

hMTechnology

technology eBook

closed-loop stepper technology
delivering servo-like performance

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Introduction to hMTechnology (hMT)

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.

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.

Servo motors may be the better choice in applications with power requirements exceeding $\frac{3}{4}$ 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 re-synchronize 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 hMTechnology (hMT) — step motors become a viable and, in most cases, preferred choice for applications requiring brushless motors.

hMT is a revolutionary closed loop control technology that, when applied to step motors, prevents the loss of synchronization due to transient or continued overload, extreme acceleration or deceleration, or excessive slew speed.

Glossary of terms

There are a number of terms used in this document with respect to this control technology.

hMTechnology (hMT) — A motor control technology representing a new paradigm in brushless motor control. By bridging the gap between stepper and servo performance, hMT offers system integrators a third choice in motion system design.

Control bounds — Control bounds establish the rotor/stator lead and lag relationship. Control bounds may be set to one of 4 parameters ranging from 1.1 to 1.7 motor full steps. When hMT is active, the technology will maintain the relationship within those boundaries, eliminating motor stalls.

Lag — The amount (in full motor steps) that the rotor lags the stator. Lag conditions are caused by loading on the motor shaft, as during transient loading or rapid acceleration.

Lead — The amount (in full motor steps) that the rotor leads the stator. Lead conditions are caused by an overhauling load, as during periods of rapid deceleration.

Loss of synchronization — In traditional stepper systems, when the lead/lag relationship of the rotor and stator reaches two full motor steps, the alignment of the magnetic fields is broken and the motor will stall in a freewheeling state. hMTechnology eliminates this.

Locked rotor — When the lag/lead limit is reached, a timer starts a countdown that is determined by the user. The locked rotor will assert itself by triggering a flag and, depending on the selected mode, by disabling the output bridge.

Position lead/lag — hMT continually tracks the position lead or lag error, and may use it to correct position.

Position make-up — When active, the position make-up can correct for position errors occurring due to transient loads. The lost steps may be interleaved with incoming steps, or reinserted into the profile at the end of a move.

Variable current control — When active, variable current control will control the motor current as such to maintain the torque and speed on the load to what is required by the profile. This leads to reduced motor heating and greater system efficiency.

The Basics of Hybrid Motion 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 therequired torque. The shaded area 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 outside the shaded area 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.

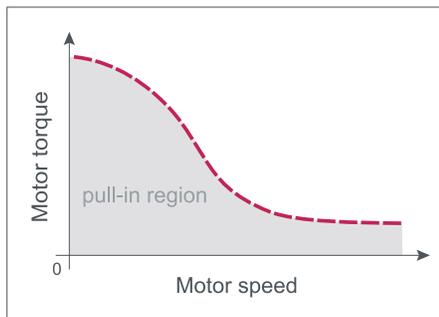


Figure 1: Pull-in region

The main purpose of hMTechnology 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.

hMTechnology 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), hMT 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 hMTechnology 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. hMT also enables a system to ride through known transient overloads, further eliminating the requirement for a larger motor.

Note: hMTechnology 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.

Principles of operation

hMTechnology introduces a range of variables into the brushless motor control equation that eliminate loss of synchronization and allow for stepper motors to be utilized in applications outside the traditional range due to their limitations.

Using variable lead/lag limits ensure that functional control of the motor is never lost. Variable current control reduces motor heating and improves system efficiency, and position make up ensures the load will arrive at its desired location

Variable lead/lag limits (control bounds)

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.

