Tuning interacting PID loops

The end of an era for the trial and error approach

SOFTWARE THAT IMPROVES YOUR PLANT PERFORMANCE
Introduction

Almost all actuators and instruments in the industry that are part of a control system are controlled by a PI(D) controller. Although they trace back to the 19th century, PID controllers still form the backbone of automatic control systems, not only in refineries and petrochemical installations, but also in power plants, cars, breweries, etc.

The success of PID schemes lies in the simplicity and the ability to understand in an intuitive way, the roles of the various parameters in the loop. However, there is one key disadvantage of the PID concept, namely that it is very difficult to optimize PID loops that interact with each other.

A typical approach to dealing with interacting control loops, is to simply assume that there is no interaction. Each loop is optimally set under the assumption that the rest of the plant does not exist. Once all “optimal” PID controllers have been put into “automatic mode” it is possible the complete plant will become less robust, less stable or even unstable. This is because each PID loop has been tuned in isolation, not taking into account interactions with other PID loops.

Perhaps the most common strategy is to detune one or several PID controllers. What to detune, and by how much, is almost impossible to estimate, hence the detuning is carried out based on the “experience” of the engineer doing the work. This heuristic approach may result in several iterations depending on the conditions prevailing in the process, the types of feed, the ambient conditions and so on. It is safe to say that the resulting tuning will never be optimal.

The INCA Apti Tune software challenges these limited, ad hoc approaches by optimally tuning multiple interacting loops without the guesswork. For example, it is ideally suited to tuning the pressure and top temperature controller at the top of a distillation column, or several PID controllers on a hydrogen network, fuel gas network or any other flow network with several PID loops acting on a single flow source.

This article explains in detail the INCA Apti Tune work flow, highlighting all the key functions and showing with real-life examples how IPCOS’ customers and engineers have benefited.

INCA Apti Tune: the work flow

INCA Apti Tune calculates optimized tuning settings that can be entered directly in the plant’s existing DCS – in other words, it facilitates “one shot tuning”. This section presents the INCA Apti Tune approach to tuning interacting PID loops, making use of modern identification methods, advances in optimization theory and the availability of fast multi-core processors.
The procedure for developing PID tuning for multivariable systems consists of a predefined work flow.

- Identify the interacting PID loops that could benefit from multivariable tuning and put these loops in "Manual mode".
- Perform a plant test of the multivariable process and collect process data.
- Identify the process model in the INCA AptiTune software. Model identification features include the ability to incorporate process knowledge on the model by imposing constraints such as gains, dead times, relationships between gains, dynamics and so on.
- Carry out constrained optimization to identify optimal PID tuning parameters based on engineering specifications such as setpoint tracking, disturbance rejection, minimum robustness, maximum overshoot and so on.
- Simulate the optimized PID loops to verify the resulting responses.
- Insert the optimized PID parameters in the target PID loops and make step changes to confirm the adequacy of the response.

All the steps from data collection to simulation of PID loops are incorporated in the INCA AptiTune package. This allows the user to interactively determine the best tuning for their application based on process safety, operability considerations and robustness specifications tailored to the specific DCS.

A plant test is performed on the various subsystems where PID tuning is desired. Typically, INCA AptiTune needs just one or two steps to compute good models. The goal is to identify a dynamic model that
accurately captures the input-output behavior of the plant. An accurate model means that the simulated responses should match the responses of the actual plant. Extra steps can be performed to increase the accuracy of the model still further. Well chosen multiple tests can reveal non-linearities - such as process gains depending on throughput, different static or dynamic behavior when stepping up or down - and valve issues such as (non-linear) Cv characteristics, valve stiction, backlash, and so on.

Once a model has been computed using Aptitune (or imported into Aptitune from another common modeling tool), the next step is to smooth the model (if necessary). A default model smoothing is applied and is generally sufficient. The smooth state space model is then used to determine optimal PID tuning parameters for the closed-loop control system.

![Figure 2- Step testing sequence used to generate models in AptiTune](image)

![Figure 3 - Typical modeling result as generated by the AptiTune modeling tool](image)
The user is required to enter instrument ranges and to select the desired PID equation associated with a particular DCS, the most popular of which are already integrated in the package and include Honeywell TDC and Experion, Emerson DeltaV, Foxboro I/A, ABB Symphony, Yokogawa and others. Optimal controller parameters can also be calculated for P-only, I only, PI and PID options.

Additional specifications and constraints may be specified for the optimization. In particular, unlike other tuning tools, INCA AptiTune allows parameters such as the maximum allowable overshoot and/or maximum allowable OP kick to be explicitly specified. This makes tuning a loop much easier as engineering specifications like overshoot and OP kick are automatically “translated” into tuning parameters (like P, I, and D). Design cases are logged and the user can analyze the different scenarios in terms of setpoint tracking, disturbance rejection, and noise amplification. The integrity of the system when one or more controllers are placed in “manual” can also be analyzed and the robustness against plant-model mismatch can also be evaluated and displayed in an easy-to-understand graphical way.

