STANDARD TUNING PROCEDURE
AND THE BECK DRIVE:
A COMPARATIVE OVERVIEW AND GUIDE

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OVERVIEW:

Tuning a control loop with a Beck drive installed usually proves simpler and quicker, and the results are more reliable, than tuning loops equipped with traditional pneumatic actuators. This is because the Beck drive eliminates pneumatic actuator non-linearity and inconsistent performance caused by valve stiction and changing loads, and provides repeatable, precise response instantaneously on demand.

There are a number of different PID tuning methods used in industry today, ranging from manual methods like Ziegler-Nichols to computerized, model-based methods. Each different methodology provides slightly different results, and the choice of which method is best is based on personal preference and the control objective. In spite of the differences, there is one commonality; almost all the standard tuning methods use the estimated process dynamics (i.e. time constant, dead time, gain, natural frequency, ultimate gain, etc.) to establish the tuning parameters. The open-loop bump test is the universally accepted method for estimating loop dynamics for almost all tuning methods. Although the bump test may be the most practical procedure for estimating dynamics, and it usually works reasonably well, it is not without drawbacks.

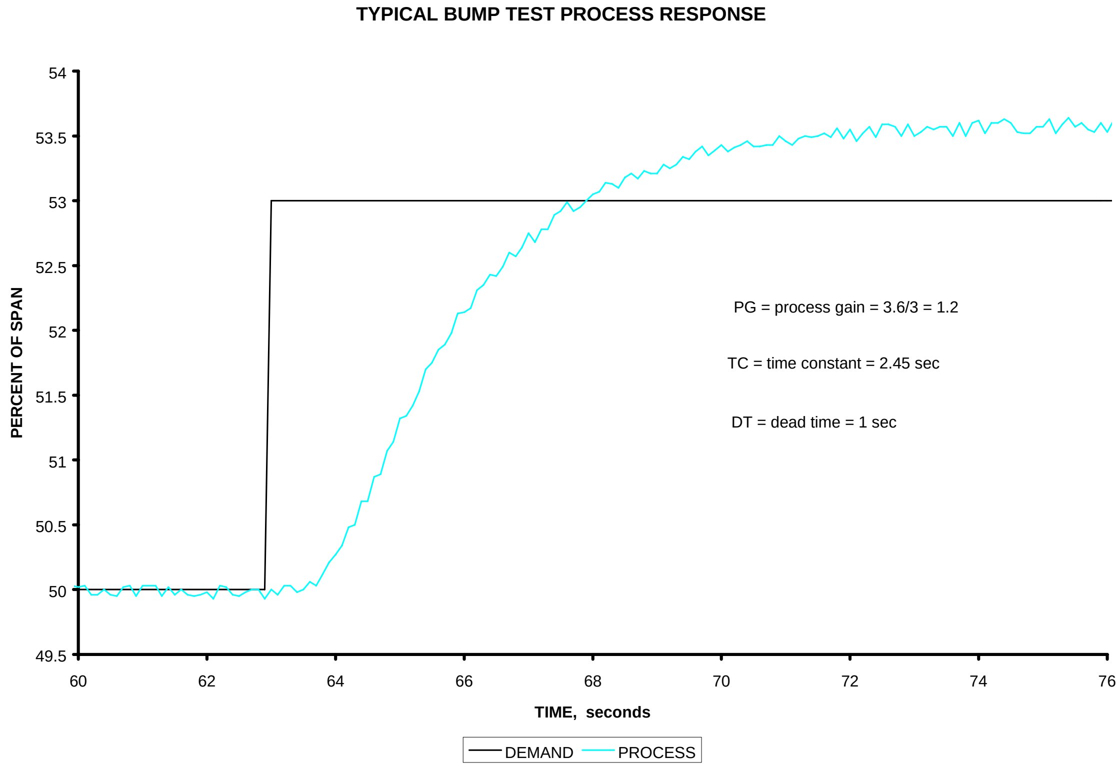
The assumption that a control loop is linear is the foundation of PID control theory. However, truly linear systems do not really exist. The reason PID control usually works is that systems can typically be assumed linear in a narrow control range. Nevertheless, non-linearity always exists, and depending on severity and degree of unpredictability, it can negatively affect control performance and make tuning difficult.

