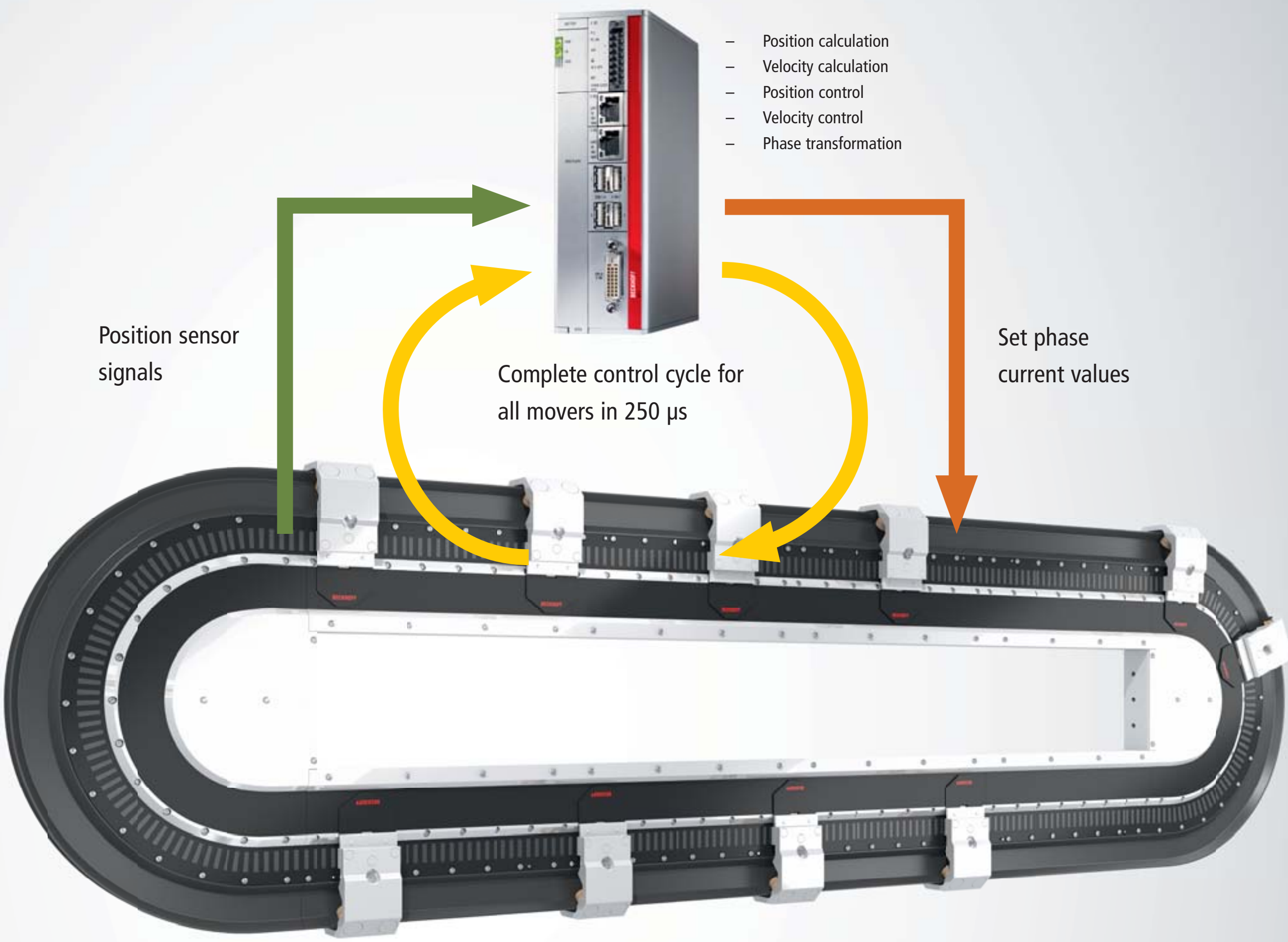


Figure 1: Overview of the whole XTS system

Linear Transport System for highly dynamic machine concepts

XTS: Significantly higher performance and simplified engineering with TwinCAT

The linear transport system XTS (eXtended Transport System) from Beckhoff combines the benefits of rotary and linear drive into one system. Where up to now the application options for rotary motors essentially ended, XTS adds the features of linear drive systems and offers new approaches for realizing highly dynamic machine concepts. An additional benefit of the XTS is its compactness, enabling machine manufacturers to design space-saving machines. The TwinCAT automation software ensures simple engineering. All "movers" of the XTS system are mapped as "normal" servo axes. Functions such as automatic accumulation, collision and jerk avoidance are integrated in TwinCAT.

