Drive Response Requirements for Web Handling

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Abstract

The response of a drive's torque, speed and tension regulators are set when initially tuning these regulators. Once tuned, the response determines how the drive responds to disturbances. We will discuss the tuning requirements for various web handling applications. These will be compared with typical tuning values found in industry.

Introduction

Tuning a drive results in a drive which gives predictable performance in the way the drive responds to a change in speed or change in tension.

In general for control systems and in particular for drive regulators used in web handling, we are concerned with the step response. That is we are interested in how the drive responds when we change the setpoint with a step function. A step is a sudden change in the setpoint. For instance, the speed may be stepped from 100 mpm to 110 mpm.

Intuitively we know that the drive will not respond instantly to a step change in speed setpoint. It will take some time before the drive settles in at the setpoint.

We must also recognise that more than one regulator is used in each drive. All drives will have a torque regulator and a speed regulator. Some drives will have an additional tension regulator. These regulators are cascaded. For good reason, we tune inner regulators at least 3 times faster than the outer regulators.

This presentation discusses the regulator aspects that can be measured on-site during the commissioning of the web handling line. We do not discuss the mathematical analysis used by control engineers at their desk.

Definitions

The response of a second order system is shown in this diagram. A few terms are defined here.

Second Order System – simplest interesting control system. Called 2^{nd} order because the denominator of the mathematical model of the system involves a quadratic equation.

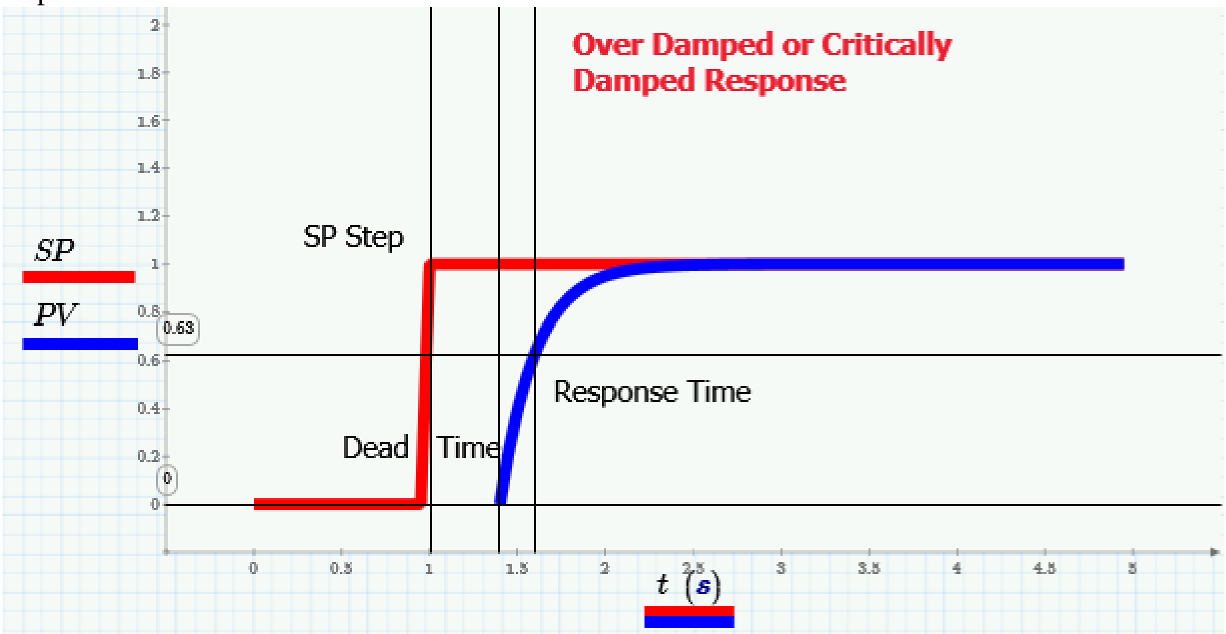
Process Variable (PV) – the measured and controlled value of interest (Speed in mpm or tension in N/m)

Setpoint (SP) – the target value for the PV (Speed in mpm or tension in N/m)

Control Variable (CV) – the output of the regulator. The CV controls a variable that will produce the desired PV. The CV in web handling may be torque (N*m) or speed (mpm).

Dead Time – the delay after the setpoint step is applied, before a change in the PV is seen.

Overshoot – the amount the PV exceeds the step value. This is usually measured in percent of step size.



Oscillatory – the PV overshoots and undershoots in a decaying sinusoidal function.

