

INTRODUCTION — AccuStep™ Control Technology

Today's motion applications are requiring more precise control of both speed and position. The requirement for more complex move profiles is leading to a change from pneumatic and hydraulic controls to electric motors. However, even the simple electric motors used today may no longer provide adequate control.

Longevity and low maintenance are also leading the shift to electronic actuation.

These requirements make brushless motor technology the logical choice in motor selection. There are two common brushless motor technologies readily available in the market; step and servo. Both provide the accuracy and control needed for precise motion. There are, however, some differences.

Servo motors may be the better choice in applications with power requirements exceeding ¾ horsepower. They also may be better suited if motor speeds are to exceed 3000 RPM, depending on the torque required. Higher peak power at higher speeds can be achieved with servo motors. However, step motors can come with real benefits for many fractional horsepower applications.

Step motors, as a result of the way they are constructed, are inherently lower cost than servo motors. Step motors do not require tuning, allow for a greater inertia mismatch and have very high torque density. This torque is 100% available immediately

upon startup, which can be very advantageous when doing short quick moves or when coupled to high inertia loads. Because step motors are synchronous motors with a high pole count, they are able to run smoothly at extremely slow speeds with no cogging.

There are some disadvantages with today's step motor technology. The most critical drawback is the loss of synchronization and torque if a large load

exceeds the motor's capacity to resynchronize once the load is reduced to a level within the motor's capability. Step motors also tend to run hot because of the use of full phase current independent of load. In some applications, if the motor needs to be overdriven by the load, it may be undesirable to feel the

poles of the step motor as the rotor is being pulled by the load.

These disadvantages may have influenced the decision to choose higher cost servo motors over step motors. Now — with the introduction of AccuStep™ control technology — step motors become a viable and, in most cases, preferred choice for applications requiring brushless motors.

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THE BASICS — AccuStep™ Control Technology

When existing step motors reach a certain point on the speed torque curve (see figure 1), they lose the ability to restart if a load is applied that becomes greater than the motor's ability to produce the required torque. The area to the left of the curve is known as the pull-in region. In this area, the motor will self-start if the load causes a loss of synchronization.

If a load exceeding the motor's capability is applied in the area to the right of the curve, not only will the motor lose

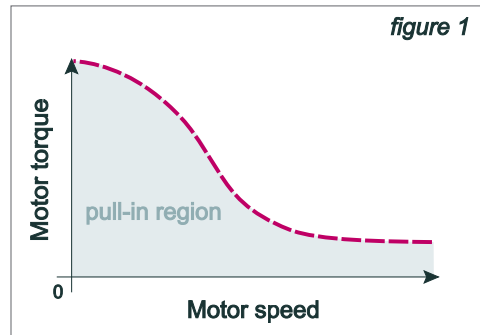
synchronization it will also stall and be unable to restart until the speed is reduced to the pull-in region. In both cases, there is an abrupt change in speed when the motor loses synchronization and stops. In the case of vertical movement of a load, the load may even reverse due to the lack of torque available until the motor is commanded to stop.

The main purpose of AccuStep control technology is to prevent the loss of synchronization, or stall, due to transient or continued overload, extreme acceleration or deceleration, or excessive slew speed. Loss of synchronization occurs when the rotor lags or leads the stator by 2 motor steps. Motor lag is defined as the rotor lagging behind the stator, while motor lead is defined as the rotor ahead of, or leading, the stator.

Rotor position is represented by an encoder. The stator position is controlled by the microstepping SIN / COS generator that energizes the phases.

AccuStep control technology monitors the location of the rotor relative to the stator in terms of motor steps. If the location equals or exceeds a set limit (or bounds), AccuStep will intervene to prevent loss of synchronization. This is achieved by "slowing" or "accelerating" the stator to a speed that equals the

rotor, such that the rotor and stator lead or lag stays within bounds. This change in stator commutation speed will continue until a change in either commanded motor speed or load requirements allows the motor to create sufficient torque at the commanded speed.



This change in commutation speed can go on indefinitely, a behavior that is much the same as a brush type DC motor. While this is occurring, the difference between the commanded steps and the actual steps taken is stored in an

internal register. This difference can be read or cleared by a host controller, or the missing steps can be automatically injected back into the system when sufficient torque is available. The speed at which the steps can be re-injected can be as fast as the system allows or limited with a setup parameter.

Because AccuStep control technology eliminates loss of synchronization, it allows safe operation of a motor at its maximum torque curve. Therefore, sizing a motor with a 25-50% torque margin is no longer required. This may also allow a smaller frame size or shorter stack length motor in some applications. AccuStep also enables a system to ride through known transient overloads, further eliminating the requirement for a larger motor.

