

MAXPOS Drive Controller: The success of dynamics

There are two basic requirements that state-of-the-art machines, systems and devices must meet in order to succeed in the market: an extensive range of functions and high reliability. However, today these two factors only allow very little scope for differentiation. Increasingly, machine and device manufacturers face the question of how to achieve a competitive advantage on the market, apart from price. One common approach is to differentiate into the product design, handling and user interface. In addition, “secondary features” beyond the actual functionality are gaining importance:

- Compactness for small space requirements and simplified machine transfer
- Modularity for application-specific upgrading and conversion
- Flexibility for fast and efficient adaptability to small batch sizes in production
- Dynamics for high production output and high profitability
- Energy-efficiency for low operating costs

These secondary features make it possible for the machine or device manufacturer to once again achieve functional differentiation and to take on a leading role in the market. Another advantage of focusing on secondary features is that competitors can only copy the concepts and knowhow by investing heavily, and even then, the copied ideas can only be applied in the newly developed products. With this in mind, drive technology can play an important role from early on in the development process. The drive technology, including the control system, has a decisive effect on the achievable flexibility, dynamics and energy efficiency.

One big challenge for almost any project is the combination of several engineering disciplines, such as mechanical and electrical engineering, software development and perhaps even hardware development. All of these disciplines are required for an optimized system design. The history and focus of a company’s development department has made it stronger in certain disciplines than others. The basic concept of drive technology and required data exchange has to be set early on before it comes to the detailed selection of motors, power stages and drive controllers. It is therefore important to have a competent, application-oriented supplier to provide consultation and assistance, starting from the initial concept phase. To reduce the development cost and risk, it is advisable to choose standardized components that match to each other and provide the required performance across the board. maxon motor as a drive and controller manufacturer provides high-quality products and offers the required consultation and problem-solving competence, based on in-depth expertise in thousands of industry-proven applications.