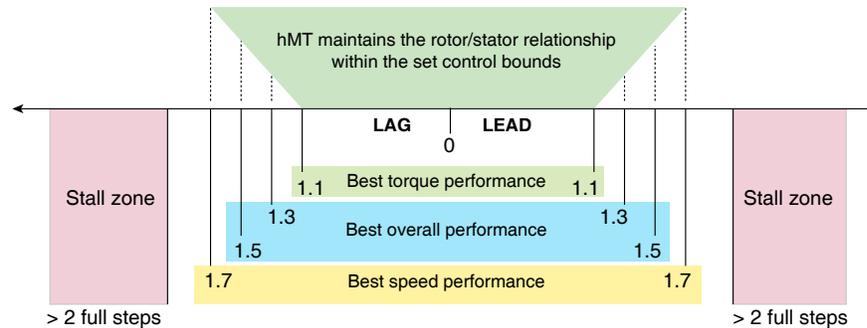


Figure 2: Variable lead/lag limits

Best overall performance is achieved with bounds of 1.3 or 1.5 full motor steps. For torque mode, the bounds are preset to 1.0 full step.

Regardless of the control bounds setting, the hMT circuitry will maintain the rotor stator relationship within those bounds, never allowing a loss of synchronization.

Variable current control

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

1. Variable
2. Fixed

Variable current mode adjusts the operating current from 2% up to 100% of a defined maximum run current (RC) 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 specified run current. When lag/lead equals 1 full step, operating current would be 100% of run current setting. The operating current is increased immediately when lag/lead increases, thus counteracting the effect of a transient overload or overhauling load. The current is decreased more slowly using a filtering algorithm to avoid oscillation.

When motion ceases, the set holding current (HC) will be static, it will not vary.

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.

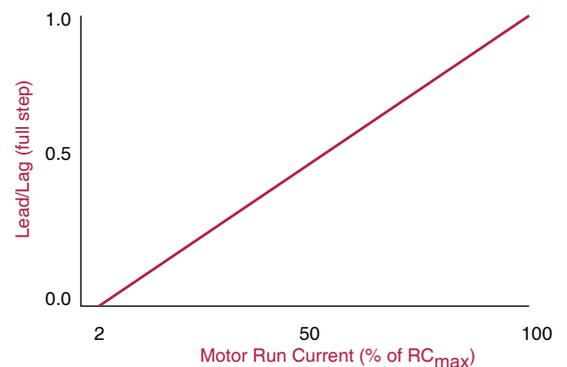


Figure 3: Variable current control

Performance advantages

The impact of this can be seen in Figures 4 and 5, which shows test results comparing the motor temperature of a motor without variable current control to one with variable current control enabled under differing duty cycle conditions.

Figure 4 shows the impact of Variable Current Control on a motor that is constantly running at a speed of 2000 full motor steps per second at 25% torque. As seen in the graph, the motor at a fixed run current quickly heats to the point of thermal shutdown at 85 °C . The motor with Variable Current enabled maintains temperature within the operating range of the device.

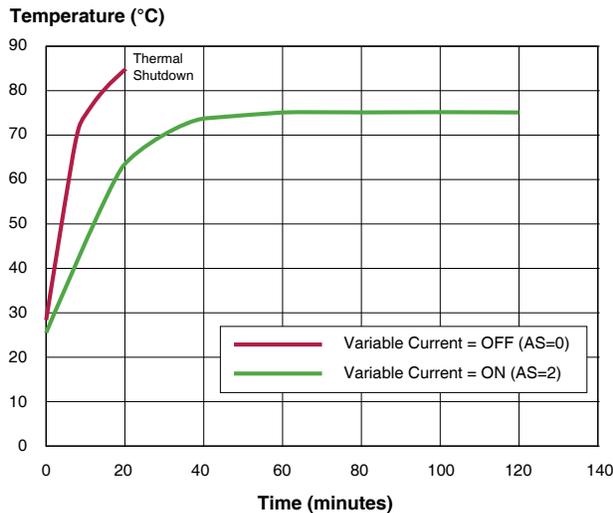


Figure 4: Temperature rise - 100% duty cycle

In Figure 5, we show the comparison of the motors running with a moderate duty cycle. In this graph we see the impact of Variable Current Control manifested in a 20% difference in the temperature, thus greater power efficiency.

