Tuning the FD Servo – a Starting Point

<u>The Relationship between *Rot Enc Res*, *V Pulse Div*, and Rotary Encoder ppr</u>

Velocity Measurement Timer

The FD uses a *velocity measurement timer* to determine the time period between pulses from a rotary encoder. The timer has a 16-bit resolution, providing 65,535 measurement steps, with each step representing approximately 101.73ns (billionths of a second). Thus, the longest period that can be measured with the timer is approximately 6.66ms (thousandths of a second).

> *For reference, the velocity of a 256 pulse-per-revolution (ppr) encoder can be accurately measured from 35.2 rpm all the way up to over 230,000 rpm. When using a drive with a top speed of 1000 rpm, this allowed system velocity to be measured down to 3.5% of full power.*

Pulse Divider

V Pulse Div is short-form for *Velocity Pulse Divider.* It is used to scale the pulses from a rotary encoder to accommodate the resolution of the velocity measurement timer. The correct setting depends on (a) the ppr of the encoder being used, and (b) the rpm of the shaft where the encoder is mounted.

For example, a 1024 ppr encoder mounted on the output of an 8:1 gearbox would yield 128 encoder pulses for every rotation of the motor driving the gearbox; a 64 ppr encoder mounted directly to the motor shaft would provide only half that resolution and twice the time period between pulses. Obviously, a 5000 rpm motor spins almost three times faster than an 1800 rpm motor, producing pulses that are closer together and thus yielding a much shorter period to be measured.

Thus, when the encoder has a higher ppr and/or is spinning at higher rpm, encoder pulses may need to be divided to yield a period more appropriate for the measurement timer. With a *V Pulse Div* of 1:4, the period between every 4th encoder pulse is measured. At 1:16, the period between every 16 pulses is measured, and so on.

> *A* V Pulse Div *setting of 1:1 is suitable for most applications.*

ppr and Rotary Encoder Resolution

Different rotary encoder manufacturers specify ppr differently. Some count the number of complete quadrature cycles, corresponding to pulses from *either* the A *or* the B data line. Others count the total number of pulses from *both* the A *and* the B data lines, for double the ppr value. Any quadrature encoder can be used either way. If you use an encoder that is 100 ppr on a single data line, it will yield 200 ppr when decoded using both lines. Similarly, if you use an encoder that is 100 ppr using both data lines, it will yield 50 ppr when decoded using a single data line.

In the FD servo system, the *Rot Enc Res* parameter determines how an encoder is read. *Normal* resolution reads a single data line, *High* resolution reads both data lines.

> *A* Rot Enc Res *of* Normal *is suitable for most applications.*

Velocity Measurement Jitter

All mechanical systems suffer from jitter. This is caused by play in bearings, bearings that are not perfectly centered, flexible or universal joints, slipping belts, shaft twist, and much more. Thus, the velocity measurement from a rotary encoder is never perfectly steady -- it bounces up and down, even when a machine appears to be running smoothly and steadily. In the case of universal joints and off-center bearings, encoder timing shifts from a circular to an elliptical pattern – the pulses spread apart for some parts of the rotation, and compress together for other parts.

Over time, the Velocity process averages period measurements to reduce the impact of jitter. Ideally, the velocity measurement timer should be able to measure periods beyond the theoretical range of a given encoder and machine, to accommodate the highest and lowest jitter values that may arise.

Resolution of the Measurement Timer

When the FD velocity measurement timer overflows, the rotary encoder is turning too slowly to be measured. In this case, the Velocity servo process assumes a period of 65535 counts and a velocity of zero (encoder not turning). (This has no impact on the Proportional process, which continues to register every encoder pulse, regardless of velocity, to update current machine position.)

When the FD velocity measurement timer is interrupted by a rotary encoder pulse before it has incremented one count, the rotary encoder is turning too fast to be measured. In this case, the Velocity servo process assumes a period of 1count and the maximum velocity.

Although the velocity measurement timer provides a maximum range of 65,535 counts, this far exceeds the range required by the Velocity servo process. A range of 500 steps or more, from the slowest to the highest motor speed being used, will result in excellent servo performance. Higher ranges do not improve performance; lower ranges may produce a "grainy" or stepped servo response.