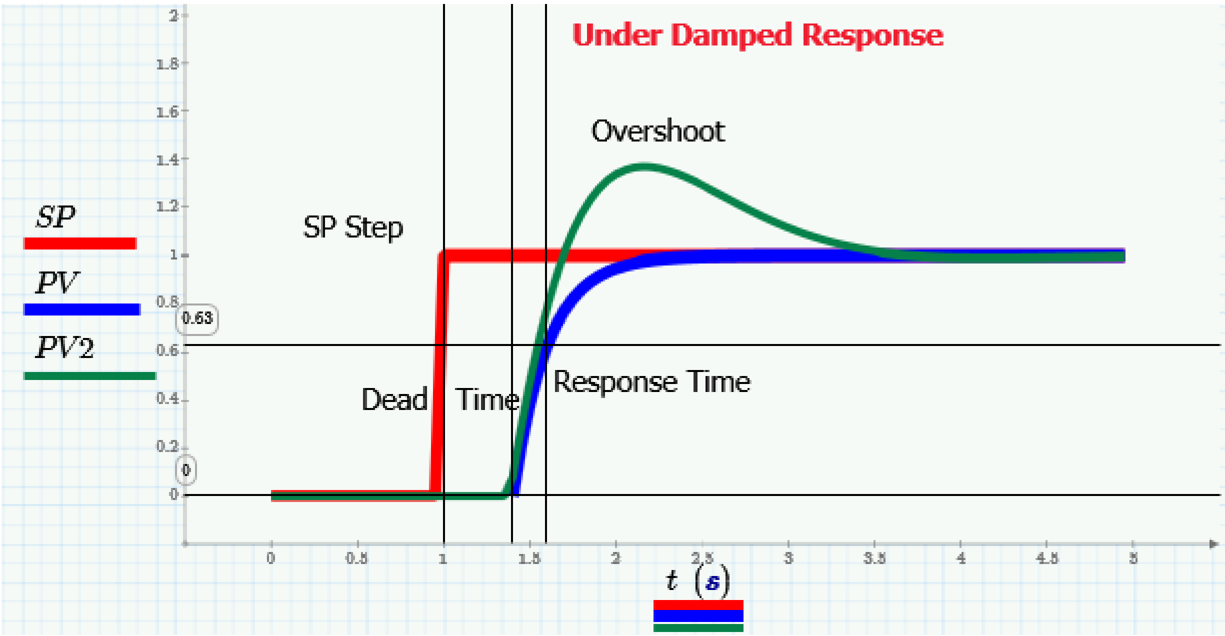
Period of Oscillation – the time for one cycle of oscillation.

Frequency of Oscillation – the frequency of oscillation. This is the inverse of the Period of Oscillation.

Instability – the oscillatory function does not decay.

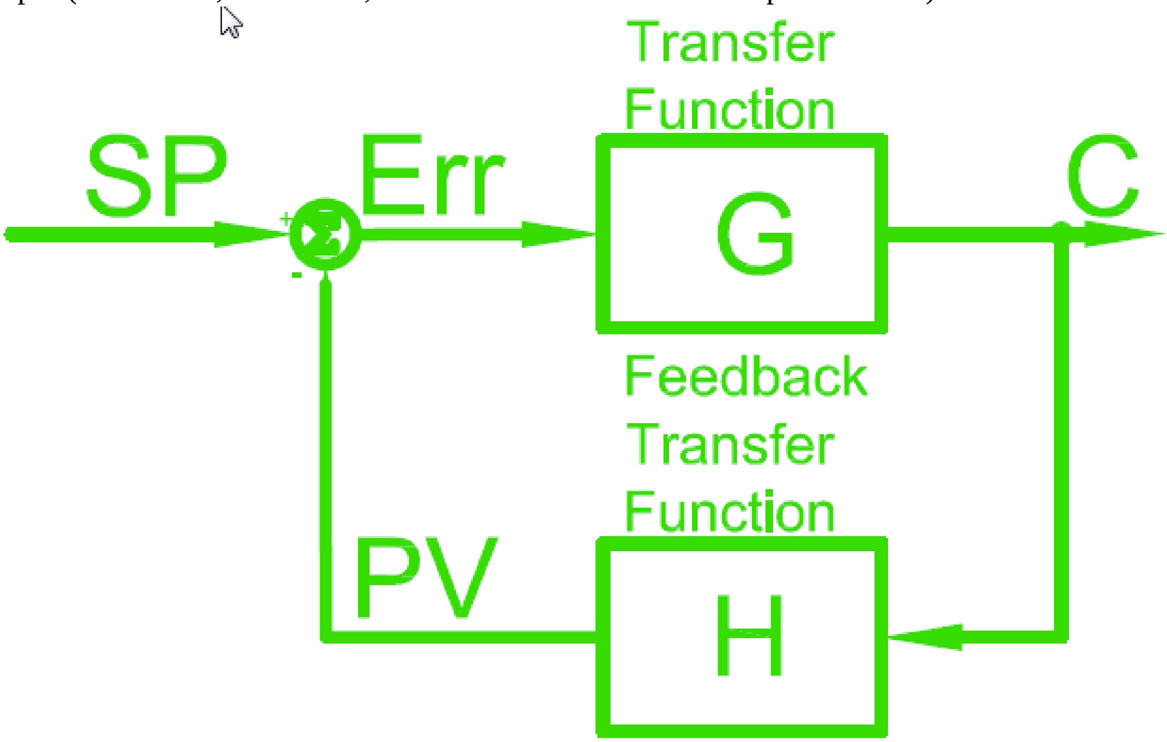
Response Time – The response time is a measurement of the time required for the regulator to respond to a step change in the SP. This is defined as the time (seconds) for the PV to reach 63% of its *final* value. This is also called the regulator time constant.

Response – The response of the regulator measured in frequency (radians/second). This is the inverse of *Response Time*. This is also called *Bandwidth*.