In servo technology for mechanical engineering, a distinction is made between rotary and linear servomotors, which each have specific features.

With rotary motors and suitable mechanical systems such as toothed belts or conveyor chains, it is relatively easy to generate an endless circulating linear transport movement. However, such a configuration has the disadvantage that the rotary motor always moves the belt or conveyor chain uniformly in all sections. It does not allow velocity variation in different areas, e.g. in order to compensate for variance in a flow of products, to group products in different ways or to account for different processing times in a continuous flow of products. Further disadvantages include higher wear and lower rigidity of the mechanical components, resulting in poorer dynamics, performance and service life.

Linear motors have the advantage of direct force coupling between the motor and the moving product or drive task. If necessary, they can execute the task with several independent carriages. However, a significant disadvantage is the finite travel path, which necessitates a return movement of the movable elements of the linear motor. This significantly disrupts the continuous flow of products in a highly dynamic machine and reduces the production clock rate. The dual braking and acceleration process is also unfavorable from an energy perspective.

State of the art servo technology

Approaches for utilizing the linear motor principle so that wireless carriages or movers can travel along an active path formed by exercisable coils have been considered for some time. The movers are returned along a second track, so that they do not have to be moved against the product flow of the machine. However, previous approaches have been subject to the following technical restrictions:

- An electronic servo function energizes and controls a section with a uniform field for all movers on this section. Transitions between sections are also energized in the same way.
- In curves, the movers are moved via a rotary motor and an auxiliary mechanical unit.
- Closed position evaluation is not possible, so that in some sections only controlled movements are possible.

XTS, the new linear transport system described in this article combines the benefits of rotary motors with those of linear motors and at the same time eliminates the disadvantages and restrictions of existing approaches.

The design of the new XTS linear transport system

In the XTS linear transport system concept the individual coils of the linear motor are arranged along the travel path and the movers are equipped with permanent magnet plates. Via the dynamic control of the individual coils along the path, a dedicated three-phase current-equivalent travelling field is generated for each mover, which moves it. The previous fixed link (wiring) between converter and motor winding is broken up and replaced with software that runs on a centralized Industrial PC.

Figure 1 shows an overview of the whole system. Signals from the position sensor are linked with the IPC via fast EtherCAT communication. Servo axis software is used to calculate the position and velocity of the mover, with subsequent execution of the control and phase transformation. During the phase transformation, the sinusoidal phase currents of all coils below the mover are calculated from the rated current of the velocity controller and dynamically transferred to the current controller for the respective coils via EtherCAT. In this way each mover is controlled exactly as required for its current travelling field. Only coils with a mover above them are energized and controlled. The system enables each individual mover to be positioned exactly, with position and velocity control synchronized within 250 µs.

Motor modules

Figure 2 (p. 20) shows a straight and a curved motor module. The modules are connected in a series. The 24 V control voltage and the 48 V power supply voltage are fed in every 3 meters, along with an Ethernet cable for the EtherCAT interface. The motor design is based on a series of individual coils, each controlled by integrated power electronics configured as H-bridges. This also applies for the 180° curve, so that the ability to freely position each mover is ensured for the curve.

Since the drive power for this system is not provided by a central axis, e.g. a rotary motor and a linked chain, but is distributed to the individual movers, a lower DC link voltage of 48 V with efficient MOSFET transistors can be used. These transistors offer the benefit of lower conduction losses and short switching times, enabling highly efficient power electronics (efficiency > 99 %). The H-bridge is operated with a switching frequency of 32 kHz and an FPGA-based current controller, with an update rate of more than 300 kHz. The power electronics are regenerative and enable energy exchange between the sections in which movers brake and feed back energy, and those sections in which motor energy is provided. Through integration of the power and Position Measurement electronics in the motor modules the space required in the control cabinet is reduced significantly.