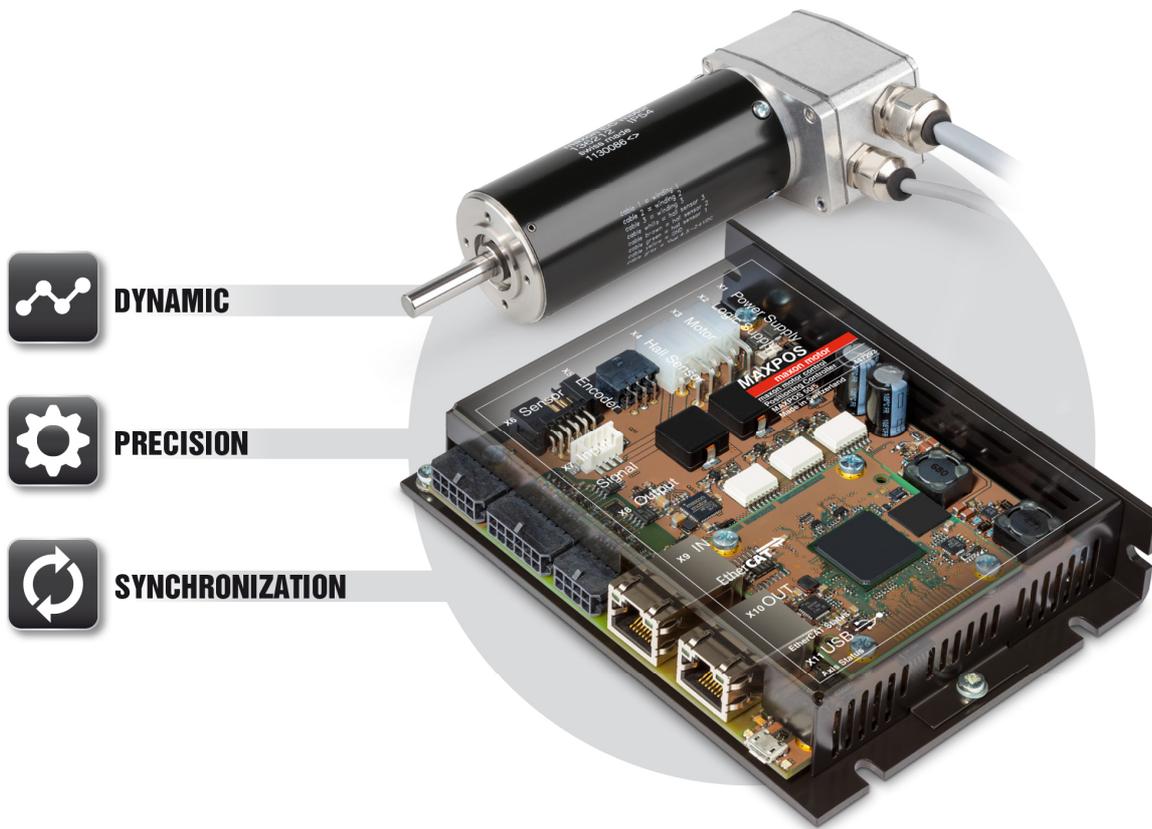


Fig. 1: The dynamic drive package

Energy efficiency & dynamics: The motor

In the case of asynchronous motors, energy efficiency is a clearly (and statutorily) defined requirement. In the “low” power range of up to 500 W, significant energy savings can be achieved by using motors with high efficiency for the 24 V to 48 V DC voltage range. The ironless maxon DC motors and brushless EC motors (= BLDC), some even offer an efficiency of more than 90%, provide an optimal starting point for this. The maxon motors have a very high power density, which makes very compact solutions possible compared to conventional DC and AC motors. The high dynamics of maxon motors, with acceleration values of just a few milliseconds, allow extremely fast, precise movements. This is a mandatory precondition to match the demands for significantly increased machine performance (= production quantities/hour). The selection of the right motor type - a frequently neglected aspect - is of central importance. Old concepts should not simply be copied, but instead, they must be critically examined. New solution approaches based on maxon DC and BLDC motors can satisfy all requirements regarding energy efficiency, compactness and dynamics and can significantly improve machine performance.

Precision: The sensor system

Information about the position, usually relative to the motor shaft, is required to track and evaluate any movement. The actual position is recorded by using rotary encoders mounted directly on the motor shaft, or linear scale encoders with a backlash-free coupling. The speed is calculated by the derivation of the position information per controller sampling period (in other words, the change in position per time unit). The higher the encoder resolution is, the more accurately the position can be measured. As a result, the actual position and speed and any deviation of the commanded value can be calculated and controlled very accurately even in the case of extreme fast sampling rates. The sensor resolution directly determines the best possible positioning accuracy and also influences the quality of the speed constancy, in particular in the case of very slow movements. In practice, a variety of sensor solutions are in use: incremental and absolute sensor types, as well as digital, analog and protocol-oriented types of sensor signal transmission. The product range offered by maxon includes magnetic and optical rotary encoders that are mounted directly on the motor and provide a very compact, cost-optimized solution for precise drive technology.

Dynamics & precision: The drive controller

The drive controller links the motor, the sensor system and the higher-level process controller, which is usually a PLC-based or PC-based solution.