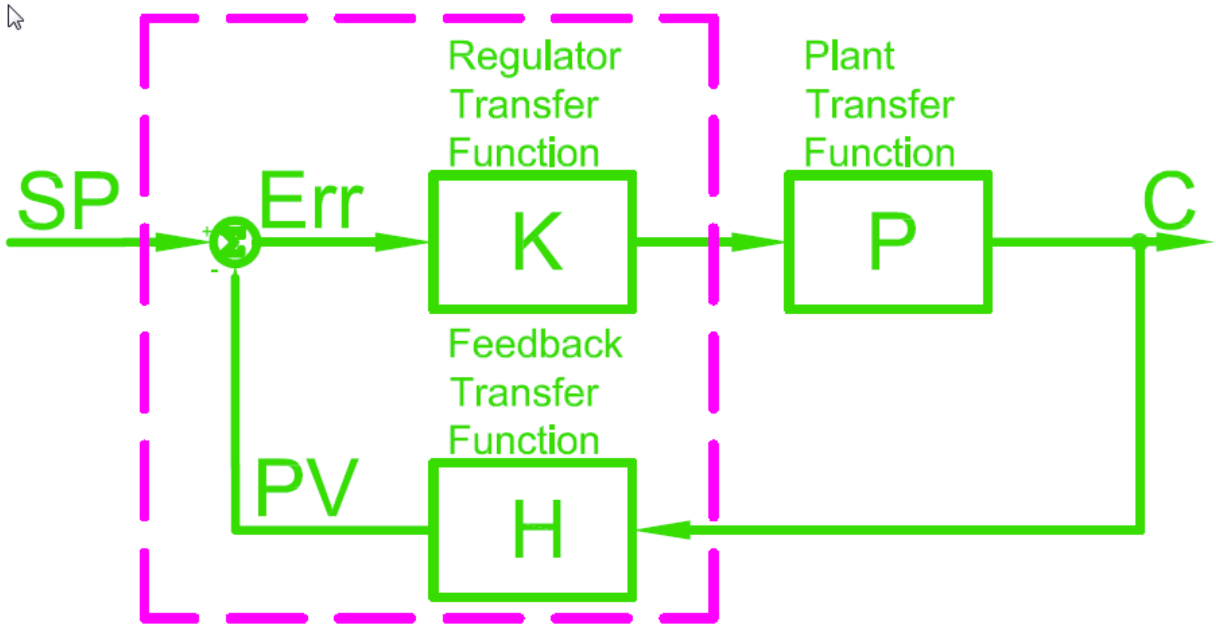


Settling Time – the time for the regulator to achieve the setpoint within +/-1%. This is between 4 to 5 times the response time for a 2nd order system with no overshoot.

Control System – a entire system of mechanical and electrical components to achieve a desired output (ex. Rollers, drive train, VSD and encoder to achieve speed control)



Plant – Control System includes the Regulator and the Plant. It costs money to replace Plant items. (ex. Motor, speed reducer, carbon fibre roller) c

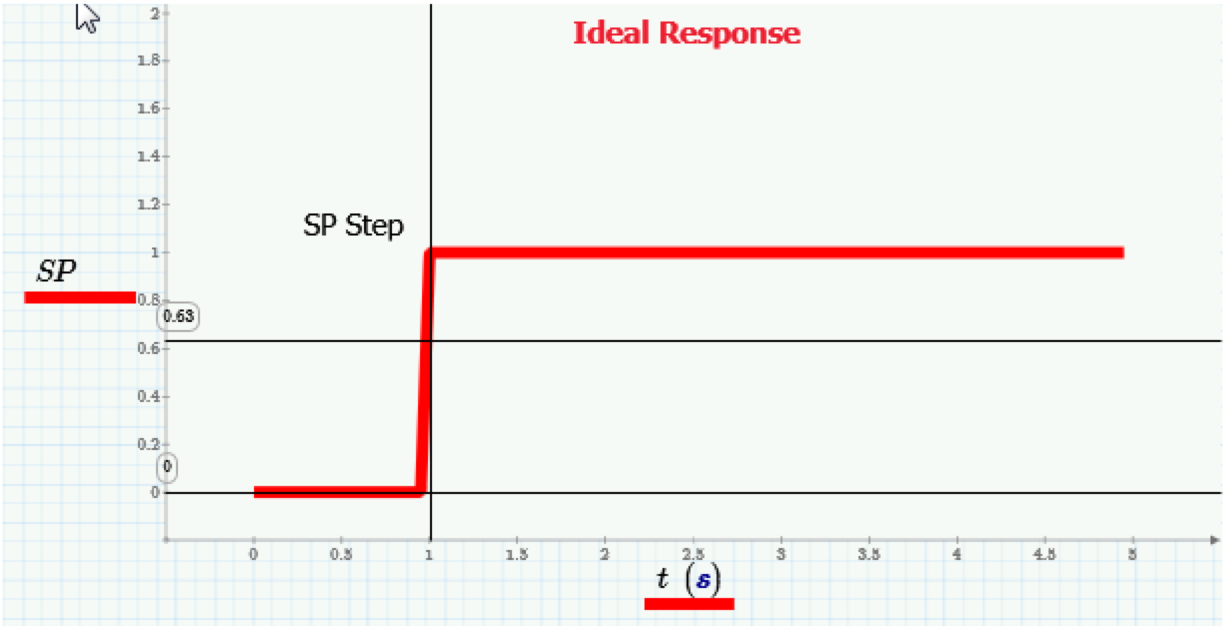


Regulator – a controller that compares the SP and PV, applies a transfer function which modifies a control variable to move the PV toward the SP.