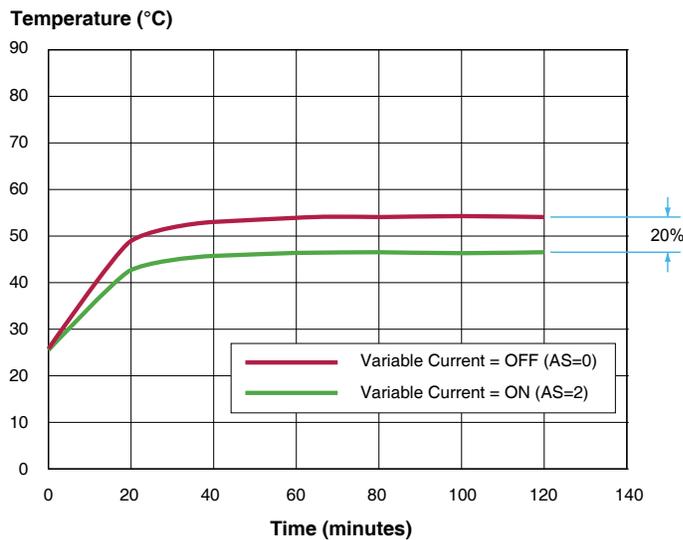


Figure 5: Temperature rise - moderate duty cycle

The overall Impact of Variable Current Control in a system will vary depending on duty cycle, load conditions and motor speed. Variable Current Control is one more way that hMTechnology overcomes some of the natural limitations of stepper motors by decreasing the losses of the motor, saving you energy and money.

Figure 4 test conditions: Power supply: 48 VDC regulated, Load: 26 oz-in (18.3 N-cm), Move profile: 1 rev/sec CW/CCW for 2.5 minutes each, then continuous @ 2000 fullsteps/sec – 1 minute CW, 1 minute CCW.

Figure 5 test conditions: Power supply: 48 VDC regulated, Load: 26 oz-in (18.3 N-cm), Move profiles: 1 rev/sec CW 1.5 seconds, wait 10 seconds, 1 rev/sec CCW 1.5 seconds, wait 10 seconds, repeat.

Fixed mode consists of static run current when steps are active, and static 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.

Position error

For reference; position lag is when the rotor lags behind the commanded step position, and position lead is when the rotor leads the commanded step position.

A count is kept of the difference (error) between the commanded step position and the actual position. The host controller can read step position error and take appropriate action when and how desired. 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 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 make-up

Automatic position make-up 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 make-up (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, when making up at maximum speed, therefore make up could be abrupt at high speed.

Position make-up 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 make-up 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.

Torque control

One of the features that make hMTechnology unique is the ability to maintain a constant torque. The hMT logic continually tracks the lead/lag offset between the rotor and the stator.

In stepper systems, the peak torque is available to the shaft when the offset between the rotor and the stator is within (1) full motor step. Beyond that difference torque will begin to decrease until the point where a lead/lag of two (2) motor full steps exists and the motor loses synchronization and stalls.

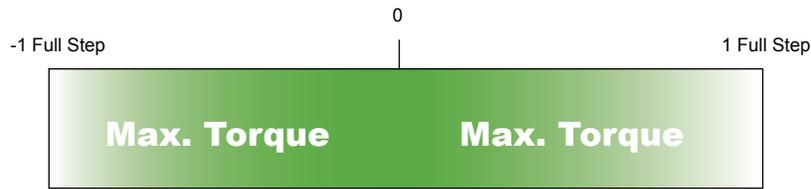


Figure 6: Torque mode maintains the rotor-stator within ± 1 full step

Motor torque is directly proportional to the motor current applied. Steps are generated at a rate required to generate a lag of one (1) full motor step, therefore, shaft speed will vary with the load from zero (0) to TS (torque speed).

Position make-up is not available when torque mode is enabled, however, position is still tracked and stored.

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 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 pre-set amount of time.

Motion systems with hMT

hMTechnology is available in industry leading integrated Lexium MDrive® motor+driver products

Lexium MDrive®

The closed loop Lexium MDrive products with hMTechnology offer low cost integrated solutions where brushless motion with closed loop control is required.

Lexium MDrive 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, and on-the-fly product marking.