The new motor design also minimizes losses: The magnetic circuit of the motor features an iron core double air gap. This enables efficient coil utilization and reduction of friction losses in the guide mechanism. The following equation applies for the force acting on the guide mechanism:

$$F_{air\ gap} \sim 4 \cdot F_{driving}$$

It follows that around four times the motor feed force acts in the direction of the air gap. In a configuration with a single air gap, the mover guide has to absorb these forces, resulting in increased friction losses and guide wear. In a double air gap motor configuration, such as the one implemented in the XTS, the forces will ideally cancel each other out – apart from forces resulting from tolerances in the mechanical system and the permanent magnets. Overall, at a nominal speed of 4 m/s, a nominal force of 30 N and losses of about 12 W, this configuration achieves an efficiency of:

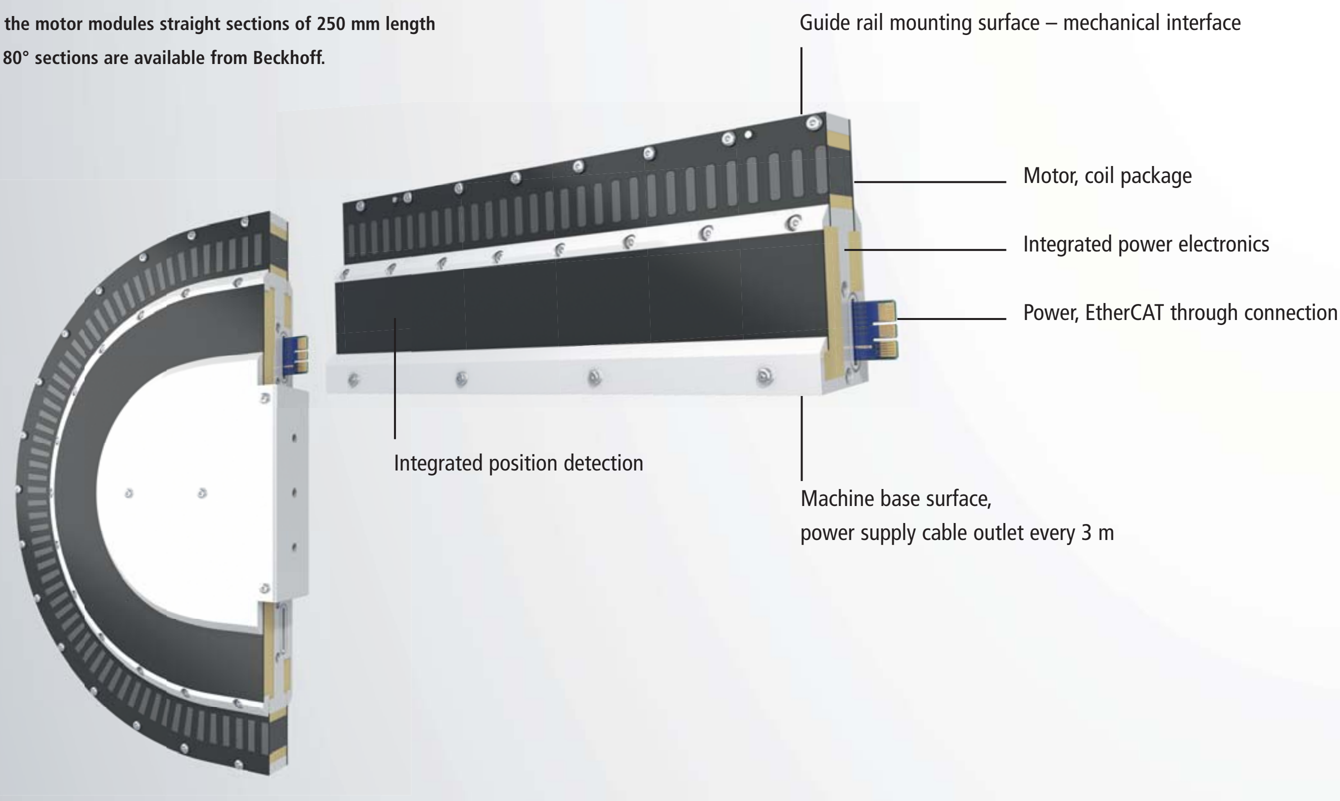
$$\eta = \frac{F_R \cdot v_R}{F_R \cdot v_R + 12W} \cdot 100\% = 90.9\%$$

Figure 3 (p. 21) shows a mechanically critical point in a circulating transport system, at the transition between straight section and curve. If this transition occurs on a circular path, the result is a sinusoidal increase in velocity in y-direction. The acceleration results in step changes, which in turn results in a theoretically infinitely high jerk, with associated stress on the guide mechanism. For this reason the 180° curve motor module, including the guide, was executed as a clothoid [1]. A clothoid (blue curve in diagram 3) is an arc with a changing radius. At the start of the transition the radius is greater and becomes continuously smaller up to the apex of the curve, before the clothoid opens up again towards the second straight section. As a result, the acceleration increases continuously, which increases the service life of the mechanical components.