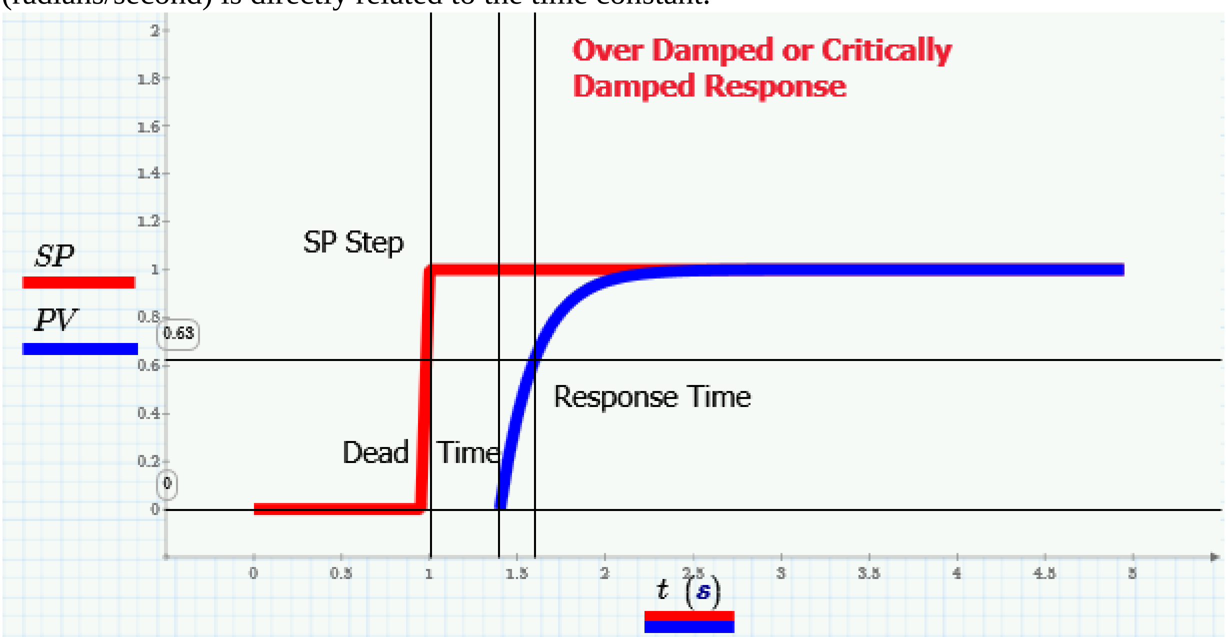
Gain – a regulator parameter that can change the amplification of the regulator (compare with volume control knob on a radio)

Lead – a regulator parameter that compensates for time lags in the control system (loosely compare with the tuning knob on a radio)

An **Ideal Regulator Response** would be very fast (no delay) and with no overshoot. In other words the PV would match the SP exactly. The transfer function for the system would equal 1. This is impossible.