All the standard tuning methods can be effectively used in conjunction with Beck drives. This paper provides a brief overview of why Beck Control Drives make tuning easier, and gives some procedural tips that can further simplify the tuning process. In general, the discussion is geared toward self-regulating loops since they are the most common, but the conclusions and procedural considerations are applicable to integrating loops as well.

THE OPEN-LOOP BUMP TEST IS A PRACTICAL AND EFFECTIVE WAY TO ESTIMATE LOOP DYNAMICS FOR TUNING, BUT IT DOES HAVE A DRAWBACK.

The open-loop bump test procedure (see **Figure 1** below) requires that the control loop be placed in manual and the valve demand is bumped in a single step to produce a process response from which the loop process dynamics can be estimated. The size of the bump must be large enough to generate clear and reliable data, but not so large as to create a severe process excursion or control problem. In most cases, the bump size ends up in the three to five percent range.

Figure 1



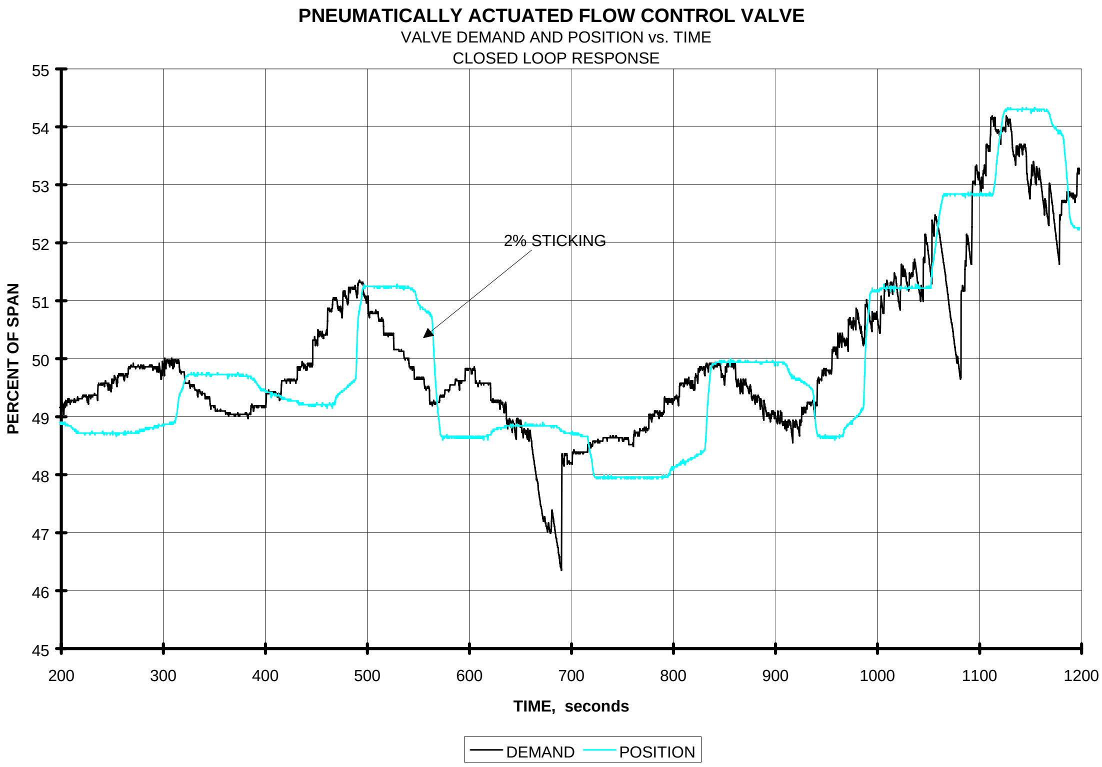
The goal of any tuning method is to establish tuning parameters that will produce optimal *closed-loop* control performance. Unfortunately, *open-loop* actuator performance is not necessarily indicative of *closed-loop* performance. Therefore, dynamics established from open-loop bump testing may not reflect the process dynamics under closed-loop conditions. This is the drawback of open-loop bump testing.