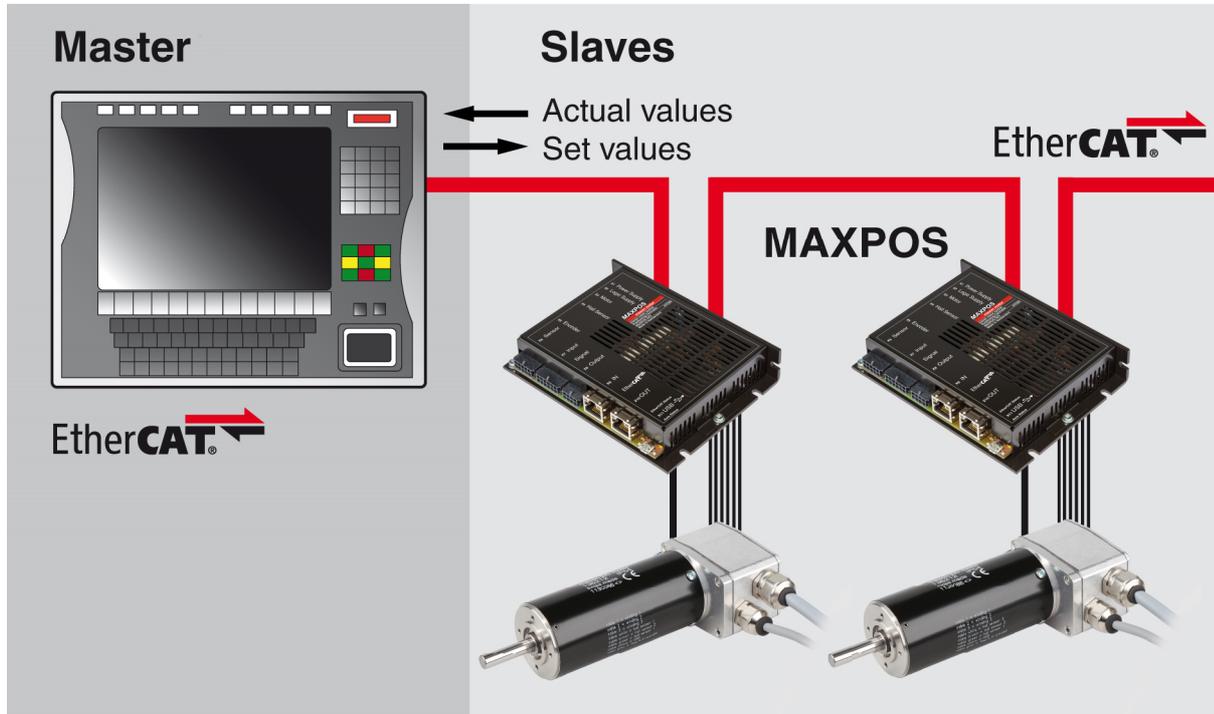


Fig. 2: MAXPOS as link between the PLC and the motors

MAXPOS, the new maxon drive controller generation, integrates one (or several) power stages in combination with a powerful processor unit that is optimized for fast processing of position sensor signals and motor current measurement in real time, which is the base input information for the internal current, speed and position controller algorithms.

MAXPOS can be connected to brush-type DC motors as well as brushless EC motors (= BLDC). It supports various incremental and absolute encoder systems used in the industry. This makes it possible to choose the encoder that best suits the application. The selection ranges from digital incremental encoders and encoders with analog sine-cosine signal shape (typically in use by glass-scales), to SSI absolute encoders and modern sensor protocols such as EnDat2.2 and BiSS C. The MAXPOS encoder interfaces have input frequencies of up to 5 MHz. This means that even high-speed motors can be freely combined with high-resolution encoders and that fast movements also benefit from precise target positioning.

The actual dynamics of drives and the reaction to quick-changing set values also depend on the processing speed (= sampling rate) of the positioning controller and in particular, the current controller. Typical current controllers use sampling periods of 0.1 ms (= 10 kHz rate). Speed and positioning controllers use typically 1 ms (= 1 kHz rate). On highly dynamic drives with acceleration times of just a few milliseconds, these sampling rates are no longer up to the task and limit the accuracy of the mechanical movements and the machine performance. The MAXPOS 50/5 drive controller rises to the challenge and offers a new dimension of controller dynamics. With sampling rates of 100 kHz (= 0.01 ms period) for the current controller and 10 kHz (= 0.1 ms) for the speed/positioning controller, the MAXPOS drive controllers are the decisive links in between the system's high-level process controller and the motors. Highly dynamic maxon motors and fast MAXPOS controller technology can dramatically improve the throughput and performance of machines as well as the quality of the goods produced by these machines.

