Lambda Tuning as a Promising Controller Tuning Method for the Refinery

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Introduction

Most undergraduate Chemical Engineering programs teach Ziegler-Nichols [1] tuning methods as the preferred choice. This old tuning method is quite oscillatory, and most engineers revert to tune-by-feel methods when operating commercial plants. The attempt is to tune each individual control loop as fast as possible without causing too much trouble with other control loops upstream and downstream. Technology has changed to allow Instrument Engineers the means to understand their processes far beyond the capabilities of the traditional DCS; tools are now available (from various vendors) that capture process data at higher speeds than the DCS which allows for process control dynamic analysis. Understanding the current process dynamics of your system is a key step in tuning the entire process for better economic performance and robustness. However, the field equipment analysis should be the first step in achieving optimal process control tuning.

Begin with Building a Solid Process Control Foundation

Process control begins in the field, not in the control room. The final control elements (usually control valves) in the field are the instruments that execute the changes required to control the preferred process parameters like flow, temperature, pressure, level, ratio, etc. If the instruments in the field do not function as required, then one cannot expect the overall process control to perform optimally. M.J. Oglesby (ICI Engineering Technology) said it best,

> "No amount of advanced control which relies on the use of poor field instrumentation can be expected to yield worthwhile benefits. Thinking of control as a hierarchy, everything must work well at the lower levels for the higher levels above to work." [2]

Basically, the regulatory loop performance needs to work properly if one expects success at tuning and implementing advanced process controls. A simple bump-test can be performed on key control loops to determine the sensitivity of output required to move the final control elements. It Is not uncommon to see control loops requiring an output change in excess of 2% (Figure 1 shows a limit cycle due to sticky valve example above) to see changes from the final control element movement. Equipment related constraints cannot be tuned out, therefore bad acting field equipment affects the overall success in achieving process control tuning that is economically beneficial and robust. Identifying bad acting field equipment is only the beginning at exercising successful tuning practices. Recent advances in predictive maintenance technology allow commercial operating plants the capability to monitor key control loop performance and the field equipment that affects the bottom line economics; typically field equipment decay is observed long before overall process degradation is observed. Ideally all loops should perform optimally to capture all economic benefits, however this is not economically feasible. Efforts should be focused on the key control loops that directly affect the product-measured qualities like yield, purity, cost to produce and up time (reliability). Field equipment deficiencies on key control loops should be eliminated prior to proceeding with tuning.

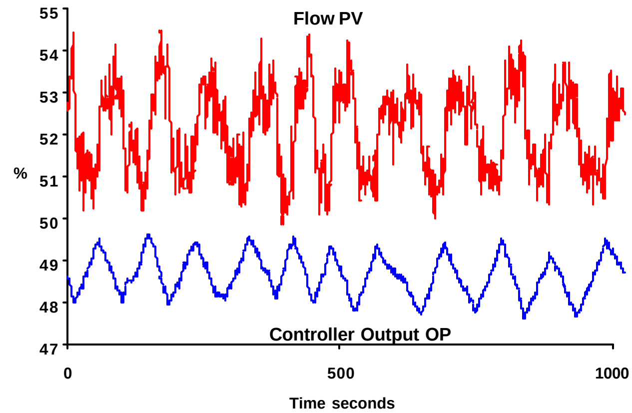

Figure 1 - Typical sticky valve limit cycle

Understanding Current Process Dynamics

After analyzing the field equipment and fixing any deficient acting devices, one can then begin understanding the current process dynamics of the system. The word “current” is used since equipment will always be degrading over time and usually process parameters and raw materials also change over time. Simple output bump tests in manual control and setpoint changes in automatic control are the means for understanding process dynamics. The speed of response, deadtime and sensitivity (process gain) of the system are measured along with the impact on other control loops to determine the overall process dynamics. This information will be used to determine the Lambda Tuning parameters once one determines how fast they want the speed of response for a self regulating process or the “arrest time” for an integrating process. Lambda Tuning allows the user the capability to set the speed of response for each individual loop unlike the tuning methods of Ziegler-Nichols or tune-by-feel.