Perfectly linear systems do not exist; therefore, establishing loop dynamics from an open-loop bump test is only an approximation. In spite of this, tuning methods utilizing the open-loop bump procedure usually provide satisfactory results. This is because most loops can be *approximated* by a linear system, at least in a narrow range. Nevertheless, skill, experience and often “tweaking” are required to compensate for the non-linearity that does exist. Pneumatic actuator non-linearity is especially problematic because it is inconsistent and varies with load, conditions and time. The fact that Beck drives eliminate closed-loop non-linearity typical of pneumatic actuators helps make tuning a simpler and more reliable process.

PNEUMATIC ACTUATORS ARE A MAJOR SOURCE OF NON-LINEARITY DETRIMENTAL TO CONTROL LOOP PERFORMANCE, BUT THIS IS NOT ALWAYS APPARENT FROM THE BUMP TEST RESULTS.

Pneumatic actuator non-linearity can make tuning a difficult and tedious process. For example, pneumatic actuators are susceptible to backlash, hysteresis and, worst of all, valve stiction problems. This creates detrimental non-linearity in the form of *closed-loop* dead time, overshoot, cycling and performance inconsistency (Figure 2).

Figure 2



Bump testing produces a "popping" action, which allows a pneumatic actuator to more easily overcome valve stiction than when it is gradually modulated, as is characteristic of closed-loop control. Pneumatic actuator performance is, therefore, far more susceptible to the ill effects of stiction under closed-loop control conditions than under bump test conditions.

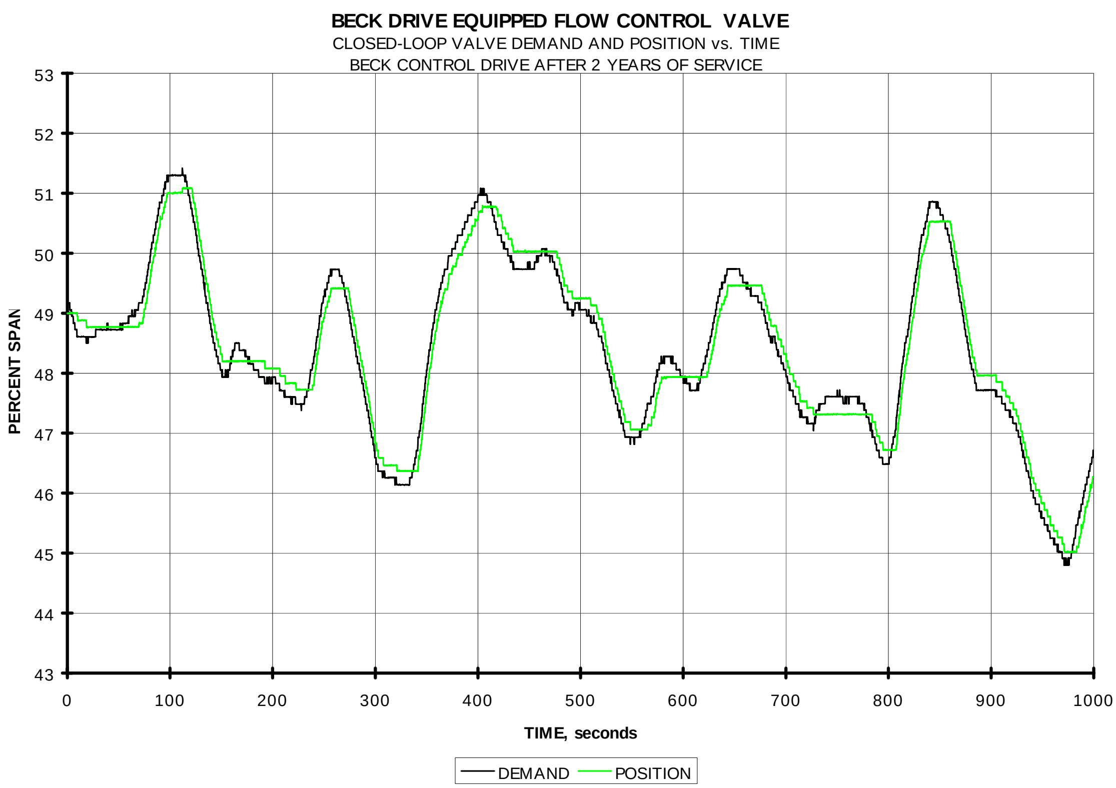
It follows that pneumatically actuated valves often respond faster, more smoothly and more consistently to an open-loop bump test than they respond during actual closed-loop control. This is a twofold problem because it not only means that non-linearity like stick (dead time), slip (overshoot), and inconsistent performance will limit closed-loop control, it also means the bump test results may not reflect that these closed-loop performance problems even exist. Therefore, tuning a pneumatically actuated control loop based on the dynamics estimated from the bump test becomes a difficult task, and the results are often unreliable.