In addition to a fast controller, sinusoidal current commutation is another precondition for precise, "sensitive" drive movements with an almost ripple-free torque profile from a speed of 0 up to the maximum. This is a common requirement in robotics, for quick handling of sensitive goods in the production process or for drive synchronization. When the sampling period of the current controller is extremely short, only 0.01 ms (as is the case with MAXPOS), all current measurements, signal conversions, complex integration calculations and transformations required for field-oriented motor control (FOC) and sinusoidal commutation have to be performed reliably within this extremely short period of time, without being influenced by any other functions. The 100 kHz rate of the MAXPOS current controller in combination with a sinusoidal commutation for speeds up to 200,000 rpm was made possible by integrating the necessary calculation algorithms on a so-called FPGA (= Field Programmable Gate Array). The hardware-based FPGA logic offers significantly higher specific computing power than what is possible with conventional solutions that use processor-based programming. Another advantage is the clear decoupling of the current controller from other interrupt-driven and less time-critical functions, those that can be implemented on the processor level. A comparison between the step response of the MAXPOS current controller with a 100 kHz sampling rate and a typical solution available on the market with only 10 kHz impressively demonstrates the positive effect.

Motor current [A]

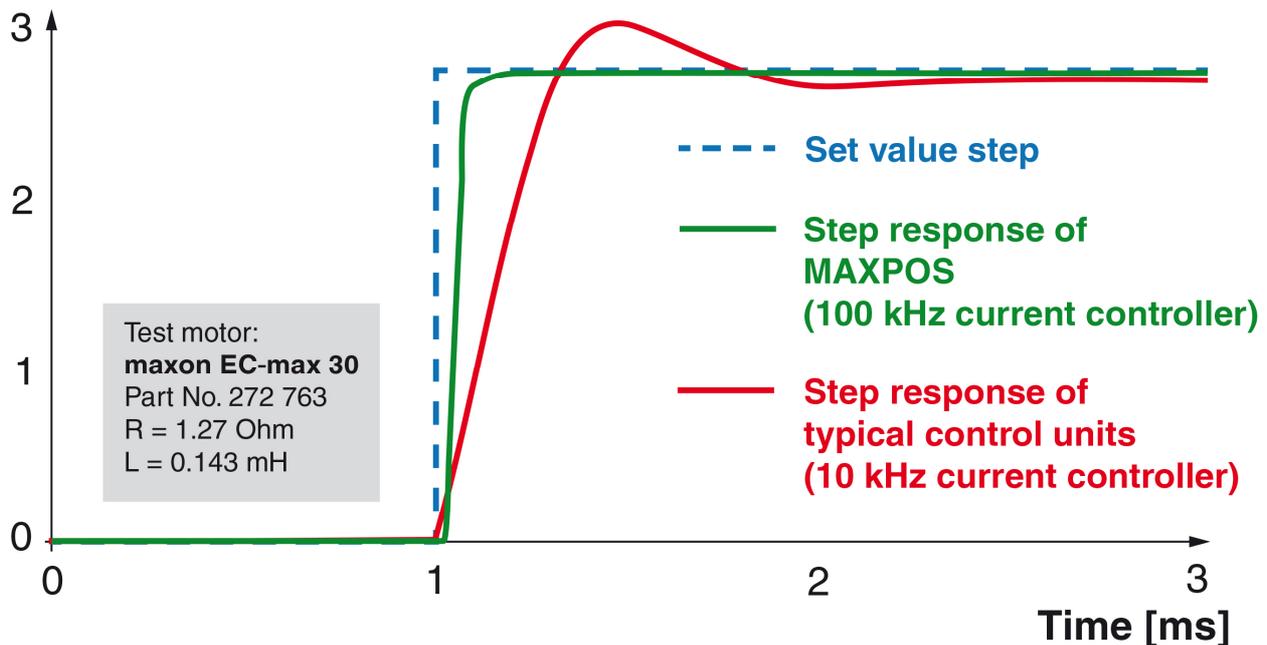


Fig. 3: The step response of the MAXPOS (100 kHz current controller) compared with a 10 kHz current controller