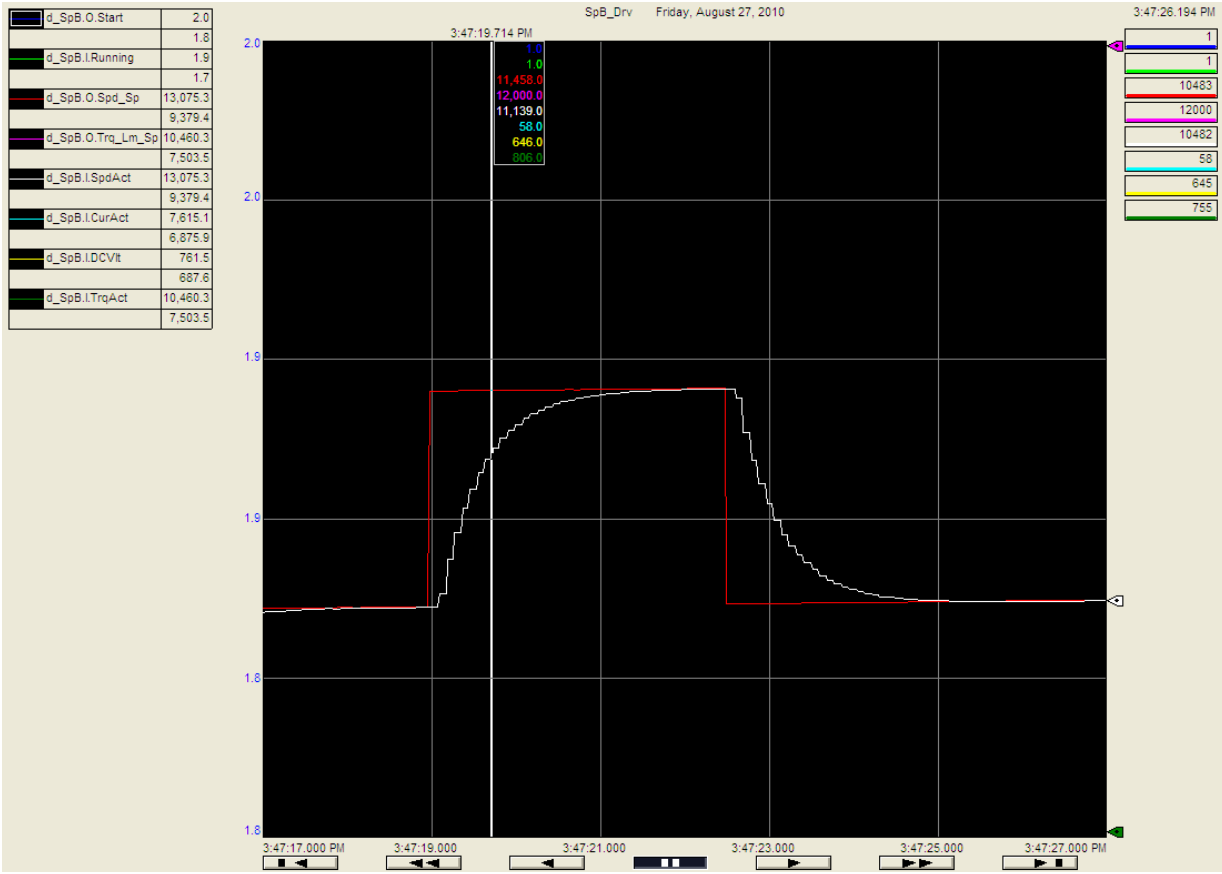


A **Practical Regulator Response** provides a critically damped response. This gives the simplest practical transfer function between SP and PV, namely an exponential function. There is no delay, no overshoot, no oscillation, no instability in a critically damped system. The only parameter is the time constant (second) of the regulator. The regulator response or bandwidth (radians/second) is directly related to the time constant.



Actual Speed Regulator Response

Tune Spindle B speed regulator for 1.4 radians/second. Kp=10.5, Ti=0.38sec



What regulator response is required or desired for speed regulators?
Some answers from experts are:

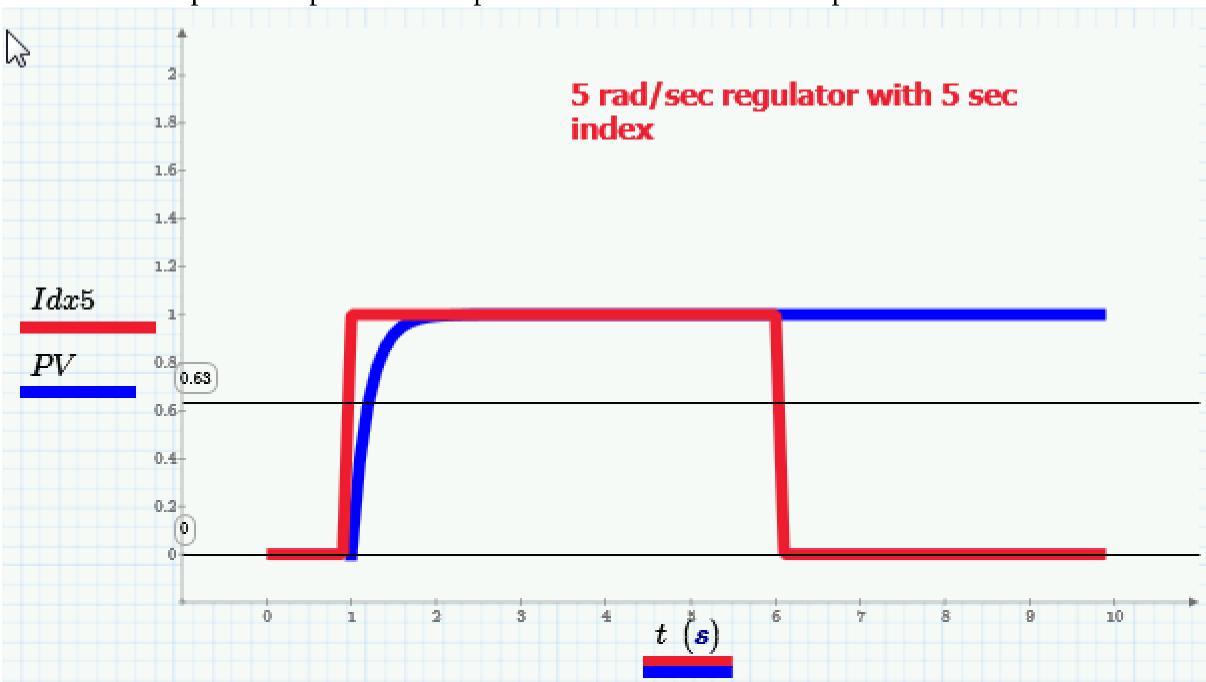
- Use the drive default settings (5 radians/second)
- Just perform the auto tune (no metrics)
- Each drive tuned as fast as possible (1 to 5 radians/second)
- Same tuning as the previous similar line. (no metrics)
- All drives tuned the same as the drive with the slowest response (2 radians/second)
- Modern drives don't need to be tuned. (no metrics)
- Brand X drives are always tuned too *stiffly* or too *aggressively* (no metrics)
- The drive is not responsive enough (no metrics)
- The drive should be tuned with 5 to 10% overshoot for better response to web disturbances (no metrics)