It is important to note that since the dynamics estimated from the bump test do not reflect the added dead time of stiction, tuning resulting from any tuning method will tend to be aggressive, erring on the side of instability. Depending on the severity of the non-linearity, and the speed of the process, tuning can range from slightly aggressive to unstable. In any case "tweaking" the tuning results becomes necessary to produce optimal control, and is usually just considered part of the tuning procedure. Most tuning packages include stability safety factors to compensate for non-linearity and produce more "robust" tuning. Robustness insures a wider range of control stability, but does so at the expense of tight, responsive control. Furthermore, "tweaking" is still typically an ongoing process because pneumatic actuator performance degrades over time, necessitating changes in the loop tuning.

BECK CONTROL DRIVES PROVIDE NEAR PERFECT CLOSED-LOOP TRACKING, ELIMINATING NON-LINEARITY TYPICAL OF PNEUMATIC ACTUATORS, IMPROVING CONTROL AND SIMPLIFYING TUNING.

Beck control drives are not subject to stiction and the performance inconsistencies characteristic of pneumatic actuators. The Beck design, coupled with its electronic controls, provides full-torque, instantaneous starting and stopping capabilities. The precise performance is unaffected by load and remains consistent over time and under varying conditions. Therefore, under closed-loop modulating conditions, the Beck drive approaches perfect tracking of the controller demand and virtually eliminates closed-loop non-linearity and dead time resulting from the actuator (Figure 3). This simplifies the tuning process, while making the tuning parameters valid over a wider operating range, over time, and with changing conditions.

<u>Figure 3</u>



As with pneumatic actuators, the open-loop bump response of a Beck drive is not necessarily indicative of its closed-loop response; however, the reason this occurs, and the effect it has on tuning is quite different from the pneumatic actuator case discussed above. Because the Beck drive is powered by a constant-speed motor, the bump test response of the drive is a constant-speed ramp, rather than the traditional first-order response from which dynamics are mathematically estimated. This means that the total response time of the Beck drive is directly proportional to the size of the bump test step. Therefore, the drive response has a greater effect on the estimated open-loop time constant as the step size increases. This can cause confusion, but concern is unfounded because the speed limitation of the Beck drive is usually insignificant given the three to five percent step size typically used for determining loop dynamics. Standard tuning practices usually produce excellent results, without “tweaking”, for step changes of this magnitude.

In tuning situations when the loop has very fast process dynamics, and/or a large open-loop bump is used, the Beck drive may have a slowing affect on the estimated time constant and the resulting tuning parameters. However, the Beck drive’s ability to precisely track closed-loop controller demand insures that the drive speed does not limit the closed-loop response speed. This means that the open-loop dynamics estimated from the bump test will reflect a slower response than will be experienced under closed-loop control, and tuning based on this will tend to be conservative, erring on the side of stability. This is in contrast to the effect caused by pneumatic actuator non-linearity, which is largely masked by open-loop bump testing, thus resulting in an overly fast estimation of response dynamics and, consequently, aggressive, or even unstable, tuning.

THE TUNING PROCEDURE FOR BECK EQUIPPED LOOPS CAN BE EVEN SIMPLER, AND THE INITIAL RESULTS EVEN BETTER, WHEN THE LOOP CHARACTERISTICS ARE CONSIDERED FIRST:

Tuning a loop that is equipped with a Beck drive is procedurally the same as tuning a loop equipped with any type of actuator. In most cases, the Beck drive’s constant-speed response has an insignificant effect on the process dynamics estimated from a bump test. The valve/actuator response, however, is only one factor contributing to the overall dynamics of a control loop. It follows then that the amount of influence the response of the Beck drive has on the loop dynamics estimated from an open-loop bump is a function of the other factors determining dynamics. As the relative dynamics of the process become faster (e.g. pressure and flow tend to be much faster than temperature, etc.) and/or more sensitive (higher gain) the contribution of the drive response on dynamics estimated from an open-loop bump has increasing significance. Therefore, tuning parameters are increasingly affected as well.