Note: AccuStep control technology will not compensate for a poor design. It will not make a motor more powerful, but will maximize the capability of the system and make it more robust.

To further enhance performance and efficiency, variable current control can be enabled to allow only the required phase current necessary to perform a move. By using variable current control, motor heating is minimized while system efficiency is increased.

AccuStep control technology is available in industry leading integrated MDrive® motor+driver products.

MDrive® AccuStep

MDrive motor+driver with AccuStep control technology offer low cost integrated solutions where brushless motion is required.

MDrive AccuStep motion systems combine a flexible operating environment and long list of features, offering clear advantages in a cost effective package for a wide range of motion control applications such as: point-to-point positioning, conveyor control, web handling, drilling, hydraulic and pneumatics replacement, rotary and linear positioning to torque specification, and on-the-fly product marking.

Two MDrive AccuStep product versions are available:

Step • Torque • Speed

A step motor integrated with microstepping driver and internal encoder features three (3) AccuStep operating modes – Step, Torque and Speed. Programming is via a GUI provided.

Motion Control

A fully programmable motion controller is integrated with a step motor, microstepping driver and internal encoder. Programming MDrive AccuStep motion systems is via an ASCII terminal emulator/editor provided.



Pictured: MDrive AccuStep 23

> For more complete product specifications, go to www.imshome.com/products/mdrive_accustep.html

DETAILS — AccuStep™ Control Technology

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. Bounds of 1.1 will produce greater torque though maximum speed will be reduced. Bounds of 1.7 will allow greater speed though transient response is decreased.

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

For torque mode, the bounds are preset.

Microstep and encoder resolutions

Twenty (20) microstep resolutions are supported in any combination. For microstep resolutions less than ten (10), performance is less than optimal and the above bounds do not strictly apply.

Eight (8) encoder resolutions from 100 to 1000 lines are supported for *Step • Torque • Speed versions*. *Motion Control versions* have a 1000 line count encoder. Higher encoder resolutions generally provide “smoother” operation.

In the *Step • Torque • Speed versions*, the encoder signals are made available to the user.

Communication

The standard communication interface is RS-422/485. The protocol used is simple ASCII commands similar to the MCode communication protocol. For the *Motion Control versions* a modified version of MCode is used for true closed loop motion.

Acceptable hosts for both the *Step • Torque • Speed versions* and *Motion Control versions* are the AccuStep GUI, IMSTerminal, HyperTerminal, other terminal program, or intelligent controller.

Calibration

Before AccuStep control operation begins, its logic requires a calibration to understand the initial relationship between the rotor and stator. A calibration is performed on power up to bring the rotor into physical alignment with the stator.

During calibration, the motor and position lag / lead logic is cleared, and any incoming steps are ignored.

Calibration occurs automatically upon various conditions; power on reset, when enabling the AccuStep functionality, when the bridge is re-enabled after being disabled, or when MSEL is changed.

Note: Regarding changing MSEL or enabling AccuStep control when in motion, the resulting calibration will stop motion abruptly.

At power up, one of two available calibration types can be selected: timed or SSM.

Timed calibration sets motor current to a defined value for a timed period. A timed calibration is generally faster, but can produce a slight rotor movement as the rotor is aligned to the stator.

SSM calibration slowly ramps the motor current from 0 to a defined value then holds for a timed period. As the motor current is ramped, small movements in rotor are observed by hardware to detect the initial relationship between the rotor and stator. The electrical position of the stator is then changed to match the rotor's position. By using SSM rotor, movement is virtually eliminated during the calibration period. The ramp

time is approximately 2.5 mS x calibration current. SSM is gentler, but typically takes longer (ramp plus hold). SSM is only available at power up.

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

Operating current

Operating current defines the peak motor current in the motor phases. There are two (2) operating current modes: variable and fixed.

Variable mode adjusts the 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 step operating current would be 51% of maximum; when lag / lead equals 1 full step, operating current would be 100% of maximum. The operating current is increased immediately when lag / lead increases, but is decreased more slowly using a filtering algorithm. Variable mode is useful to reduce heat when the torque requirement is generally modest or varying, but comes with a downside of a slight increase in torque ripple. Variable mode provides a smoother response to an external torque applied on the rotor. Variable mode, when enabled, becomes the 1st defense against loss of synchronization.

By only applying the 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 for extreme acceleration and / or short moves with a downside of potentially more heat.

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

Locked rotor

A locked rotor is defined as no rotor movement while at the maximum allowed lag for a specified period of time. When lag becomes equal to the bounds, a timer starts to count down. Upon reaching zero, a locked rotor will be indicated by the assertion of a status flag. The timer reloads on any encoder movement. The timer timeout period is user selectable from 2mS to 65.5 seconds.