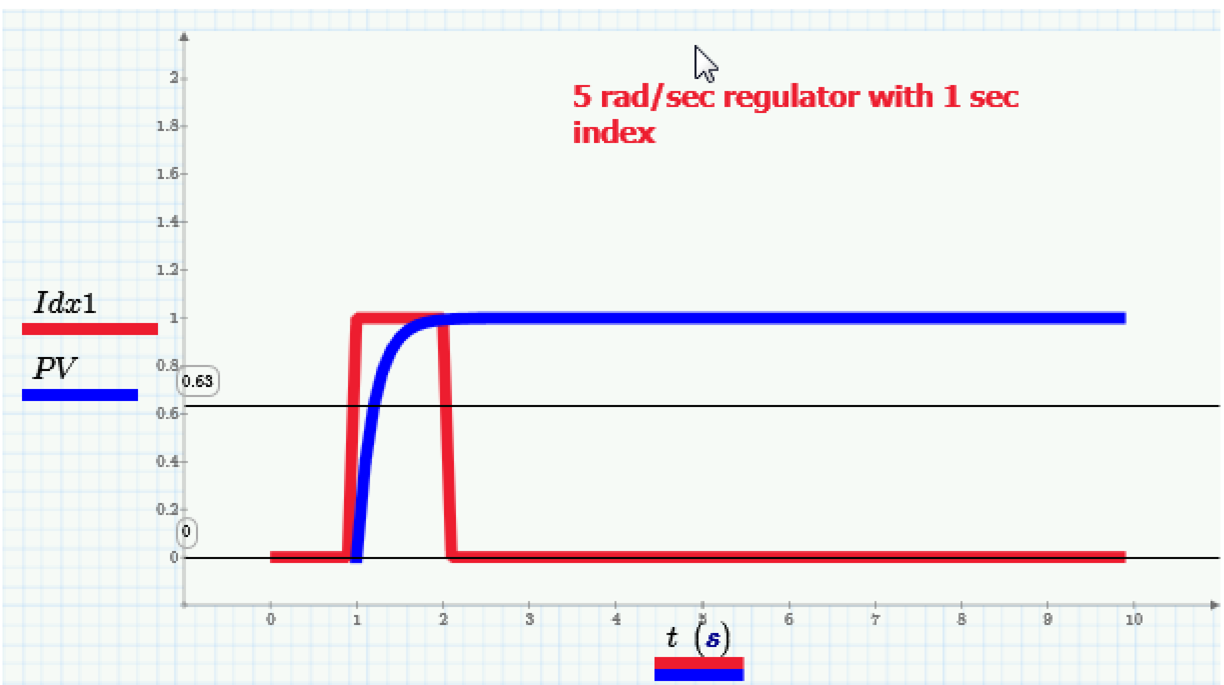
Assume a 5 rad/sec Speed Regulator
A 5 rad/sec speed regulator is a typical tuning target for many new drives. A 5 rad/sec regulator will respond to a speed SP change or a disturbance in 5*1/5 rad/sec = 1 second. Over this 1 second, the speed is incorrect therefore the tension is most certainly incorrect. For a 500 mpm line, this represents 8.3 m.

Turret Winder

The index sequence for a turret winder takes 1 to 5 seconds. The incoming spindle must be started during the index cycle. The incoming spindle must react to the disturbance of the knife cut. The 5 rad/sec spindle drive is adequate for the slow case. It is doubtful that 5 rad/sec is adequate for a 1 second index sequence.

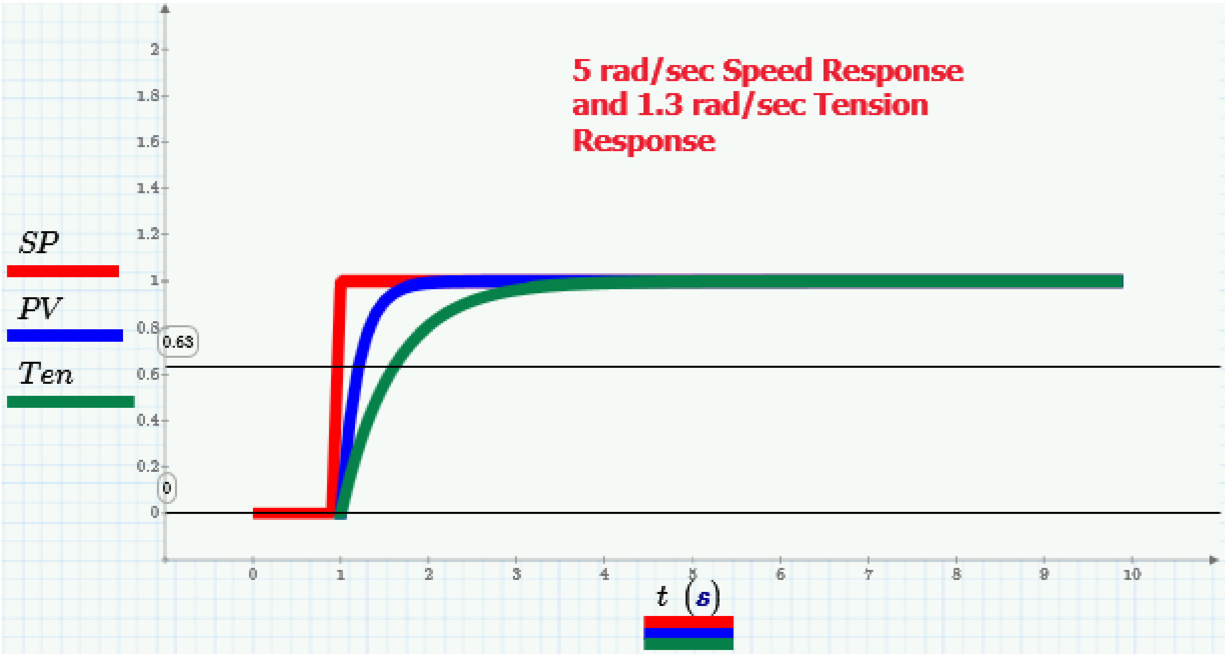
Chart here of spindle exponential response and a 5 and 1 second pulse.





