# Servo Integration and Tuning (DS01061/B)

## 1. Safety

## 2. Introduction

The following describes points to consider when integrating ThrustTube components or modules to a servo control system. Brief guidelines are also given on common tuning terms and the adjustments available.

## 3. Encoders

One of the advantages of ThrustTube linear motors is that there is no inherent backlash in the motor. It is therefore possible to produce systems that can be moved to the same position from either direction without errors due to mechanical backlash. It is always desirable to use encoder systems that do not suffer from backlash (i.e. the use of rotary encoders with conversion systems is not advisable). Basically, any type of system that can produce a measurable signal based upon distance moved can be used. The encoder type used is normally dependent on the resolution required, operating environment and signal type.

The most commonly used linear encoders available consist of an encoded strip (attached to a surface parallel to the forcer) and a sensor readhead mounted on the moving part (forcer). These can be optical, magnetic or inductance based systems. ThrustTube modules are supplied with either a magnetic or optical encoder system that is contained within the module extrusion.

Magnetic encoder strips can be affected by the high magnetic fields produced by the thrust rod. It is possible for the magnetic field of the rod to interfere with the field of the strip or affect the readhead directly, it is therefore necessary to ensure that there is sufficient distance between the components to ensure that this does not occur. If the rod and strip come into contact or very close proximity with one another then the magnetic profile in the strip will be permanently damaged.

It is important to ensure that the encoder type selected is compatible with the controller that is being used, and is capable of counting the encoder pulses as they are produced. The higher the resolution of the encoder being used the higher the frequency of the pulses that are produced at any given speed. The higher the resolution the easier it is to maintain a particular repeatability and reduce settling time.

It is advisable to use the error output signal from the encoder sensor when available. This signal normally indicates that the sensing signal is unreliable and may cause loss of count. This normally transpires as a shift in the motors actual position and/or poor commutation and control. If a complete failure of the encoder occurs the controller may apply full force to the motor, resulting in uncontrolled motion. To prevent this occurrence it is imperative that the encoder error is monitored by a latched fast interrupt within the controller. Refer to the specific encoder data sheets for the error availability and signal type.

Note: ThrustTube forcers are capable of very high speeds, the frequency of encoder pulses can be higher than might normally be expected from a conventional motion system.

### 3.1. Sinusoidal encoder commutation

Where sinusoidal encoder commutation is used, the electrical cycle of the motor is required within the amplifier configuration set up. The electrical cycle is normally defined in terms of encoder counts per pole pair (the distance between consecutive like poles).

For example, a 25 series forcer (where the pole pair pitch is 51.2mm) with a 10-micron encoder, the number of encoder counts per pole pair is 51.2/0.01=5120. Similarly for a 38 series forcer (pole pair pitch =71.2mm) this value would be 7120.

### 3.2. Encoder commutated systems.

Some amplifiers and drives use the feedback encoder to commutate the motors as well as providing positional feedback for position or velocity control. For optimal control the amplifier should provide sinusoidal commutation.

### 3.3. Encoder count direction

The direction of count of a two channel (Quadrature decoded) incremental encoder is defined such that as signal denoted as channel ‘A’ should lead channel ‘B’ when the motor is moving in the forward direction from the reset end. It is sometimes not possible to fit the encoder system so that the counts will conform to this convention. Under these circumstances it is necessary to reverse the direction of count as seen by the controller. There are two possible methods of reversing the direction of the count from an incremental encoder.

a) Changing encoder count direction by inverting a channel.

If a channel is inverted (i.e. ‘A’ wired to ‘/A’ and vice versa) then the signal from channel ‘A’ will then lag behind channel ‘B’. This will cause the controller to reverse the count as perceived from the encoder.

b) Changing encoder count direction by swapping channels.

If the signals from channel ‘A’ and channel ‘B’ are swapped completely with one another (i.e.’A’ wired to ‘B’, ‘/A’ wired to ‘/B’, etc.) then this will result in channel ‘B’ leading channel ‘A’ and will reverse the count.

## 4. Hall effect commutation

Servo amplifiers have different commutation arrangements. The ThrustTube forcer range has in-built flexibility to cater for most types.

### 4.1. Analogue Hall effect devices

Analogue Hall effect devices can be used where commutation is achieved through analogue multiplication of the current demand from the servo controller and the Hall effect device signal (as in the 7X26 amplifier). Analogue Hall effect devices provide commutation by sensing the field of the thrust rod directly. The analogue Hall effect devices are at a different pitch for the 38 and 25 series of forcers.