Prioritizing Process Parameters to Reduce Control Loop Interactions

Similar to implementing Advance Process Control (APC), one should prioritize the process parameters that achieve the best current economic benefits (energy usage, product yield and purity, market demands, contractual commitments, etc). Unlike APC which continuously shifts constraints to achieve overall process performance, prioritizing individual control loops speed of response prior to Lambda Tuning helps reduce control loops fighting one another. Higher priority control loops can be tuned faster (faster speed of response that is still robust) and lower priority loops can be tuned slower (slower speed of response). This freedom of selecting speed of response for each loop helps reduce unwanted loop interactions that are detrimental to the overall process performance. A simple example of this is a cascade control loop where the inner cascade loop should be tuned five to ten times faster than the outer control loop. With Lambda Tuning methods, one can be sure this rule of thumb is met.

Lambda Tuning

"Lambda Tuning" refers to all tuning methods where the control loop speed of response is a selectable tuning parameter; the closed loop time constant is referred to as "Lambda" (?). Lambda Tuning originated with Dahlin [3] in 1968; it is based on the same IMC theory as MPC [4, 5] is model-based and uses a model inverse and pole-zero cancellation to achieve the desired closed loop performance. Lambda Tuning is used widely in the pulp and paper industry [6, 7, 8, 9] where it was realized early-on that a strong connection exists between paper uniformity and manufacturing efficiency on the one hand, and control loop interactions with upstream hydraulics on the other. Paper is a solid product that can be judged (see and feel), therefore it captures all upstream variability in its final product. Lambda Tuning offered a new way of coordinating the tuning of the paper mill loops to gain improved process stability along with a uniform product. By contrast, the Lambda Tuning technique is not well known outside the pulp and paper industry at this time.

As stated above, one should first eliminate any bad acting field devices prior to beginning Lambda Tuning. Once the field devices have been checked and corrected as required, a bump test with the controller in manual is performed to understand open loop dynamics of the process. One should keep in mind the testing should be performed over a range of typical operating parameters. The collected data should be fitted to a simple dynamic model (common models include both first order plus deadtime and integrator plus deadtime). The user selects a closed loop time constant for the control loop based on the process requirements and calculates the PID controller parameters as follows:

<u>Self-Regulating Process (First-order with deadtime model)</u>
? = time constant
T_d = dead time
K_p = steady state process gain
? = closed loop time constant

✍ $T_r = ?$
✍ $K_c = (1 / K_p) * T_r / (? + T_d)$

Lambda Tuning for an Integrating Process is slightly different in that the user needs to determine the arrest time for a disturbance; the arrest time or Lambda is the time to stop the rise or fall of the process variable (PV) due to a step change in load. The technical aspects of Lambda Tuning are described in detail elsewhere [6, 7, 8].

Lambda Tuning Example

Consider the reactor feed problem shown in Figure 2 where the need is to maintain the reagent ratios and reaction stoichiometry constant. In the following example the reagent flows 'A' and 'B' have target ratios of 68% for 'A' and 32% for 'B'. A level controller cascades down to the setpoints of the two-flow control loops via ratio stations. The example illustrates the consequences of using old tuning methods such as QAD, and Figure 3 (left) shows both loops responding to setpoint change at the same time. Both loops oscillate with an initial overshoot