The system includes an easy to operate lock so that the movers can be replaced, if necessary. To make this system as versatile as possible – using only a few standard components –the motor modules have an additional mechanical guidance interface, consisting of locating pin and screw connections. This enables different specific guides for special requirements to be developed and installed, even for the standard motor modules. Also, the installation position of the system is not specified, but is freely selectable.

[1] http://en.wikipedia.org/wiki/Clothoid (accessed on September 3, 2012)

Figure 2: For the motor modules straight sections of 250 mm length and curved 180° sections are available from Beckhoff.



Position Measurement

Position Measurement is integrated in the XTS system and enables the absolute position of each mover in the system to be calculated without active components on the mover. The inductive displacement sensor principle used here is very resilient against EMC interference. It can be imagined as an unwound resolver: An excitation winding and several internal sine- and cosine-shaped receiver loops are laid out on a level surface. An encoder flag made of light, robust and fiber-reinforced material travels in parallel with the mover, with an air gap of 0.5 mm to the fixed displacement sensor. The flag contains several metallic surfaces, resulting in an interaction with the electromagnetic fields of the excitation winding and a position-dependent voltage, which can be measured in the secondary windings. This voltage curve has a sinusoidal shape, if the encoder flag is moved with constant velocity over the fixed sensor, for example. The absolute position of all movers can be calculated centrally by the IPC, based on the voltages, the inverse tangent function and a fixed position allocation of the secondary windings or their voltages in the system. The position measurement is contactless and absolute for all movers, so that no further homing or movement for commutation finding is required.

During the transition between two modules a position calculation from both modules is possible within a short transition section. In this way the position of all movers can be calculated reliably and consistently, immediately after switching on. In automated measurement travels, any position discontinuity, which may be caused by mechanical installation tolerances, can be taught and compensated for once the system has been assembled in the machine. In contrast to an optical measuring principle, the inductive procedure is insensitive to non-conductive contamination. High precision, for example, a standstill repeatability of less than 10 µm at a position resolution of approx. 0.2 µm, can be achieved through a suitable geometry. Excitation, sampling and digitization (controlled by an FPGA), can take place within a cycle time of 10 µs.

The surfaces of individual encoder flags can be customized without reducing the precision of position measurement such that movers are identified and uniquely assigned to the servo axes in the application software.

EtherCAT connects all elements to form an innovative system

A key prerequisite for realizing the linear XTS transport system is fast and synchronous EtherCAT communication between the IPC and other hardware. A motor module with a length of 250 mm encompasses 132 bytes of process data, consisting of set and actual current values, position measurement data, as well as control and status words. A 2 m long transport system with an unwound length of 5 m, consisting of curves and straight travel and return sections generates around 2640 bytes of process data, which are transferred synchronously in two EtherCAT segments with a cycle time of 250 µs. This corresponds to a data quantity of 84 Mbaud. The system can be subdivided into different 100 Mbaud EtherCAT segments, so that the data transfer takes no longer than half the cycle

