SERVOTRACK™

Bridging the Gap Between Servo, Brushless DC, and Stepper Performance

Shift from stepping motor to servo performance – ServoTrack™ makes it easy and cost-effective

INTRODUCTION:

Step motor systems have unique characteristics such as smooth motion, stiffness at stand still, easy setup, and low cost. Popular for decades, these systems continue to be a widespread choice among design engineers.

More specifically, step motor technology provides several advantages over servo motor systems. One of these is inherently lower cost as compared to servo motors due to step motor construction. Step motors do not require tuning, allow for greater inertia mismatch and have a very high torque density. Because this torque is 100% available immediately upon startup, step motors can be very advantageous for applications requiring short, quick moves or when coupled with high inertia loads.

In addition, since step motors are synchronous motors with a high pole count, they are able to run smoothly at extremely slow speeds with minimal torque ripple. Both servo and step motors share a common identity as permanent magnet synchronous motors; however, there are differences that impact how the motors perform. For example, brushless servo motors typically have (2) to (8) magnetic poles on the rotor, whereas the 1.8 degree step motor has (50) poles. Due to this pole count difference, the step motor is, in essence, electromagnetically geared down as compared to the servo motor, allowing for better low end torque performance and positioning capabilities.

As with any technology, there are also some disadvantages associated with use of a step motor system. The most critical drawback is the loss of synchronization and torque (stall) if a large load exceeds the motor's capacity and its ability to resynchronize once the load is reduced to a level within the motor's capability. In addition, step motors tend to run hot due to use of full phase current, independent of load.

In many cases, these disadvantages, along with the limitations associated with available 'bridge' technology to overcome them, may have influenced the decision to choose higher cost servo technology rather than traditional step motor technology.

THAT IS, UNTIL NOW…. ServoTrack™ closes this 'bridge' technology gap and provides a closed loop stepper system by eliminating unintentional stalling due to transient loads, or excess friction, and enabling torque control as an integral function of your stepper system.

Why ServoTrack™? After all, different variations of closed loop stepper systems have been introduced to the market in recent years. Unfortunately, most all of them accomplish the task through a form of PID

(Proportional–Integral–Derivative) software, an algorithm similar to that designed for use in servo motor systems. As a result, optimization requires tuning of the closed loop stepper system, much like a servo system.

Another consideration is that, as in the servo systems that they closely relate to, most closed loop stepper systems require a high-resolution encoder in order to get feedback and thus achieve the benefits of closing the loop. Response from these software-based controls is also limited to processing speed. As functionality is added or faster loop times are needed to maintain load requirements, higher speed processing becomes necessary and system cost increases.

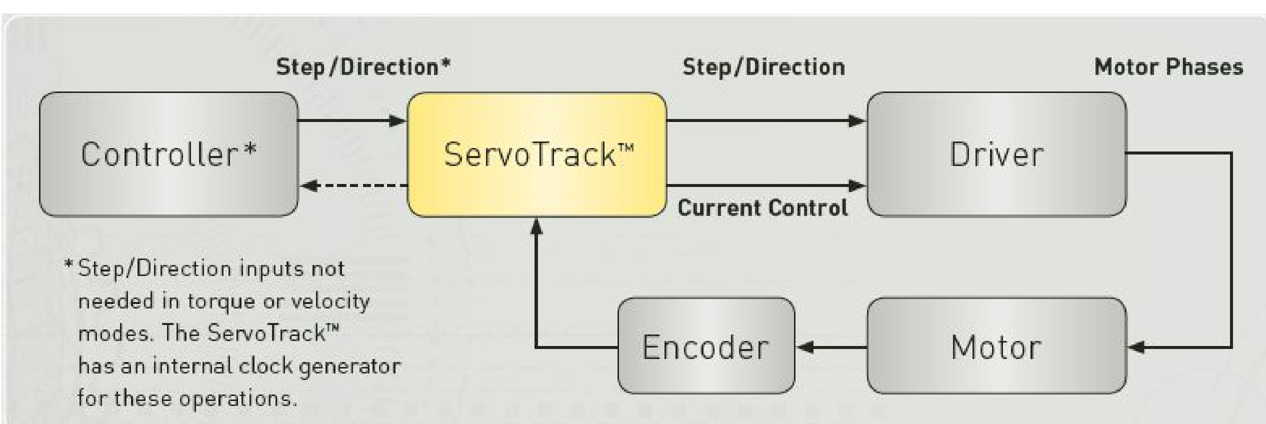
In contrast, ServoTrack™ accomplishes the benefits of "real time" closed loop control through the use of hardware, not software, with real time nanosecond updates.