The step response of the MAXPOS current controller shows a very fast and steep current rise, but equally important, practically no overshoots and no transient oscillation is present. The actual motor current reaches the set value specified for the step and stays stable after only 0.15 ms. Within this rise time, the MAXPOS current controller performs approximately 15 current measurements and controller cycles. The “standard” current controller (10 kHz) of this comparison needs 0.3 ms before it reaches the set value for the first time. On this slower controller, these 0.3 ms correspond to only 3 cycles. Due to the less frequent reaction to the latest changes in the current values, this controller has more difficulty achieving a stable transition to the set value. In other words, it overshoots and needs more than 1 ms to achieve an actual stable motor current. It is easy to see that the sampling rate of the controller stands in direct relation to the achievable rise times and the transient oscillations. This applies not only to the current controller, but also to all cascaded higher-level controllers (e.g. speed and position). The current controller as a subordinate controller has to meet the highest performance requirements, as the rise time of the motor current is limited only by the very small electrical time constant of the motor (keywords: inductance, winding resistance = L/R time constant). As far as possible, the current controller must react to each current change in real time, in order to limit overshooting to an absolute minimum. The speed or positioning controller can (and will) typically be 10 times slower than the current controller. The mechanical time constant of the entire drive including the load has a limiting effect on fast changes and it is acceptable if the speed/positioning controller reacts “more slowly.” This rule of thumb also applies to the speed/positioning controller of the MAXPOS, which runs at 10 kHz and still provides

significantly more performance than typical other controllers (1 kHz) or servo amplifiers. The speed/position control algorithms of the MAXPOS have been implemented in a so-called soft-core processor, which has been integrated into the FPGA. This still ensures excellent performance, with a 10 kHz sampling rate, but provides greater flexibility for adapting to application-specific solutions that might require additional control features or specific path planning and motion profiles.

Optimization for use in practice: Autotuning

The configuration of the control parameters has significant influence on the resulting control and motion quality. In practice, optimally configuring the controller is one of the biggest challenges for the user. Frequently, the configuration is only performed in a very rudimentary way. Manual tuning and optimization requires a great deal of experience and lots of effort and time for testing. Additionally it is not always easy to find an initial basic configuration. The “incidentally” found initial configuration is therefore frequently retained even during later operation, with negative effects on the precision and performance of the actual mechanical movements. The advantages provided by a highly sophisticated controller design that is fast and accurate in principle can be nullified by such a configuration. During the development of MAXPOS and the free of charge software “MAXPOS Studio”, maxon put a high premium on a mature, reliable Autotuning function that optimally supports the user and reduces the effort required for startup and optimization tasks.

The MAXPOS uses a PI current controller and a PID positioning controller, each with feed forward control. The results of the Autotuning automatically and efficiently lead to a controller configuration that provides optimal controller and motor behavior for almost all applications, without the need for time-consuming manual tests or simulation calculations. With the “MAXPOS Studio” software the controller and motor response can be monitored online during specific movements and load conditions as a moving graphic called a live trace plot. The controller parameters can be adapted manually while the motor is running. The PI, PID and feedforward gains of the controllers can be easily adapted by means of factors that are directly relevant to the drive and mechanical system, such as the mass inertia, friction, controller bandwidth, damping and integral time constant. The live trace plot is an important feature for verifying the controller settings at a specific operating point of the application, as well as for evaluating the effects of manual changes to the controller parameters. The live trace plot is the key for an efficient fine-tuning.