Figure 3: Comparison between a circular arc and a clothoid

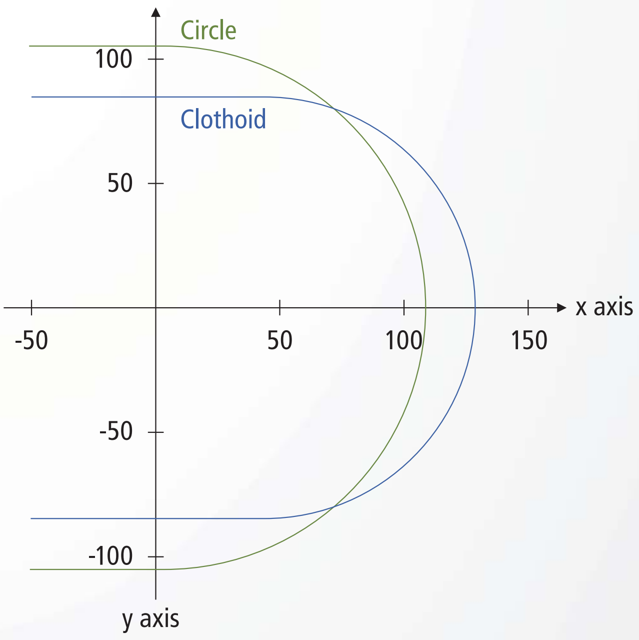
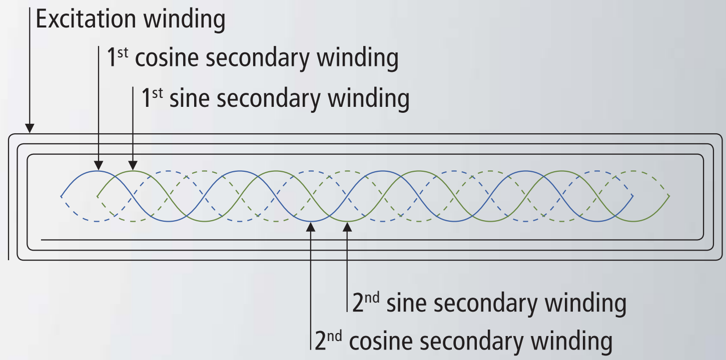


Figure 4: Position Measurement segment



time of 250 µs. If necessary, a port multiplier bundles the process data of the 100 Mbit strands to form a 1 GBaud EtherCAT connection to the IPC and also handles – via distributed clocks [2] – synchronization of the connected hardware in the segments with nanosecond precision. The following calculations of the servo algorithms of all movers take place during the remaining cycle time of at least 125 µs:

- Axis monitoring of the different signals of the position measuring system
- Position calculation
- Velocity calculation
- Fine interpolation of the set axis values
- Position control
- Velocity control
- Higher-order load filter
- Phase transformation of the set current value to the respective hardware channels

Thanks to the short delay times in the FPGA-based hardware components (Position Measurement and power electronics), the central system achieves deceleration and cycle times that are comparable to a distributed solution, but offers the crucial advantage that the hardware associated with an axis is moved and switched continuously via axis monitoring software. Additional communication – with associated delays between intelligent modules – is not required. Figure 5 shows the chronological sequence in the system.

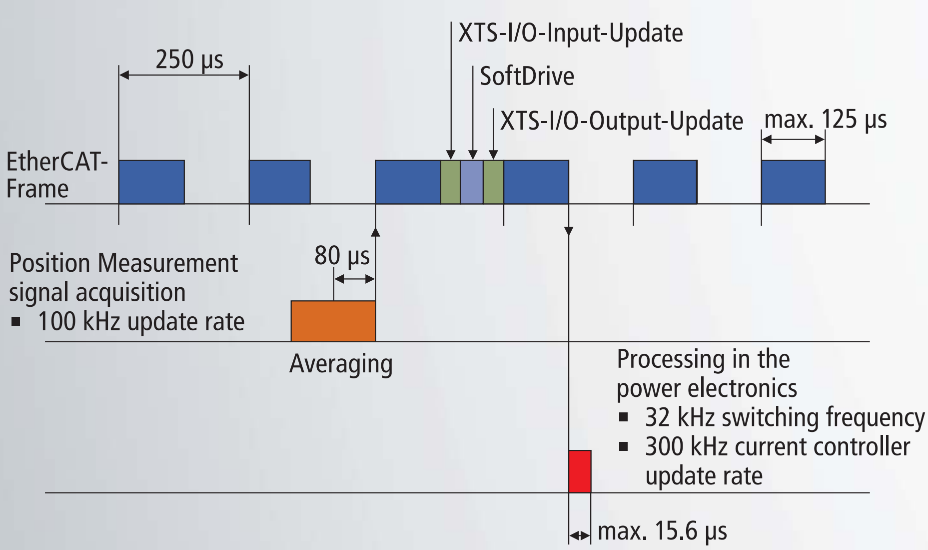
Configuration and machine programming

At first glance, this kind of system change – away from axes with fixed assignment between control, power electronics, motor and its own motion space – may appear daunting and complicated, particularly due to the large amount of data that have to be transferred and allocated in the system. For this reason, the development of XTS has been focused on simplicity and ease of operation for the user. The hardware is assembled and connected to the PC via EtherCAT. All hardware components in the system are detected and added to the configuration with a simple scan command in the TwinCAT [3] control software, which is issued with a mouse click. No other hardware settings are required. The current controller is already optimally adapted to the individual coils and movers. The individual process data in the system are allocated via an XTS I/O wizard. The wizard automatically detects the system components connected in the configuration after a further scan command, visualizes them and offers an option to move the segments in the visualization. Once the modules have been arranged, a further mouse click generates all allocations and links, so that all I/O data are