Tension Regulators have 1/3 the Response of the Speed Regulator

The tension regulator response is limited to 1/3 to 1/10 the response of the speed regulator. If we have 5 rad/sec on the speed regulator, the fastest theoretical response of the tension regulator will be 1.3 radians/second.



Unwind Splice

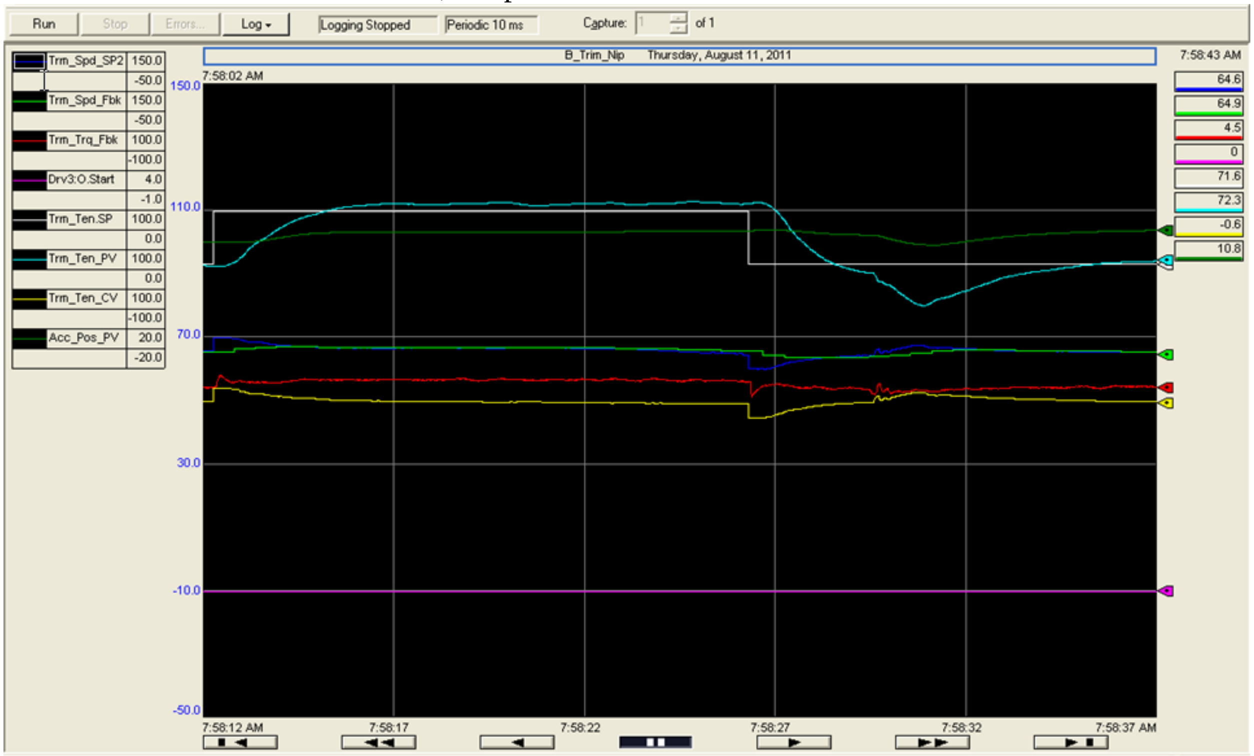
An unwind splice creates a tension disturbance which affects all sections in the line. Even though the splice is complete in a fraction of a second, the tension regulators recover using their response. With a 1.3 rad/sec tension regulator, the settling time will be 3 to 4 seconds. The web may see wrinkling and other defects during this interval. The web will also be more prone to a break during this interval.

Limits to Speed and Tension Regulator Responses

- Backlash – gear, coupling – gets worse with wear and tear
- Belts Slipping – use timing belts
- Torsional Resonance between motor and roller – use large diameter shafts, as short as possible
- Power Limited – torque limit, When stepped to a higher speed, the roller has more kinetic energy. This comes from the motor power integrated over time. Not usually a limiting factor. There is no substitute for horsepower.
- Noise in the control system
- Tacho or tension PV filtering due to noise
- Tension response limited by the slow response of the speed regulator – control Tension into Torque
- Regulators purposefully tuned for specific responses ***by design***.

