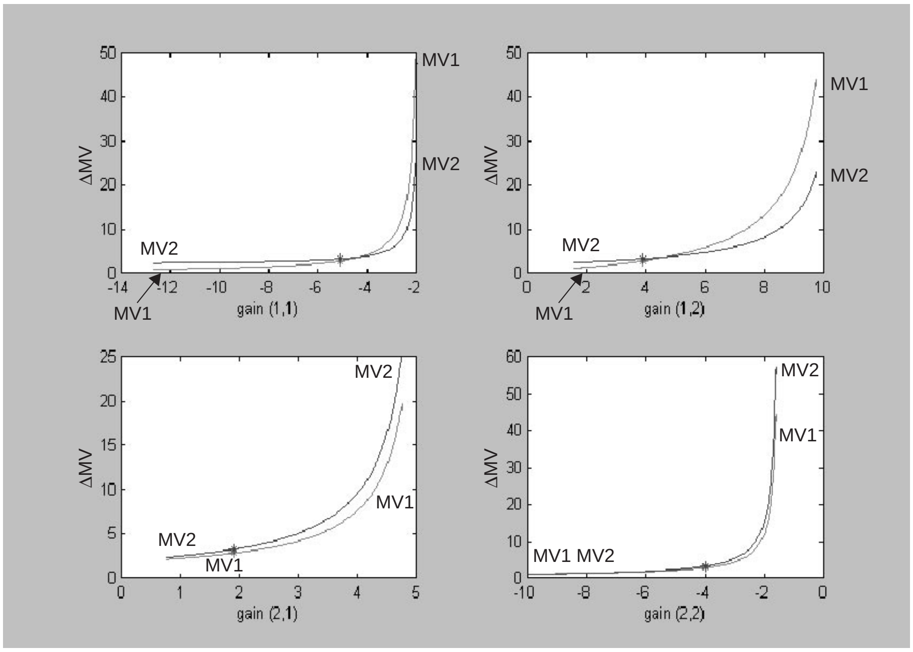

Figure 7 Required MV against Process Disturbance in Response to Gain from Sufficient Test

extremely large but also changes suddenly against a slight change in model gain.

Figure 6 and Figure 7 show how much delta MV, which is required to cancel the unit change of DV, changes against the change of the model gain from 2.5 to 1/2.5 times for the ill-conditioned model and well-conditioned model, respectively. The position of the "*" mark shows the original model gain and the delta MV. If the model is ill conditioned, the delta MV is not only extremely large but also changes suddenly against a slight change in model gain. This example shows that the condition number is a good index as to whether or not the model is suitable for MVC.

The causes for extreme increases in the condition number are as follows.

(1) Insufficient data has been used for identification, leading to the change in MV or DV being too small or some MVs and DVs being changed simultaneously.

(2) The selection of MVs and CVs is not reasonable.

CONCLUSION

The key to successful MVC is to obtain as perfect a process model as possible. The actual process always contains non-linearity in varying degrees. This means it is very difficult to obtain the perfect process model and there is always some degree of model mismatch. However, despite this model mismatch, we are still required to design a stable engineering technique for MVC. MVC has become an important technology of advanced process control and there are many engineers who are concerned with MVC engineering. I hope this paper proves to be useful as a guide for MVC engineering. ◆

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