[2] http://www.ethercat.org/pdf/ethercat_e.pdf (accessed on September 3, 2012)

[3] http://infosys.beckhoff.com/ (accessed on September, 4 2012)

Figure 5: Time sequence and transfer in the system



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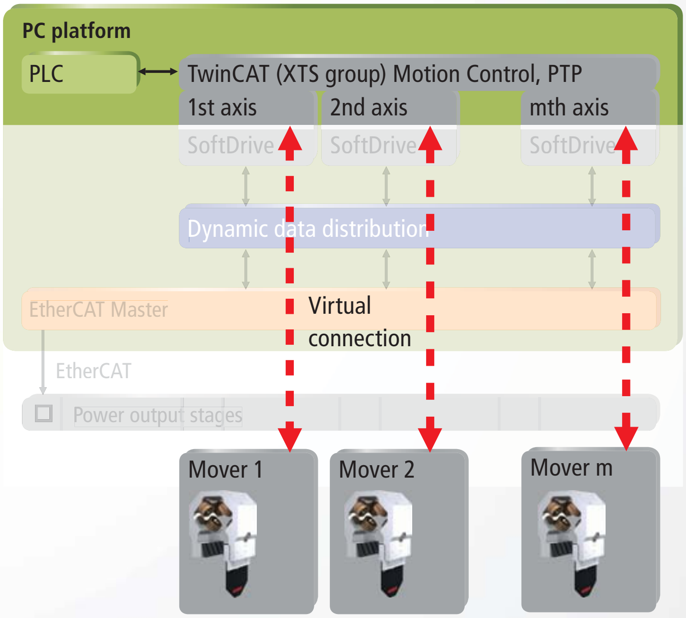
available in a servo axis interface. The corresponding number of control axes, including their links with the axis interfaces of the hardware, is then created as SoftDrive from a parameter file. Users can edit this XML or tmc file as required for setting the control values determined for their mechanical configuration. Different parameterization, e.g. to account for different masses in certain position sections, is also possible. In this way the new "substructure" of this system can be easily mapped and configured in the controller based on conventional, tried and tested TwinCAT NC axes (see Fig. 6).

A further difficulty arises due to the fact that all movers alternately move in the same path. For this reason, an XTS group was developed as a software component which monitors the interdependencies of the movers without the need for intervention by the application programmer. Collision monitoring enables automatic continuation in the event of jams. For example, a mover may have transferred a product to a downstream production step at a transfer point. It now has a waiting position allocated as a target position, just before a new product is picked up. If several movers are in a queue at this stage, the approaching mover detects this and brakes automatically – and in an optimized way, based on the set dynamic parameters – before it reaches the end of the queue. As soon as the first mover receives a new instruction and leaves the waiting position in order to synchronize with a newly arriving product, all movers in the queue continue to move, again based on the set dynamic parameters. Once the mover has reached its target position, it reports the movement as complete. Each mover can receive a new travel command at any time. Collision monitoring is permanently active along the whole travel path and in all movements. The individual travel commands are programmed from TwinCAT PLC with standard blocks according to PLCopen. The familiar motion set value generators of an advanced control system, such as robot kinematics, "flying saw," cam plate or PTP positioning can be used without restriction.

Further Information:
www.beckhoff.com/XTS

Product announcement
estimated market release:
1st quarter 2013

Figure 6: Interaction of XTS software modules



XTS – benefits for mechanical engineering

Application examples and further analyses of machines from the packaging, printing or production industries illustrate the high potential for performance gains and simplification offered by this innovative system. Particularly beneficial effects for mechanical engineering:

- Smaller and more efficient machines.
- Improved functionality.
- Simpler and faster system design.
- Simplified construction and assembly thanks to fewer components.
- Highly specialized mechanisms are no longer necessary.
- Format changes become significantly simpler.
- There are fewer and more standardized wearing parts.