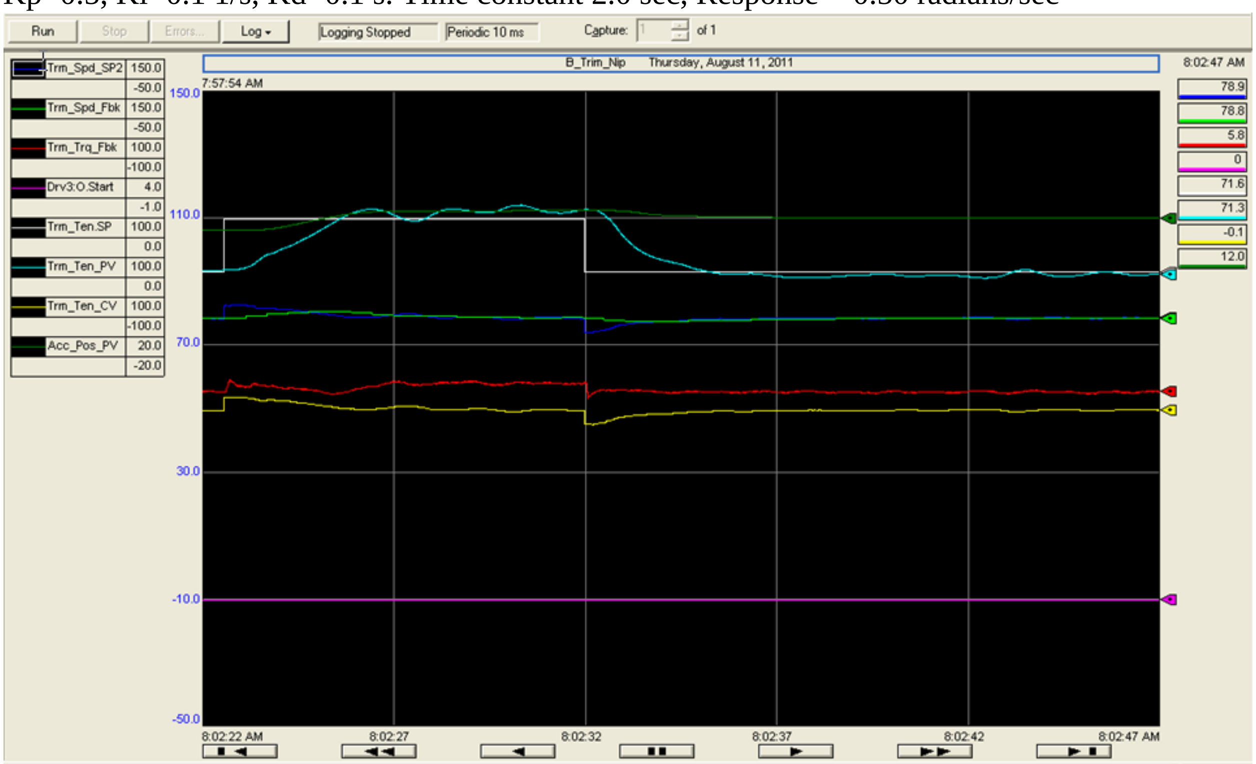
Trim Nip with fabric

Kp=0.5, Ki=0.1 1/s, Kd=0.1 s. Increase in tension was good. Decrease in tension has undershoot. Time constant 1.6 sec, Response = 0.63 radians/sec



Trim Nip with plastic.

Kp=0.5, Ki=0.1 1/s, Kd=0.1 s. Time constant 2.0 sec, Response = 0.50 radians/sec



What responses do we see in Web Handling lines?
Typical values

Web	Drive	Speed Reg. Response rad/sec	Tension Reg. Response rad/sec
Metal Rolling	Vector or DTC	10	3.3
Paper Mills	Vector or DTC	0.3 to 1.0	0.3
Converting lines	Vector or DTC	1.5 to 5.0	0.5 to 1.5
Converting lines	Servo	10 *to 120???*	3 *to 40???*
Paper Mill Best Case (Unwind on Coater using dancer)	DC	0.3	10.0 (into torque regulator 1996)
Converting lines Worst Case (laminator for fabric and poly)	Vector or DTC	5.0	0.001 (purposely tuned this slowly-no justification available from the drive rep.-2011)

*Sample provided by one person with 3 decades of experience in the web handling industry.

What Operators Want
The drive is not responsive enough!
Threading
Speed Changes
Closing Nips, Applying Coating
Turret Indexes

When Drive Response is Important
A new line is not as responsive as an older line.
Following a drive upgrade, the line is not as responsive as it was.
Guidance is needed for a new process.

Top Secret
Regulator Response information for web handling is not published.
Regulator theory is well known – 4th year controls class.
Drive vendors know their regulator response and tuning procedures and targets.
Sophisticated producers know the regulator responses on their lines.
Many Web Handling OEM's, producers and drive vendors do not have good guidance for tuning drives for web handling lines.

Conclusion
Operators would like faster response for easier operation of the line.
Managers like faster response because it reduces waste due to tension variations.

Maintenance likes slower responses because equipment lasts longer. Maintenance likes faster response because they like happy operators.
We can’t arbitrarily increase response without consequences – there are mechanical limits.
How responsive is responsive enough?
I suggest 5 rad/sec for speed and 1.3 rad/sec for tension as generally acceptable values. Many web handling drives do not achieve these values. In particular, the paper industry is happy to achieve0.5 to 1.0 radians/second for the speed regulators and less for the tension regulators.
Discussion, experiences and opinions are welcome. Metrics will make the discussion meaningful.