BASICS OF OPERATION:

In order for ServoTrack™ to achieve a closed loop step motor system, the step motor must have a mounted encoder, which enables ServoTrack™ to monitor the relationship between the rotor and stator (reference **Fig. 1, ServoTrack™ System Block Diagram** below). If during a commanded move by the controller, the demanded speed and torque of the motor begins to exceed the capability of the motor, ServoTrack™ will intervene. ServoTrack™ intervenes by temporarily taking control of the step and direction output of the controller, slowing down the motor speed and thus gaining torque until the torque demand subsides, at which point ServoTrack™ can re-inject the stored missed step and direction pulses to finish the commanded move successfully. If the speed and torque demand are not exceeded during a move, ServoTrack™ passes the controller pulses directly through to the drive unaltered.

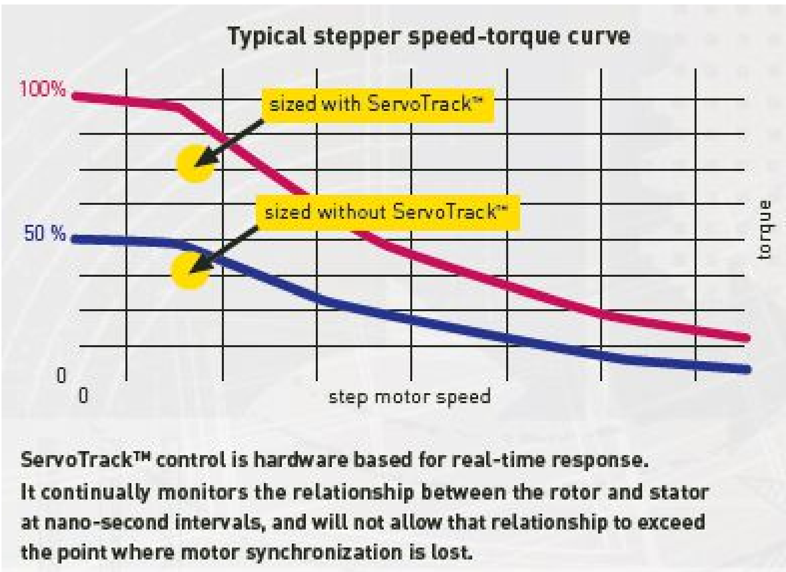
Commanded positioning is done solely through microstepping resolution of the motor, rather than encoder resolution. With ServoTrack™, the encoder is limited to monitoring system performance.

Fig. 1, ServoTrack™ System Block Diagram



Because it allows the motor to run at the speed-torque curve threshold, ServoTrack™ essentially maximizes motor capability (reference **Fig. 2, Typical Stepper Speed-Torque Curve** below). This is especially true given that most stepper systems today are still sized using a 50% torque margin rule of thumb. Maximizing motor capability can in turn allow designers to reduce the motor size for a given application and while preserving the same performance level.

Fig. 2, Typical Stepper Speed-Torque Curve



With the ability to control and maintain a set relationship between the rotor and stator, ServoTrack™ makes it possible to achieve torque control with a step motor. Applications such as bottle capping, clamping, and web tensioning, once limited to using servo motor systems, can now be effectively supported with lower cost step motor systems.

ServoTrack™ capabilities also include variable current control. This feature minimizes motor heating by providing only the amount of phase current needed to control the load. Energy efficiency is maximized, thereby reducing unnecessary heat buildup within enclosures.

Finally, an on-board speed controller has been embedded into the ServoTrack™ IC. This eliminates the need for step clock generation in simple conveyor and other constant speed applications.

UNDERSTANDING SERVOTRACK™:

> **NOTE: ServoTrack™ will NOT compensate for a poor design, NOR make a motor more powerful. ServoTrack™ WILL optimize system capability and robustness.**

- **Variable Lead / Lag Limits:**
  One of four (4) limits, or control bounds, can be selected. They are 1.1, 1.3, 1.5, or 1.7 full motor steps (reference **Fig. 3, ServoTrack™ Control Bounds Diagram** below). Control bounds of 1.1 will produce greater

torque; however, maximum speed will be reduced. In contrast, control bounds of 1.7 will enable greater speed, though transient response would decrease.

Best overall performance is achieved via control bounds of 1.3 or 1.5 full motor steps.

For torque mode, control bounds are preset.