When AccuStep is configured as a step/direction drive or in speed control mode, a locked rotor will also cause an internal fault disabling the motor bridges. The bridges may be re-enabled by cycling power, cycling the enable input, or via software command.

In torque mode, a locked rotor does not disable the bridges. 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 is when the motor lags behind the commanded step position, and 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 an encoder, for example a 512 line encoder provides a resolution of 2048 while a 1.8 degree motor microstepping at 256 has a resolution of 51200. It is important to note that the rotor position can vary by the amount of programmed lead/lag bounds from the stator position. The count is cleared when AccuStep control technology is disabled or when a calibration occurs. The count may also be manually cleared via software command.

A host controller can set a position lag and lead limit. When either limit is reached or exceeded, a status flag will assert. This may be useful as possible indications of excessive binding, maintenance such as lubrication required, or other mechanical system issues.

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 the commanded number of steps and actual steps taken to zero, and the rotor being within the specified bounds.

The speed of position maintenance (the 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 at high speed.

Position maintenance will only occur when the motor lag / lead is within 1.1 full motor steps independent of the 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. Where in time position maintenance occurs is dependent on motor lag/lead, step input frequency, and selected make up speed.

Example: Position lag occurred 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. Or 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 the make up frequency is lower than commanded frequency. Make up can also occur during multiple segments of a move profile.

For a very aggressive move profile that is also dependent on time, 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 in the allotted time as 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, then immediately moving left from B -> A, the ending position could initially be 3 steps to the left of A. The ending position would be corrected. However, the intermediate position would have been off by 3 steps.

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

Maximum system speed

There is a process delay timer within the AccuStep logic to set the maximum system speed. This is the speed at which step clocks are internally generated. The maximum speed is set via a system speed parameter. For example: a step width of 200 nS sets the maximum system speed to 2.5 MHz. The absolute maximum speed is limited to 5 MHz by the SIN / COS generator.

There is a potential issue to setting the system speed too slow. 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 the position error is correct and make up would proceed normally.

Note: In torque mode *torque speed* can be used to limit the speed of an unloaded system.

Attention output

On the *Step • Torque • Speed versions*, an output is provided to indicate selected condition(s) have occurred or are occurring. A number of conditions may be combined (a logical OR) to assert the output. For example: when position lag, position lead, and locked rotor are selected any combination will assert the output.

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

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

The Make Up (MU) active condition is also useful for evaluation. It will show when steps are inserted during the motion profile. The user could adjust the make up frequency for the desired result. For example: if time is not critical but speed during profile is, the user could adjust the parameters so steps are added at end of move rather than being inserted during the move.

MU 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.

Speed control function

On the *Step • Torque • Speed versions*, when setting AccuStep control technology to function in speed control mode, the analog input is used as a reference to internally generate a step pulse whose frequency is relative to the analog input. A large array of programmable functions such as acceleration/deceleration, and max frequency, as well as many others are available.

Torque function

On the *Step • Torque • Speed versions*, when setting AccuStep control technology to function in torque mode, the analog input is used as a reference to generate a torque whose magnitude is relative to the analog input. When the Motion input is asserted in torque mode, an offset between the rotor and stator of 1 full step will try to be maintained to create a torque on the rotor. If the load applied to the rotor is less than the torque required to maintain a 1 full step offset, the rotor will begin to rotate. The speed of rotation will vary dependent on load. Rotational speed will increase until such time as 1 full step phase shift between the rotor and stator is achieved. Torque is set via command on the *Motion Control versions*.

Note: If the rotational speed becomes greater than the speed at which the motor can produce the necessary torque, as shown in the speed torque curve, the torque available will be less than required.

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

On the *Step • Torque • Speed versions*, varying the voltage on the analog input changes the torque generated from low to maximum. Maximum torque is set as a percentage of the absolute torque. The absolute torque available is the rated holding torque of the motor.

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

Bypass

When AccuStep control technology is disabled, an incoming step is routed directly to the SIN / COS generator (stator). The motor and position lag / lead calculation logic is disabled and the values are cleared. This can be useful in comparing the performance of a standard system without AccuStep control.

The user can freely move between AccuStep control and bypass. Note that an automatic calibration will be performed when AccuStep control technology is enabled.

Configuration test

Note: This is not required for MDrive products containing AccuStep.

In order to correctly calculate lag / lead, the resolution of the installed encoder must be correctly specified and the encoder direction must match the commanded motor direction. For example: if the motor direction is positive (dir = 1) the encoder must turn such that channel A leads channel B (dir = 1), and if a 500 line encoder is installed a 500 line encoder must be specified.

It is strongly recommended a configuration test be performed on a newly set up system. An incorrectly wired or improperly specified encoder will cause erratic operation.

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