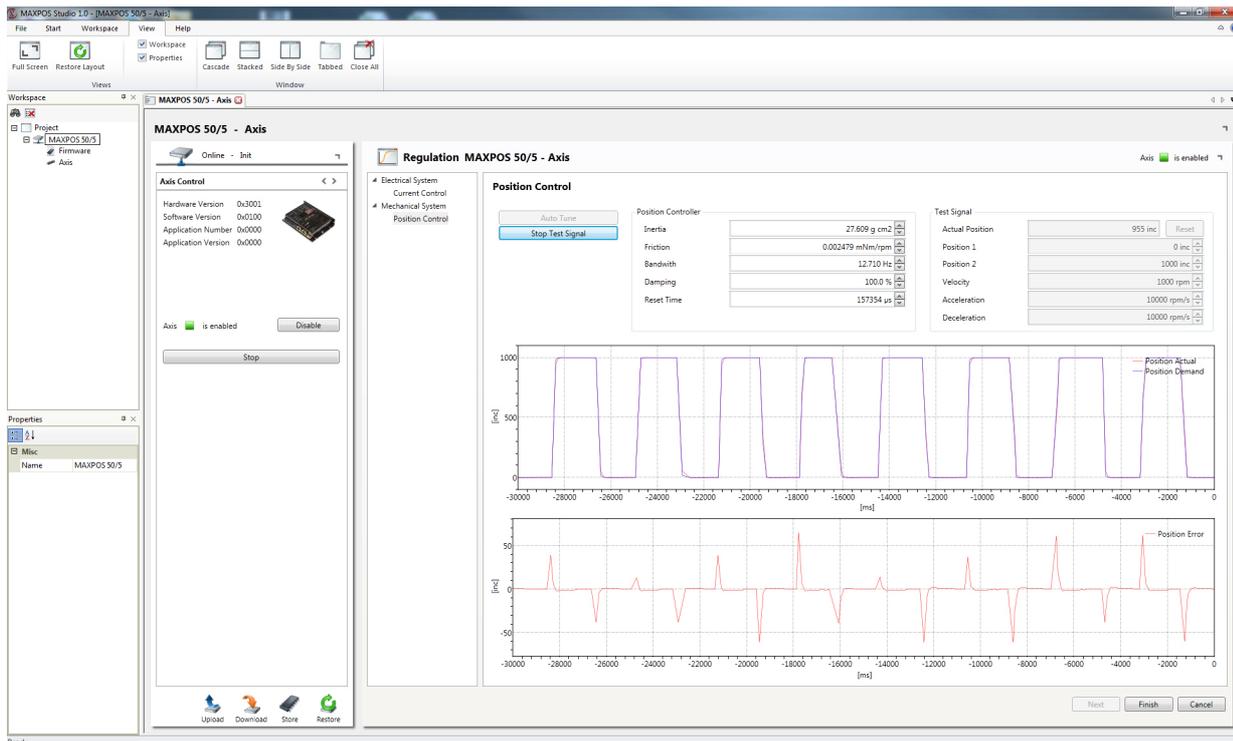


Fig. 4: Screenshot: MAXPOS Studio: Live trace plot of the positioning controller

Applications: Added value resulting from dynamic drive concept

The advantages of a modern motion controller design, high controller sampling rates and optimally configured controller parameters are not only theoretical. In practice, the fast reaction to any changes of the set value commands and the resulting extremely precise actual motion profiles are an obvious benefit. For many applications, these are exactly the drive-related essential requirements for producing high-quality goods and achieving high production output of machines. The need for highly dynamic drives in combination with a high-performance controller such as MAXPOS can be derived from the following requirements:

- Extremely precise positioned or synchronized movements
- High accelerations
- Short, dynamic motion profiles that are frequently repetitive
- “Sensitive” reactions, in other words very precise torque control and limiting

One or more of these requirements apply to almost all machines and systems:

- Rotary printing press and systems for paper processing, e.g. for production of magazines and books
- Filling and sealing systems for bottles and cans, e.g. in the food industry
- Rotary transfer and revolving machines, e.g. in the automotive or tool manufacturing industry
- Systems for labeling, perforating and cutting material in running production line processes, e.g. for paper, wood, plastics or cable processing
- Pick-and-place, die- and wire-bonding machines, e.g. in the production of electronic modules and in the assembly of electronics
- Delta and Scara robots for handling parts, e.g. in the food, medical or automotive industry
- Electrical screwdrivers for controlled fastening of components, e.g. in the automotive or watchmaking industry
- Robotic grippers for handling sensitive goods, e.g. in the food, pharmaceutical or medical industry

This list could be extended almost indefinitely. A single drive is usually not used alone, but it is integrated into a larger system consisting of several drives, sensors and actuators.