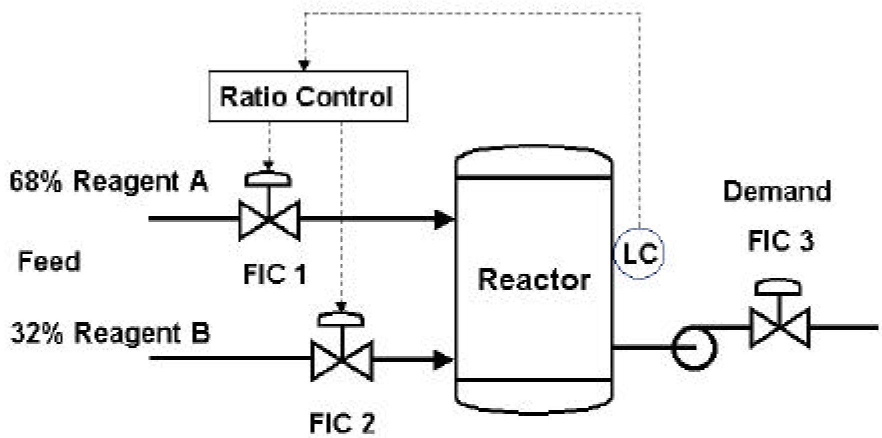

Figure 2 Reactor Feed

of 50% as required by QAD. Clearly, the oscillations and unequal speeds of the two loops have resulted in a significant, yet unnecessary disturbances being created in the flow ratios of Reagents 'A' and 'B' as shown in Figure 3 (right). In sharp contrast Figure 4 shows the same loops Lambda tuned for exactly the same speed of response, with the result that the flow rations are maintained absolutely constant. Oscillatory tuning offers no benefit for uniform manufacturing. Figure 3 above represents traditional tuning with

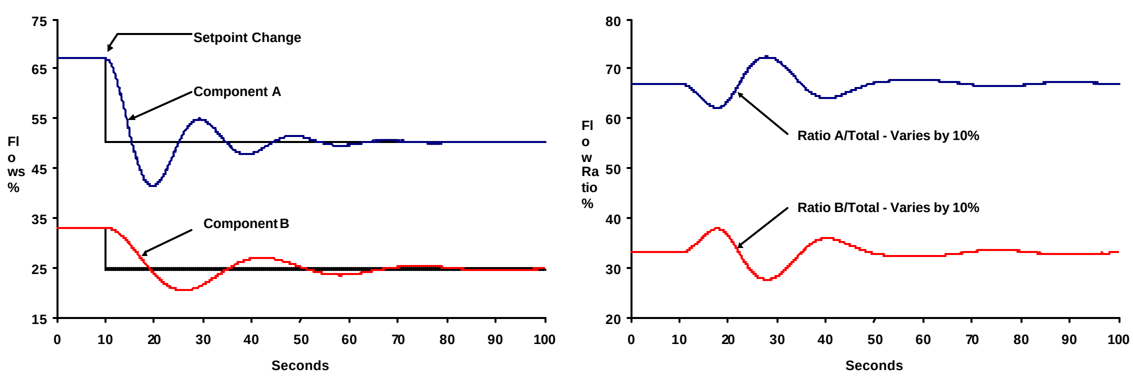

Figure 3 Blending - Ziegler-Nichols Tuning and Impact on Blend Ratios

Ziegler-Nichols and two components being blended (a simple example to illustrate the benefits of Lambda Tuning). With different speeds of responses, the end result is a blend that is not as expected. With Lambda Tuning below, the ratio always remains constant no matter what disturbances go through the system.