### 4.2. Digital Hall effect devices

Digital Hall effect devices can be used where trapezoidal commutation is required or where commutation is achieved through encoder feedback but the vector position of the motor relative to the stator flux profile is required on power-up. This is achieved through either energizing motor phases to a known vector or by monitoring the digital Hall effect devices.

The digital Hall effect devices are at a different pitch for the 38 and 25 series of motors and are in a different position relative to the position used for the analogue Hall effect devices.

Refer to Hall effect commutation data sheet options for full details of the relationship between analogue and digital Hall effect signals to the back EMF of each motor phase.

## 5. Limits and homing

Limit (end of travel) switches may be used when the system is initializing, and when unforeseen errors occur during normal operation. They can also be used to provide a datum signal or act as part of the homing sequence if required.

The optional limit switches fitted on the ThrustTube module are mounted on the base extrusion via a fixing block and are triggered by an activator bracket on the forcer. Normally one switch is fitted at either end of travel. If the controller used has dedicated limit inputs (+limit and – limit), the switches should be connected to them otherwise they should be connected to digital inputs or error inputs that should be read during the program cycle. The -limit connection is normally for the limit switch at the end of travel that the encoder count decreases, and the + limit connection is normally for the limit switch at the end of travel that the encoder count increases.

When initially commissioning a system a common error (that may result in forcer damage) is to leave the forcer applying force against an end stop. If limit signals are used to disable the amplifier or to allow motion only in the direction away from the end stop then this type of damage can be avoided.

In the event that a system starts losing counts, (if the encoder stops producing them correctly or the controller counts them incorrectly) the physical position of the motor will change for the same count values. Limit switches can be used to ensure that if the forcer passes a defined maximum physical position it can be disabled/stopped thus minimising damage potential.

### 5.1. Homing sequence

If an incremental encoder is used it is not possible for the controller to know the absolute position of the motor when the system is initially powered on. In order to establish a known position it is necessary to perform a search for an index or datum mark, often referred to as the homing sequence. For linear encoders with only one datum it is only necessary to search for the index mark from the encoder. However, many linear encoders have index marks at regular intervals along the length of travel. In this case it is possible to use the limit switches as a proximity sensor, which is searched for prior to search for the actual index mark.

### 5.2. Using the limit as a datum marker.

If a limit is used as the datum, the normal method for using it would be as follows: -

a) Disable the limit switch safety function.

b) Search for the limit by moving towards it.

c) Move off the limit at very slow speed.

d) As the limit signal disappears take that position to be the datum.

e) Enable the limit switch safety function.

The datum position set by the above routine can be quite accurate depending upon the devices used as the limit switches and the speed at which the motor is moving when trying to find the switching edge.

### 5.3. Using the limit as a proximity sensor for homing.

If the limit is used as the datum before homing, the normal method for using it would be as follows: -

a) Disable the limit switch safety function.

b) Search for the –limit by moving towards it in the reverse direction at slow speed.

c) When the –limit is detected, change to the forward direction at very low speed.

d) Take the next detected index pulse as the home marker.

e) Enable the limit switch safety function.

This routine is normally automatically achieved through correct setting of the home sequence parameter in the servo controller.

## 6. Amplifier/servo type

In order to control the position of the motor it is necessary to employ a servo controller and amplifier combination. There are very many different models of amplifiers available but they tend to fall into one of three possible categories: -

a) Intelligent amplifiers that have built in servo controllers.

b) Velocity amplifiers capable of controlling only the velocity of the motor.

c) Current/torque amplifiers that control only the force of a linear motor (torque in a rotary motor).

### 6.1. Intelligent amplifiers

Intelligent amplifiers do not require external control signals in order to position the motor. Depending on the unit they can perform very simple point-to-point programs up to very sophisticated moves with external synchronization and I/O handling. Generally they can operate in either position/velocity or force control modes.

### 6.2. Velocity amplifiers

Velocity loop controllers are used to move the motor at a velocity determined by a demand. The unit requires an external controller to determine the profiles through which it moves. In addition, some are available where the demand can be input through a serial link. Units of this nature can sometimes be given a position set point that can be used to move the motor to a defined position. The motor will move towards the required position at a predefined velocity and acceleration.