Fig. 5: MAXPOS – Examples from practical applications

Modular design & compatibility: System concept

The higher-level controller, which is usually a PLC, coordinates and synchronizes the individual drives and handles the process and control functions of the complete solution. The advantage of this centralized approach is a uniform, efficient programming environment independent of the power of the required drives or the manufacturer of each drive controller. This allows the developers to concentrate on the application and on selecting the optimal components for their requirements. Due to the use of established industry standards for the programming environment and bus system, machine and device manufacturers profit from high portability, less training costs, a reduced development risk and a shorter time-to-market for new solutions. For the drive controller, this means that the following requirements are absolute essentials:

- Industrial, fast bus connection
- Easy integration into established PLC concepts
- Transparent integration into PLC programming environments
- Commanding by the function blocks of the PLC's motion control library

Compatibility: Industry standards

The MAXPOS has been designed as an EtherCAT slave based on the functionality according to the standards of the EtherCAT Technology Group (ETG). MAXPOS uses the CoE (= CAN application Layer over EtherCAT) protocol for bus communication and supports the following operating modes of the established CANopen standard device profile CiA402 for drives and motion control:

- CST – Cyclic Synchronous Torque
- CSV – Cyclic Synchronous Velocity
- CSP – Cyclic Synchronous Position
- HM – Homing
- PP – Profile Position
- PV – Profile Velocity

MAXPOS successfully demonstrated the compatibility with the master systems of various manufacturers at international plugfest events of the ETG. The interoperability of products with the EtherCAT bus are tested in actual practice during the plugfest sessions. The EtherCAT Conformance Test was also successfully passed by the MAXPOS, another important step in ensuring compatibility and reducing development work and risk for the system integrator. This also safeguards investments and acquired knowhow in the field of drive technology for the future and enables fast and efficient integration of the MAXPOS in EtherCAT-based PLC environments (such as Beckhoff TwinCAT®), on the basis of established standards.

Performance: Data exchange in real time

Typically the path calculation, coordination and drive synchronization for multi-axis machines and drives are performed within the PLC. When such a concept is used, the MAXPOS cyclically receives new set values via the EtherCAT bus and processes these in CST, CSV or CSP mode in real time. Up to 3000 times per second, new current, speed or position set values can be commanded and extensive actual information about the drive (e.g. actual position, motor current, etc.) can be exchanged via the EtherCAT bus almost without any limitation. Depending on the configuration, even data exchange rates of up to 10,000 times (!!) per second (that means a bus cycle time = 0.1 ms!) are possible, for example for high-speed applications that require very fast commanding of new set values in CST mode. The content of the data exchange can be configured by means of variable PDO mapping, which offers high flexibility to select right the information required by the application. The MAXPOS interpolates between the set values to achieve drive movements that are as smooth and continuous as possible. Distributed clocks are used to synchronize the data transfer and the controller cycles. Fast bus data exchange and distributed clocks enable the high-level control unit (e.g. PLC) to accurately command and monitor motion profiles and synchronization of several axes.

Conclusion:

Machine performance starts with the drive technology

The MAXPOS fulfills all preconditions for performing dynamic, precise and synchronous mechanical movements driven by brush-type or brushless motors. By using the many different operating modes based on the CiA402 industrial standard and the real-time capable EtherCAT bus, the MAXPOS can efficiently be integrated into PLC concepts while using the existing development environments.

The MAXPOS provides top of the line dynamics in the field of drive technology. It offers machine and device manufacturers, leaders in their fields, one important key to set new benchmarks for performance and efficiency of their systems.

Version 2.10 / 4.9.2014

Author: Juergen Wagenbach

Approx. 3,200 words, approx. 21,000 characters (including spaces)