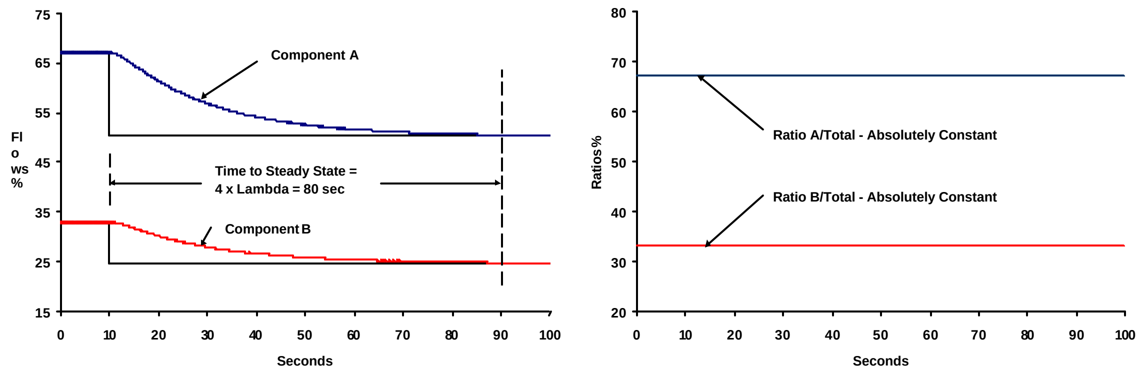

Figure 4 Both Loops Lambda Tuned (Lambda = 20 seconds) & Impact on Blend Ratios

Example: Crude Desalter Pressure and Flow Controller Interactions

With market conditions favorable, a refiner tries to maximize crude flow through their refinery to capture economic benefits. Ideally, all equipment related constraints would happen at the same time (absolute limit of the plant); unfortunately, all constraints do not happen at the same operating parameters and can not only be equipment related but control related, or even feedstock related. One of the most common constraints in getting maximum throughput into a refinery is the performance of two control loops acting together within the Desalter Unit – the crude flow controller and the desalter pressure controller. There is a tendency for the two controllers to fight each other unless the speed of response is set as described above with Lambda Tuning. In addition, the time constants are usually long (several minutes) which makes tune-by-feel methods more difficult. Figure 5 below illustrates a desalter flow example in which the flow and pressure are initially tuned-by-feel and Lambda Tuned later.

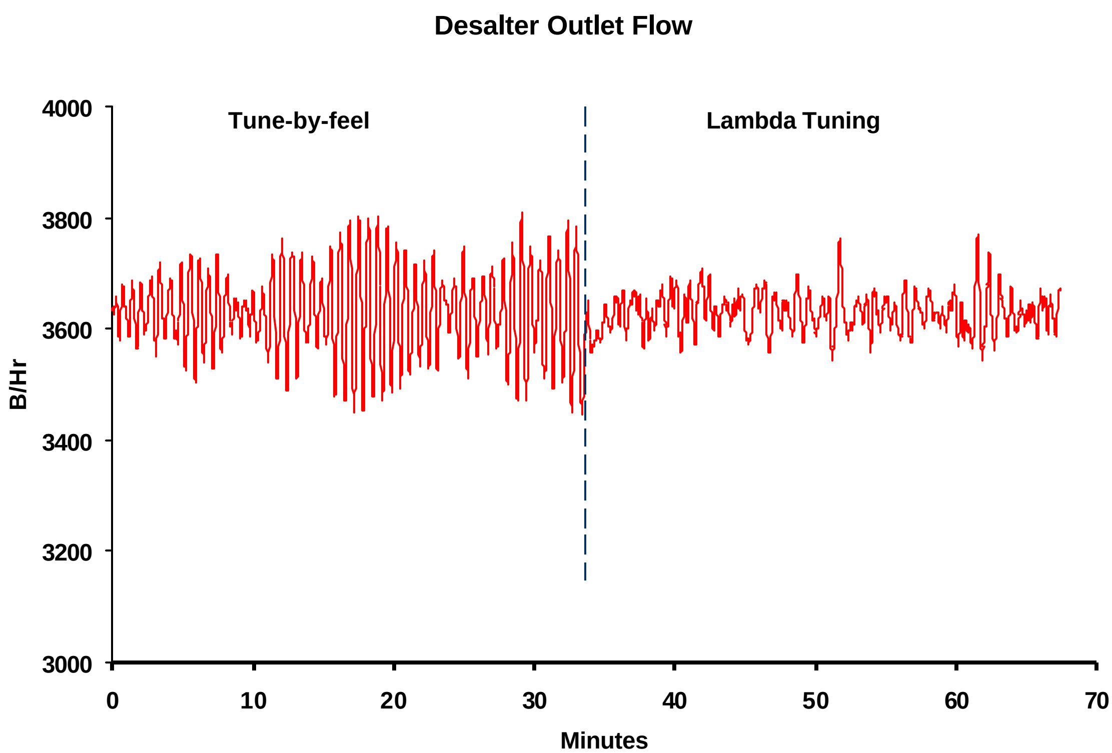

Figure 5 Impact of Lambda Tuning on Desalter Outlet flow

Example: Gasoline Blending Ratio Flow Control

Every refiner is challenged with the daily routine of non-linear gasoline blending. Many refiners depend on APC systems that themselves depend on the functionality and performance of the regulatory control loops. Field equipment deficiencies are very detrimental with gasoline blending since blend-engineers may mistake poor performing field devices as non-linearities in the blend, thus learning non-repeatable performance of the system (apply the same recipe conditions on the next blend). Gasoline blending is difficult enough without having the addition of poor performing field equipment constraints. Figure 6 below shows an FCC flow to a gasoline blending unit with nearly 80% variability in flow due to a sticky control valve. Clearly no amount of blend ratio control can overcome the resulting variability in gasoline blend caused by this poorly performing control loop.