Lexium MDrive products offer interchangeable ease to system designers. Each product size has one common product envelope. So choosing different communication protocols — whether it is Ethernet, RS-422/485 or CANopen — does not change the product footprint. Overall product length varies with choice of single, double or triple stack in NEMA motor sizes 17, 23 & 34 (42, 57 & 85 mm).

Enhancing ease-of-use and simplifying setup, locking connector styles are consistent across all product sizes. Mating connectors are robust, do not require special tools, and are keyed against wrong-plugging.

Product versions

- **Pulse/Direction motor + driver**, RS-422/485 communication operational modes: step/direction, speed control, torque control, velocity control
- **Motion Control programmable motor + driver + controller**, RS-422/485 communication, memory: 336 user labels and 11,120 bytes flash
- **Ethernet motor + driver + controller**, EtherNet/IP and Modbus/TCP slave device; or Profinet IO
- **CANopen motor + driver + controller**, CANopen DSP402 system node

Note: hMTechnology is only available with closed loop Lexium MDrives with integrated encoder.



Figure 7: Lexium MDrive product family

Lexium MDrive[®] features and functions

- Smooth operation at low speed
- Reliable performance at high speed
- High starting torque
- Torque mode feature
- Protection against over voltage and DC switching
- Isolated communication and I/O
- LED status indicators
- Closed loop hMTechnology

hMTechnology monitors motor shaft position in sub-microsecond increments, closing the feedback loop and eliminating many negatives traditionally associated with stepper systems. Without increasing product size, closed loop Lexium MDrive products blend stepper and servo motor benefits, delivering enhanced performance including:

- Lower energy consumption and cooler operating temperatures
- Higher torque from smaller motors for economic efficiency
- Real time closed loop control, eliminating loss of synchronization
- Lower cost option to servo motors in many applications

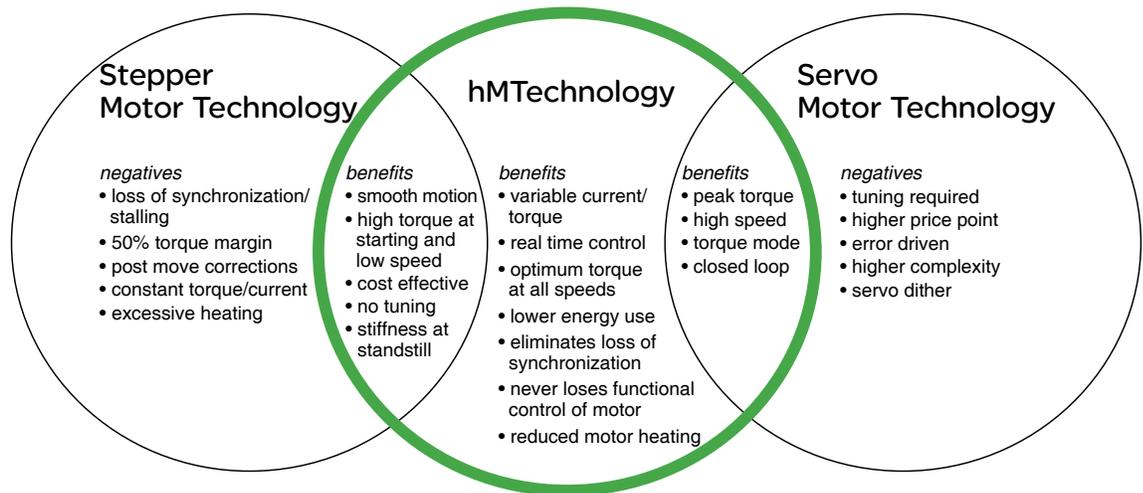


Figure 8: hMTechnology bridges the gap between stepper and servo performance

Communication networks



RS-422/485 serial

The RS-422/485 serial interface is standard on the following Lexium MDrive product models:

- Pulse/direction input
- Motion Control

The serial interface to the Lexium MDrive features the following:

- Port is isolated
- 4.8 to 115 kbps
- Full(422) or half duplex (485)
- Point-to-point communication, Multi-drop (422) or multi-point (485) addressability using ASCII characters (up to 62 devices)
- Plug-n-play USB to RS-422 converter and cable variable at nominal cost

Pulse/direction input

The Lexium MDrive Pulse/direction input can be set to operate in one of the following modes:

- **Pulse/direction mode:** the device will move the stepper motor as referenced by input signals via the multifunction interface.
- **Speed control mode:** the device will move the stepper motor at a velocity determined by a reference voltage fed to the analog input of the multifunction interface. The pulses are generated via an internal clock generator.
- **Velocity control mode:** the device will move the stepper motor at a constant velocity determined by an integer value input via the serial interface. The pulses are generated via an internal clock generator.
- **Torque control mode:** the device will maintain constant torque on the shaft at a value determined by a reference voltage fed to the analog input of the multifunction interface.
- The primary role of the serial interface for the Pulse/direction products is to set the operating mode and configure the various parameters.

A persistent serial connection to the device is only required under two conditions:

1. The device is used as in velocity mode, where a slew command is sent from a controller
2. Operating mode or parameters are to be changed during operation

Motion Control

The Lexium MDrive Motion Control is a fully programmable motion control system allowing for complex program and I/O interaction. Operating modes may be used interchangeably:

Immediate mode: In immediate mode, also known as streaming commands, the device will respond to 1 and 2 character ASCII commands sent via the RS-422/485 fieldbus interface

Program mode: In program mode the device may be programmed with multiple functions, subroutines and process interactions using the MCode programming language, which is made up of 1 and 2 character ASCII mnemonics. Stored programs may be executed using an input, by labeling a program SU to run it on start up, or via an immediate mode command.

A persistent serial connection to the device is required in most cases, the exception being if the device is being used in such a way that program and process control is performed via I/O interaction and device status information is not required.

Ethernet TCP/IP

Lexium MDrive TCP/IP products use the standard TCP/IP networking model and support the following industrial protocols:

Lexium MDrive Ethernet



Modbus/TCP: may be used in MODBUS/TCP networks, A standard open industrial convention supported by a variety of machine components such as programmable controllers, drives and controls, I/O modules and switches.



EtherNet/IP: may be used as a fully ODVA compliant Adapter class device on EtherNet/IP networks.

Lexium MDrive Profinet



Profinet IO: may be used as an IO-DEVICE on Profinet networks with Siemens PLCs. Motion commands, variables and flags from the standard MCode control language are mapped to input and output registers of the device. There are 38 output registers and 34 input registers.

Both models may also be used a fully programmable motion control system using the proprietary MCode/TCP language. This allows for complex program and I/O interaction. Operating modes may be used interchangeably:

Immediate mode: In immediate mode, also known as streaming commands, the device will respond to 1 and 2 character ASCII commands sent via the RS-422/485 fieldbus interface

Program mode: In program mode the device may be programmed with multiple functions, subroutines and process interactions using the MCode programming language, which is made up of 1 and 2 character ASCII mnemonics. Stored programs may be executed using an input, by labeling a program SU to run it on start up, or via an immediate mode command.



CANopen

The Lexium MDrive CANopen uses DS301 communication profile is the interface between device profiles and CAN bus. It was specified in 1995 under the name DS301 and defines uniform standards for common data exchange between different device types under CANopen.

The DSP402 device profile describes standardized objects for positioning, monitoring and settings of drives.

- **Profile position:** defines the positioning of the drive. Speed, position and acceleration can be limited, and profiled moves using a trajectory generator are also possible.
- **Homing mode:** describes the various methods to find a home position, reference point, date, or zero point on start up, or via an immediate mode command.
- **Profile Velocity:** used to control velocity of the drive with no special regard of the position. It supplies limit functions and trajectory generation.
- **Profile Torque:** defines the torque control with all related parameter. (Available on closed loop models only.)
- **Cyclic Synchronous Position:** used to define position control where the device, or multiple devices initiate and complete a point to point move at a specified time.

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