Considering the relative process dynamics before beginning the tuning process can produce more reliable tuning results, and reduce the need to fine tune or “tweak”. The repeatable, instantaneous response of the Beck drive already makes tuning easy and reliable. Some consideration of the general loop characteristics can further simplify the tuning procedure, and provide even better initial results. The four issues to be considered are the following:

1. The relative speed (time constant) of the process.
2. The gain of the process.
3. Process dead time.

4. The type (load or setpoint), size and speed of typical loop disturbances.

For all tuning methods that use loop dynamics estimated from a open-loop bump response the initial procedure is generally the same, with some differences for integrating processes. However, several variations of the basic procedure can be used depending on the considerations described above. The decision to select a procedure is a subjective one based on process knowledge, experience, historical process data and personal preference, but as a rule of thumb a Beck-equipped loop can be categorized into one of two simple situation types. Determining the loop type helps determine the appropriate procedure as follows:

Type I: Beck drive response is invisible to closed-loop process dynamics.

Type I process control loops are those loops in which the Beck drive speed is never a limiting factor. This means that under *closed-loop* conditions, the final control element is not modulated at a speed in excess of the drive speed, and the drive is essentially invisible to the loop. Most loops fit into this category, and Procedure I is best suited for tuning. Note that determining this initially requires either some historical knowledge/data of how this loop performs under closed-loop control, or how similar loops perform under closed-loop control.

Procedure I: Generic tuning procedure used for most loops regardless of actuation method.

Step 1 - Place control loop in manual.

Step 2: -Estimate the smallest step change that can be applied to the final control element that will produce results acceptable for estimation of dynamics (time constant, effective dead time, gain), and bump the controller output. Three percent is usually a good starting point.

Step 3 - If the process response is easily evaluated, and it appears valid, proceed to Step 4. If the response is difficult to interpret, continue to make larger bumps until useable data is obtained. If the bump is already quite large, other problems need to be corrected.

Step 4 - Estimate the process dynamics from the response obtained in Step 3 and plug into the tuning package.

Note: Many tuning packages perform Step 3 & 4 automatically.

Step 5 - Enter the resulting tuning parameters into the controller and evaluate performance. Modify as necessary.

Type II: Beck drive response may affect loop dynamics under certain *closed-loop* situations.

Type II process control loops are those in which, under some circumstances, the speed of the Beck drive may become a limitation. These situations are typically rare, and even when they occur the effect is usually minimal. Examples of this type of loop include loops with extremely fast dynamics and high gain which are subject to large, rapid load swings. Procedure II is best suited for these types of loops because it takes response speed of the valve assembly into account and provides conservative tuning parameters.

Procedure II: Tuning to consider Beck drive response.

Step 1 - Place controller in manual.

Step 2 - Estimate the largest step or rapid disturbance that the loop may be subject to under closed-loop conditions. This requires a certain level of knowledge about the process and related loops, and it can be difficult. Historical data or simulation are good tools for estimating a value. Bump the controller output by this amount. Be careful that the bump size is not so big as to create a control problem.

Step 3 - If the process response is easily evaluated, and it appears valid, proceed to Step 4. If the response is difficult to interpret, continue to make larger bumps until useable data is obtained. If the bump is already quite large, other problems need to be corrected.

Step 4 - Estimate the process dynamics from the response obtained in Step 3 and plug into the tuning package.
Note: Many tuning packages perform Step 3 & 4 automatically.

Step 5 - Enter the resulting tuning parameters into the controller and evaluate performance. Modify as necessary.

Note: By determining the dynamics from a step as large or larger than any rapid disturbance the loop might experience under closed-loop control, the worst case drive speed limitation is accounted for in the resulting tuning. This tends to make the tuning conservative under most conditions, but eliminates the possibility of instability when the loop does experience a large, rapid upset.