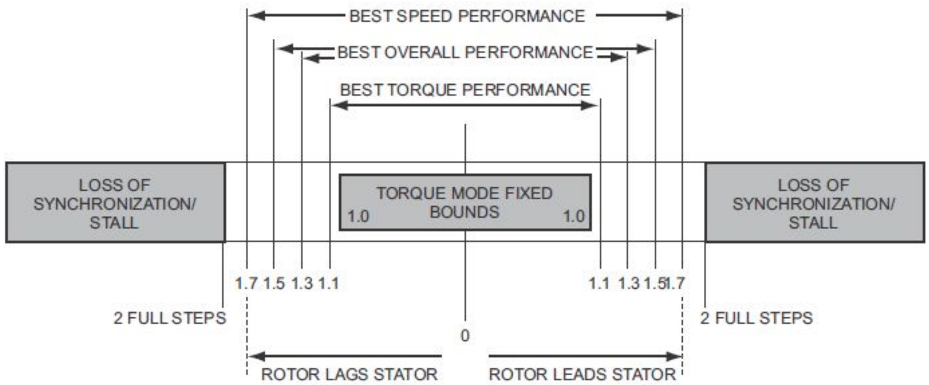


Fig. 3, Control Diagram **ServoTrack^{TM} Bounds**

- **Microstep & Encoder Resolutions:**
  Fifteen (15) microstep resolutions and nine (9) encoder resolutions (from 100 to 1024 lines) are supported in any combination. Higher encoder resolutions generally enable "smoother" operation.

- **Calibration:**
  Logic requires calibration to understand the initial relationship between the rotor and stator before ServoTrack^{TM} operation begins. Calibration is performed at power up to bring the rotor into physical alignment with the stator.
  During calibration, motor and position lag / lead logic are cleared and any incoming steps are ignored.

  Calibration occurs automatically with the following conditions:

  1. Power on reset,
  2. When enabling ServoTrack^{TM} functionality,
  3. When bridge is re-enabled after being disabled, or
  4. When MSEL is changed.

  NOTE: Calibration resulting from changes to MSEL or ServoTrack^{TM} while system is in motion will cause an abrupt halt to that motion.

  Any rotor movement during the timed period will reload the timer. Therefore, specified calibration time is the minimum duration for the timed period. Calibration may be initiated at any time via software command.

- **Operating Current:**
  Operating current defines peak motor current in motor phases. There are two (2) operating current modes – variable mode and fixed mode.

  Variable mode adjusts operating current from 2%, up to 100% of a defined maximum based on the motor lag / lead from (0) to (1) full step. For example, when lag / lead equals (0.5) full steps, operating current would be 51% of maximum. Conversely, when lag / lead is equal to (1) full step, operating current would be 100% of maximum. Operating current is increased immediately when lag / lead increases, but can be decreased more gradually via a filtering algorithm. Variable mode is useful in reducing heat when torque requirement is generally modest or varying, but comes with the drawback of a slight torque ripple increase. Variable mode provides a smoother response to external torque applied on the rotor, and when enabled, becomes the 1st defense against synchronization loss.

  By applying minimally necessary current needed to move the load, variable mode can greatly reduce motor heating and increase system efficiency.

  Fixed mode consists of run current when steps are active, and hold current when no steps have occurred for a defined period of time. This mode works well in situations such as extreme acceleration and / or in short moves with a potential drawback of increased heat.

  Users can freely switch between variable and fixed current modes. When using the torque function, variable and fixed current modes do not apply.

- **Locked Rotor:**
  A locked rotor is defined as no rotor movement while at maximum allowed lag for a specified time period. When lag becomes equal to control bounds, a timer begins counting down. Once the timer reaches zero, a locked rotor will be indicated via assertion of a status flag. The timer reloads on any encoder movement. The timer's timeout period is user selectable, and ranges from (2) mS to (65.5) seconds.

  In torque mode, the locked rotor flag can be used to indicate the rotor has been stopped at the specified torque for a preset amount of time.

- **Position:**
  For reference, position lag refers to a situation where the motor lags behind the commanded step position. Position lead is when the motor leads the commanded step position.

  A count is kept of the difference (error) between the commanded step position and the actual stator position. The host controller can read step position error and take appropriate action when and how desired. NOTE that the position is step accurate, which typically provides higher resolution than that of an encoder. For example, a 512-line encoder provides a resolution of 2048, while a 1.8 degree motor micro-stepping at 256 has a resolution of 51200. It is important to note that rotor position can vary by the amount of programmed lead / lag bounds from stator position. The count is cleared when ServoTrack™ is disabled or when a calibration occurs. The count also may be manually cleared via software command.