Encoder feedback is required to calculate the motors velocity. The advantages of using such a system is that the processing by the main controller is reduced and the loop time within the amplifier for the velocity loop can usually be much higher.

### 6.3. Current/torque amplifiers

Current amplifiers produce a force proportional to the signal on the demand input. The speed with which the motor will move is therefore controlled entirely by the external servo controller.

The most common type of programmable digital servo controller used with current amplifiers employs a PIDF (see tuning section) algorithm to control the position of the forcer.

## 7. Tuning

PIDF controllers use the error between the desired position of the motor and its current position to control the force that the motor will produce. PID refers to proportional, integral and differential terms applied to this error (referred to as the following error) that are used in this type of control system. Many of these controllers will also have feedforward (F) terms to help reduce the response times of the system. In order for the controller to move the motor to the desired position it is necessary to set values to these terms. The process of selecting the value to which these parameters should be set is called tuning. In order to tune a system it is necessary to understand the effect of each of the terms. Refer to the individual controller servo-tuning guide for detailed information.

### 7.1. Proportional gain

The proportional gain in a system causes the motor to produce a force directly proportional to the following error. The result of this is that the further away from the desired position the motor is, the greater the force produced to a limit of the maximum force output of the motor. The larger the value of proportional gain the faster the motor will respond, however large values of proportional gain will cause the system to be unstable and increase settling times. This parameter also provides stiffness when in position.

### 7.2. Derivative gain

The derivative gain acts on the rate of change of following error. Derivative gain will increase the response of the motor to the initial change in demand and decrease overshoot. Too large value of derivative gain will cause the motor to be unstable and oscillate during travel.

### 7.3. Integral gain

When the above two terms have been set there may still be an unacceptable following error in the system. This integral term is combined with the value in a continuously incrementing accumulation of the value of the following error to produce a force to drive the motor. Because of the time dependency of this term it tends to have a much slower response rate when compared to the above two terms.

For most systems a quick response is required and so a high value for this gain is desired. Unfortunately even at fairly low values this term can cause the system to become unstable. Putting a maximum value on the value in the accumulator can help to reduce the possibility of this happening. For ThrustTube systems this term is generally very small or set to zero.

### 7.4. Velocity feedback

One method of reducing overshoot in a system requiring a high proportional gain is to introduce a velocity feedback factor into the loop. This parameter reduces the force that is available to the motor as the speed of the motor increases. Although this allows higher gains to be used the maximum value is still limited, as the system will become unstable if very large values of velocity feedback are used.

### 7.5. Feedforward gains

There are several different types of feedforward gains that can be available, depending on the controller type. Velocity, acceleration, deceleration and friction compensation are a few of the more common ones. During a move, feedforward terms allow the controller to produce a drive force based upon the expected requirements rather than on the requirements due to the following error.

The two main terms are velocity feedforward and acceleration feedforward. Velocity feedforward is used to correct any following error when the motor is travelling at constant velocity. Acceleration feedforward is used to correct any following error when the motor is travelling at constant acceleration.

If any feedforward terms are too large the system will be unstable. In general the feedforward terms are used to minimise following errors.

## 7.6. General tuning guide

There is no universal method of tuning or predetermined gain values that can be used on all servo controllers. Each has its own control algorithm and scaling. Before attempting any tuning of a system, read the servo controller manual and understand the principles of what each term is used for.

**The following is a brief guide to tuning: -**

a) Remove any sensitive equipment and fit a dummy payload if possible. Fit soft sponge or dampers at the ends of travel in case of runaway conditions.

b) Set the RMS continuous current limit of the amplifier (if applicable) to a low value to prevent damage to the motor by over-current.

c) Set all gain terms to zero.

d) Enable the amplifier.

e) Increase the proportional gain by small increments until the motor just starts to become unstable when pushed out of position and released.

f) Now increase the derivative (velocity feedback) gain until the motor is completely stable when pushed out of position and the motor does not overshoot when returning to position.

g) Now increase the proportional gain, whilst increasing the derivative gain to maintain stability and minimise overshoot, until either you have reached required positioning accuracy or the system is unstable. If the system is unstable reduce the gain values appropriately.

h) Do some short moves to check overshoot at higher velocities and increase the derivative term (or reduce proportional gain) if necessary. These should be recorded as your starting gain values.

You can now tune the system more accurately for your particular application, including the integral and feedforward terms as required. It may be necessary to reduce the proportional and derivative starting gains to achieve the final desired motion profile.