RC4-RX4-FD Servo Setup Helper Spreadsheet

RC4 Wireless has created an Excel spreadsheet to assist in choosing mechanical components and configuring FD servo parameters. This spreadsheet, *RC4-RX4-FD Servo Setup Helper,* starts with five values from the user:

- maximum rpm of the encoder shaft
- ppr of the encoder being used (using A+B resolution)
- user setting for *Rot Enc Res* (High or Normal)
- user setting for *V Pulse Div* (1:1, 4, 16, or 64)
- distance that the target machine will travel with one rotation of the encoder

Experimenting with these settings makes it easier to understand what the servo controller is doing. The spreadsheet calculates values for:

- decoded (internal) ppr being used (based on High or Normal resolution)
- minimum rpm that can be measured by the servo controller, and it's percentage of full speed
- maximum rpm that can be measured by the servo controller
- the number of velocity measurement timer counts for the user-specified maximum rpm of the encoder shaft
- the maximum number of encoder rotations within the Proportional servo range (32767 counts)
- the maximum distance the target machine may travel within the Proportional servo range
- a recommended starting value for *Vel Mult* when tuning the Velocity servo process

To assist in finding optimal values, flags indicate when the minimum and maximum measurable rpm are in an optimal range. Experiment with various input values to achieve the **USEABLE** flag in all categories, along with a suitable servo travel distance.

The rpm of an encoder is easily calculated from the frequency of pulses on one data line. Many digital multimeters include a frequency measurement feature (the B&K Precision 2704B is a good example). The *Servo Setup Helper* spreadsheet includes a frequency-to-rpm converter: enter the ppr of the encoder, and the frequency measured on data line A (or B), and the spreadsheet calculates the rpm of the encoder shaft.

Contact RC4 Wireless to obtain the latest version of the RC4-RX4-FD Servo Setup Helper spreadsheet.

A Simple Servo Tuning Procedure

All servo systems require some effort to tune them to the machine they are controlling. This is true of all servo drives and controllers, from all manufacturers. Tuning servos gets easier, and the results get better, with experience.

Here are a few steps to follow when getting started:

1. Use the *RC4-RX4-FD Servo Setup Helper* spreadsheet to choose the most appropriate rotary encoder ppr, and settings for *Rot Enc Inc* and *V Pulse Div*.

2. Set *Vel Mult* to zero (0), and *Min Speed* to 15. Set *Enc Range* and *Top Speed* to appropriate values for your application. If unsure about what is required, set *Top Speed* to a low value for initial testing. Set *m4 Damping* to 10, *Stop Window* to 5% of *Enc Range*, and *Slow Window* to 50% of *Enc Range*. *Stop Window* must always be less than *Slow Window*, which must always be less than *Enc Range.*

3. From your controller (DMX or CV inputs, as assigned at the RC4 transmitter), set the destination position to one extreme. Slowly bring up the servo speed channel and watch the performance of the system. If the motor runs continuously without stopping, the drive polarity may be backwards. You can either change *V Polarity*, or switch the wires to the motor, but *not* both. Either change will reverse the direction that the motor turns relative to encoder position increments.

4. Adjust *Top Speed* so the target machine runs at the desired speed when the servo speed control channel is at maximum. Readjust *Enc Range* if required, to fine tune the range of motion.

5. If the machine overshoots or hunts at the end of travel, increase the size of the *Slow Window*, and reduce *Min Speed.* However, ensure *Min Speed* is always high enough to avoid a stall condition. If *Min Speed* is too low and the machine stalls, the machine will stop before reaching the intended position. It is easiest to adjust Min Speed when *Slow Window* is set quite high. It may also help to set *Top Speed* and *Min Speed* to the same value to find the optimum setting for *Min Speed.*

6. Find the smallest useable setting of *Stop Window.* The smaller the setting for *Stop Window*, the more accurate and repeatable the servo stop positions will be.

7. Reduce the size of *Slow Window* until the machine smoothly decelerates with a small amount of overshoot and hunting or ringing to find final position. (Rringing is a decaying oscillation around the stop location, and will be further minimized in the next step.) If the unit oscillates continuously, you may (a) increase *Stop Window*, (b) reduce *Min Speed*, and/or (c) increase *Slow Window.*

8. Introduce a small amount of *Vel Mult***,** starting with the value recommended by the *RC4-RX4-FD Servo Setup Helper* spreadsheet. At the ideal setting, *Vel Mult* will reduce overshoot and hunting for a more immediate stop. If *Vel Mult* has no apparent affect, double the setting and test again. Continue this until an affect is observed. For best results, set *Vel Mult* to the lowest value that suitably improves performance. Note that some servo applications are most pleasing with no Velocity process at all, in which case *Vel Mult* should remain at zero (0).

Repeat steps 4 through 8 to further fine-tune parameters and improve performance with various control speeds and target positions. Experiment with different relationships of the various parameters. Often, there is more than one suitable setup for an application, and different setups may be more or less appropriate for the way you will be using the servo system in your application.