A third procedure (Procedure III) is also applicable to **Type II** processes. It is a variation of procedure II that can be used when adaptive gain tuning is possible, and the closed-loop operating range is very non-linear and wide. Using the procedure requires a thorough understanding of the process to be controlled. The added complexity of the procedure is not warranted for most loops, but it can help provide a broader range of control in loops with problematic non-linearity.

Procedure III: Tuning when loop operating range is extremely non-linear or the loop is subject to a wide variety of disturbances from small and gradual to large and rapid.

Note: The following procedure is nothing more than the implementation of adaptive gain tuning. Generally, it applies to any loop that is subject to significant non-linearity in the operating range. In the specific case of the Beck drive, it especially applies to loops that are subject to a very wide range of disturbances, including large, rapid ones, which could cause the Beck drive to slow the loop response during closed-loop control. Procedure II above addresses this scenario in a simpler, more conservative format. It can be used for less extreme situations, or when adaptive tuning capabilities are not available in the controller. Utilizing the procedure outlined below, however, will produce tuning that is better suited for the entire range of possible operating conditions rather than optimizing the performance for the worst case situation at the expense of performance everywhere else in the operating range.

Step 1 - Perform Step 1 - 5 described in Procedure II above.
Step 2 -Once acceptable performance has been achieved for the worst case disturbance or non-linearity, move to Procedure I above and perform Steps 1 - 5 only.
Step 3 - At this point both ends of the tuning spectrum for the loop are defined and can be entered into the controller per the method for the controller. If the reason for using the adaptive tuning procedure is that the loop is subject to a wide variety of disturbances, which can cause the drive to create speed non-linearity, the tuning procedure should be complete. The adaptive trigger is, therefore, a simple linear function of process-setpoint error. If the adaptive tuning is a result of more complex non-linearity, the procedure becomes much more complex, and is beyond the scope of this basic document.
Step 4 - Evaluate performance and modify the tuning as necessary.

SUMMARY & CONCLUSIONS:

PID control theory is an inexact science because it assumes linearity, but, in the real world, perfectly linear systems do not exist. Depending on the degree and type of non-linearity in a control loop, traditional tuning methods may provide excellent tuning parameters or nothing more than a starting point.

Pneumatic actuators are a leading cause of non-linearity, and are more problematic than other sources because the performance problems vary with load, conditions and time. Nevertheless, this is often overlooked, and the effect on tuning is underestimated. Open-loop bump testing of a pneumatic actuator tends to hide or minimize *closed-loop* non-linearity and inconsistency because bumping the actuator helps overcome stiction. Therefore, a major non-linearity like stick/slip response may not be accounted for in dynamics estimated from an open-loop bump test, and tuning that results will tend to be aggressive, or even unstable if the non-linearity is severe enough. This can make any tuning method a more tedious and difficult process by requiring trial-and-error “tweaking”.

Beck drives eliminate the detrimental inconsistencies that cause pneumatic actuator non-linearity, and provide consistent, precise and instantaneous response. In fact, the Beck drives ability to start and stop instantaneously, coupled with its ability to make extremely small steps (as small as 0.075%), produces nearly perfect closed-loop tracking (linearity) of the controller demand. Therefore, the Beck drive is virtually invisible to the loop, and almost never creates closed-loop speed limitation.

The Beck drive’s constant speed response, which is only evident during open-loop bump testing, can slow the time constant estimation of an open-loop bump response; however, the effect is usually insignificant. In the rare case (very fast process and/or large bump test step) that the Beck drive significantly limits the open-loop bump response, the resulting tuning will tend to be conservative, because the time constant estimation will be slower than true closed-loop performance. This is in contrast to the pneumatic actuator case described above.

In conclusion, traditional tuning methods based on estimated, open-loop dynamics work well for loops equipped with Beck drives. Often, they produce more optimal and stable results than produced when a pneumatic actuator is installed in the loop, because Beck drives virtually eliminate closed-loop actuator non-linearity. In any case, the initial results of any tuning method should be used cautiously. Every loop has different requirements and every tuning method has different objectives. Experience, skill and knowledge of the process are essential to success.