Recently IPCOS added the functionality to tune cascading loops in one go. A step test on the output of the slave controller and the recording of the CV variations on the master and slave produces a 2 x 1 model. This model is used to tune both master and slave simultaneously. Tuning cascading loops is easy when the dynamic behavior of the slave is significantly faster compared to the dynamics of the master. However, even when the dynamic behaviors are less distinct INCA AptiTune is still able to extract the optimal parameters.

![Figure 4 - Simulated behavior of 2 interacting PID controllers. On the diagonal (A,D) the performance of the PID controllers within its own loop is shown. Off diagonal (B,C) plots show the interaction with the other PID loop](image)
Case studies

Improved quality from a DIB using INCA ApteTune

The first case study shows the typical use of INCA ApteTune on columns. In the refining market, alkylate is a high value product which is produced from the reaction between isobutane (iC4) and olefins catalyzed in an acidic environment. A distillation column, a so-called de-isobutaniser (DIB), is used to obtain iC4 from mixed streams also containing high quantities of linear butane (nC4) and other heavier compounds (C5+). An improvement in the quality of iC4 will result in better yield of alkylates, resulting in significant benefits. Due to the similar boiling points of iC4 and nC4, DIBs are normally big pieces of equipment with slow dynamics which operate with high reflux ratios and consume high amounts of energy. Improved operation of the column will also result in a reduction in energy costs.

The separation of the two compounds iC4 and nC4 is very sensitive to the column pressure, which in turn affects the column temperature profile. In order to achieve finer control of the iC4 top product quality a pressure compensated temperature (PCT) controller was installed on stage #10 of the DIB column, which is the sensitive tray for top quality. The temperature controller output is cascaded to the reflux flow setpoint, as shown in figure 5.

INCA ApteTune was used to obtain direct and cross dynamic models connecting the reflux flow and the pressure valve to tray #10, with temperature and pressure. A step test was carried out with the reflux flow controller in “automatic” and the pressure controller in “manual”. The models showed that the reflux flow did not need retuning. Figure 6 shows the models obtained scaled to the typical moves of the independent variables. Figure 7 compares the simulated behavior of the loops facing typical setpoint changes with the original tuning parameters (red curves) and with the new tuning obtained with INCA ApteTune (blue curves).
Figure 6 - Open loop step test models – scaled to independents typical steps

Figure 7 - 2x2 simulated typical step test response
(red = existing tuning; blue = AptoTune tuning)
Figure 8 shows the simulation comparison for typical load disturbances.

The two figures below show real data comparing the original tuning with oscillations and the loop performance after the new tuning implementation for DIB top temperature and pressure. Notice that with the original tuning (left) the setpoints were always constant. With the optimal tuning (right) the setpoint tracking was much better and the setpoints themselves were moved in order to optimize the process. The quality of iC4 extracted using the new tuning enabled more alkylate to be produced, with the associated financial benefits.

Figure 9 - DIB top temperature control: before and after “AptiTuning” it. Notice that the setpoints on the left picture are constant, while they are moving on the right picture.
INCA AptiTune improves uptime and process stability at KJO

Another example comes from Al-Khafji Joint Operations (KJO) in the Kingdom of Saudi Arabia. The company operates a gas processing facility to treat gas associated with the offshore oil production for gas lift and power generation. Shortly after the plant was revamped in 2014, IPCOS was asked to conduct an audit and optimize the base control layer to improve production uptime and processing stability. The schematic below shows an overview of the KJO gas processing facility for which PID tuning activities were performed.

This was a highly interactive process so a multivariable tuning approach was taken for tuning these PID loops. The PID tuning services for KJO included a review and analysis of all PID loops of the gas plant. Poorly tuned PID loops were identified, prioritized and tuned using IPCOS’ INCA AptiTune software.

It was found during the data analysis that the gas coolers and gas dryers caused temperature and level fluctuations in the Low Temperature Separator (LTS). The effect of stabilizing the temperature of the gas cooler is clearly visible in figure 12. It has a stabilizing effect on the level in the LTS as well as the flow out
of the LTS going to the deethanizer and condensate stabilizer. During the data analysis and interviews with operators it was observed that the deethanizer flow, level and temperature fluctuations were caused by:

- Flow coming from the LTS.
- Poor tuning of Level controller.
- Poor tuning of the deethanizer hot-oil reboiler.

The effect of the improved tuning is clear in figure 12: after tuning, the temperature, flow and level of the deethanizer stop oscillating and follow setpoint correctly.

Thus the LTS was stabilized by updating the PID parameters of the gas cooler's temperature. Due to the interaction between the different units of the gas plant, the stabilization of the LTS also has a stabilizing effect on the deethanizer. The different setpoints of the deethanizer level, flow and temperature are better tracked, as clearly seen in Figure 13. The control of the hot oil outlet temperature was made more robust and the temperature setpoint tracking was made more accurate.
Conclusions

With the introduction of INCA AptTune the era of tuning interacting loops by trial and error is over. Iterating endlessly between tuning trials on the plant and analysis in the office has become obsolete. Translating engineering specifications like maximum allowed overshoot and OP kick into tuning parameters is no longer an art: instead it is a matter of entering the constraints and running the tuning optimizer of INCA AptTune. Based on modeling techniques utilized in Advanced Process Control all interacting loops on process plants can be tuned in an accurate, optimal, robust and efficient manner.

Figure 13 - Improved tuning deethanizer