A host controller can set a position lag / lead limit. When either limit is reached or exceeded, a status flag will assert itself. This may be useful as possible an indication of excessive binding, maintenance (e.g., lubrication required), or other mechanical system issue.

- **Position Maintenance:**
  Automatic position maintenance can be enabled, which will insert steps as required when conditions allow, in the appropriate direction, to bring the position difference between commanded number of steps and actual steps taken to zero, and the rotor being within specified control bounds.

  Position maintenance speed (make up frequency) can be performed at one (1) of two (2) speeds. Insertion can be at a specified speed, or can be set at the maximum speed the load will allow. There is no acceleration or deceleration applied to position make up; therefore, make up could be abrupt if set at a high speed.

  Position maintenance will only occur when the motor lag / lead is within (1.1) full motor steps independent of set bounds; this provides maximum torque.

  Depending on various conditions, make up steps may be interleaved with incoming steps and / or made after a move has completed. When position maintenance occurs during a time period is dependent upon motor lag / lead, step input frequency, and selected make up speed.

  For example, position lag occurs due to overly aggressive acceleration. Make up steps could be interleaved during the slew portion of the move if the make up frequency is higher than the slew frequency. Alternatively, make up could occur during the deceleration portion of the move if make up frequency is higher than initial frequency. Make up could also occur at end of profile if make up frequency is lower than commanded frequency. Finally, make up can occur during multiple segments of a move profile.

  For a very aggressive move profile that is also time dependent, it is possible there will be no opportunity to make up missing steps during the time allowed for the move; therefore, the move will not complete within the allotted time since make up steps will occur at the end of the move.

  Position lag for bidirectional moves with no opportunity for make up may produce an intermediate position offset. For example, moving right from A -> B caused a (3) step lag. By immediately moving left from B -> A, the ending position could initially be (3) steps to the left of A. This would correct ending position; however, intermediate position would be off by (3) steps.

  Position error is maintained in a 32-bit signed counter. This equates to 41,943 revolutions, with a micro-step resolution of 256 micro-steps / step. If maximum count is reached, the counter will stop and an error is generated. The counter will not roll over.

- **Maximum System Speed:**
  ServoTrack™ logic contains a process delay timer to set maximum system speed. This is the speed at which step clocks are internally generated. The maximum speed is set via a step width parameter. For example, a

step width of (200) nS sets the maximum system speed to (2.5) MHz. Absolute maximum speed is limited to (5) MHz by the SIN / COS generator.

There are potential issues associated with setting the system speed too low. For example, if the system speed is limited to (1.5) MHz and the incoming slew speed is (2) MHz, the system will only produce steps at the maximum (1.5) MHz rate. This is a fairly benign issue as all incoming steps are still accounted for, so position error is correct and make up would proceed normally. A more serious, though unlikely, issue is the case of motor lead due to extreme deceleration in a high inertia system. In this instance, the stator may be unable to keep pace with the rotor, causing loss of synchronization.

> **NOTE:** In torque mode, *maximum system speed* can be used to limit unloaded system speed.

- **Interrupt Output:**
  An output is provided to indicate selected condition(s) have occurred or are occurring. A number of conditions may be combined (e.g., a logical OR) to assert output. For example, when position lag, position lead, and locked rotor are selected, any combination will assert output.

  When multiple conditions are selected, the specific cause of a given condition can be determined by reading status register and / or error code.

  Using output with an indicator lamp can be very helpful when evaluating a motion profile. A good example is to select ServoTrack™ active condition to light the indicator. ServoTrack™ active condition asserts when ServoTrack™ is intervening; therefore, if the acceleration portion of the profile is too aggressive, slew is too fast, or deceleration is too aggressive, the indicator will light up.

  The Make Up active condition is also useful for evaluation. It will indicate when steps are inserted during the motion profile. The user can adjust make up frequency to achieve the desired result. For example, if time is not critical but speed during the profile is, the user could adjust the parameters such that steps are added at end of move rather than during the move.

  Make Up could also be used to indicate to a host controller that move has not been completed and will continue even though the host has completed generation of the required steps.

- **Velocity Control Function:**
  When setting ServoTrack™ to function in Velocity mode, Start / Stop input is used to initiate or end movement at a pre-programmed velocity (internally generated and routed to the Step Clock Output). A large array of programmable functions such as acceleration / deceleration and max frequency are available.