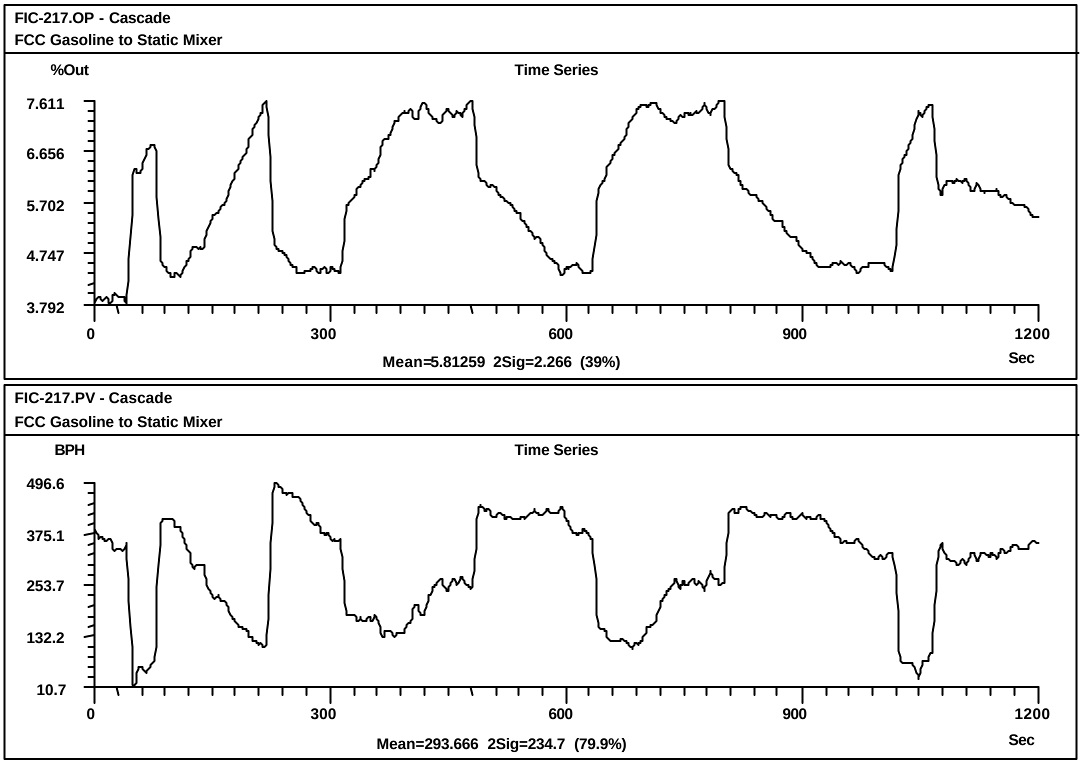

Figure 6 FCC Gasoline Flow to Blend System Static Mixer

Having good performing field devices is still no guarantee for good blending practices. Loop interactions between the blend component flows and the individual non-linearities in the component flow control loops themselves can cause additional unwanted constraints. A 3” linear trim control valve (e.g. Reformate flow) and a 6” equal-percentage trim control valve (e.g. Cat gasoline flow) will have different dynamics, yet an APC will expect the two to respond the same. As stated above, with Lambda Tuning the speed of response can be set; all the component flows will have the same speed of response based on the slowest dynamic time constant of the control loops.

Conclusion

Lambda Tuning has been around since 1968 and has been extensively used for many years within the Pulp and Paper Industry. In recent years the Chemical Industry has begun to take advantage of the Lambda Tuning methods with significant economic impact. It is only a matter of time before the Refining Industry realizes the benefits of Lambda Tuning (producing more uniform products at less cost with more process control reliability).

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