- **Torque Function:**
  When setting ServoTrack™ to function in torque mode, the Start / Stop input is used to initiate or end a torque whose magnitude has been pre-programmed into the unit. When Start input is asserted in torque mode, ServoTrack™ will try to maintain an offset of (1) full step between the rotor and stator in order to create a torque on the rotor. If the load applied to the rotor is less than the torque required to maintain the (1) full step offset, the rotor will begin to rotate in an attempt to generate the required offset. Rotation

SYSTEM DIAGNOSTIC TOOL:
ServoTrack™ has dedicated registers for keeping track of missed steps. These registers also track the amount of time a system spends in make-up mode. Setting up the controller to monitor this register data output will allow the user to monitor system performance. This can also be done remotely to enable monitoring of systems that have been installed throughout the world.

speed will vary dependent upon load. Rotational speed will increase until such time a (1) full step phase shift between the rotor and stator is achieved.

The maximum speed may be limited electronically by setting the maximum system speed. However, this may prevent the rotor from reaching the set torque if the stator cannot move fast enough to maintain (1) full step of offset.

Position make up is not available in torque mode; however, the position counter is still active.

NOTE: If rotational speed becomes greater than the speed at which the motor can produce the necessary torque (as shown in **Fig. 2, Typical Stepper Speed / Torque Curve** above), the torque available will be less than that required by the application.

- **Bypass:**
  When ServoTrack™ is disabled, an incoming step is routed directly to the Step Clock Output. Motor and position lag / lead calculation logic is disabled and values are cleared. This can be useful in comparing performance against that of a standard system without ServoTrack™.

  The user can move freely between ServoTrack™ and bypass. NOTE that an automatic calibration will be performed when ServoTrack™ is enabled.

- **Configuration Test:**
  In order to correctly calculate lag / lead, the resolution of the installed encoder must be correctly specified and encoder direction must match commanded motor direction. For example, if the motor direction is

NOTE: It is strongly recommended a configuration test be performed on a newly set up system. A miss-wired or improperly specified encoder will cause erratic operation.

positive (dir = 1), the encoder must turn such that channel A leads channel B (dir = 1); if a 500-line encoder is installed, a 500-line encoder must be specified.

SUMMARY:

ServoTrack^{TM}'s unique technology dramatically simplifies and expands the ways in which the design engineer can apply low cost step motor technology to satisfy motion control application requirement.

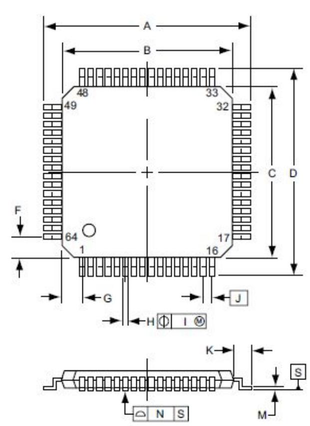
ServoTrack^{TM} will….

1. **Allow** full use of your motor's torque with minimal de-rating of the speed / torque curve.
2. **Never** lose functional control of your motor.
3. **Lower** the cost of your servo axis.
4. **Minimize** the impact of system resonance.
5. **Allow** for higher inertia mismatch when sizing your system.
6. **Add** torque control for clamping, winding / unwinding, and tension control.
7. **Minimize** motor heating and improve efficiency.
8. **Prevent** transient load stalling on smart conveyor systems.
9. **Operate** in velocity mode without the need of a controller.
10. **Provide** for simple set-up with no tuning required.
11. **Function** through hardware, not PID software, thereby greatly improving response time and eliminating the need for a high resolution encoder.
12. **Reduce** servo system complexity.

ServoTrack^{TM} is available in the following versions:

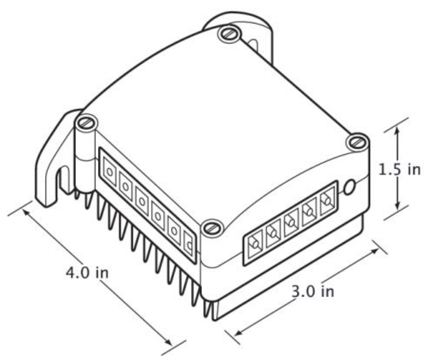
1. ServoTrack^{TM} IC (10mm x 10mm)

3.1 64-Pin Plastic TQFP (Fine Pitch) (10x10)



2. ServoTrack™ Module and IC Evaluation Unit

3. ServoTrack™ Microstepping Driver and Controller Versions



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