XFC THE NEW CLASS OF CONTROL PERFORMANCE

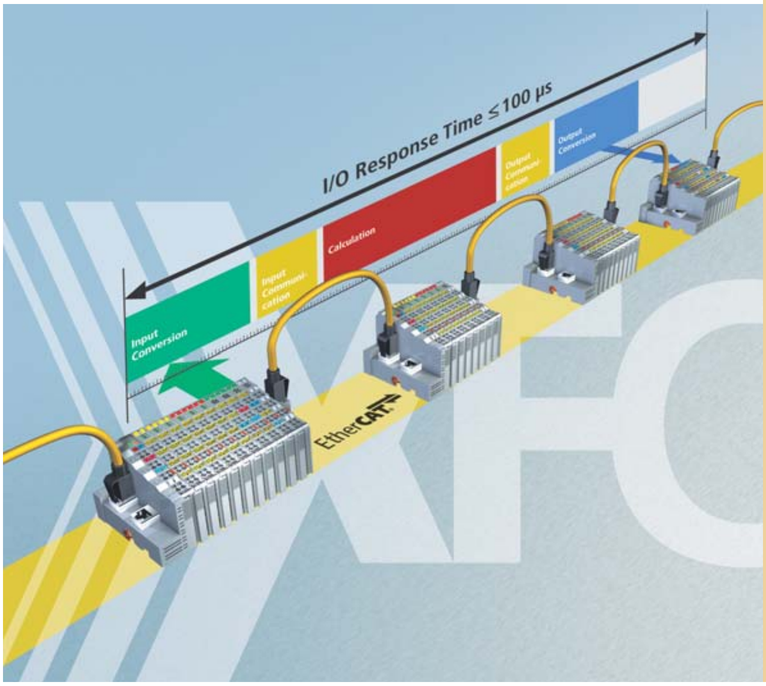
With XFC technology (eXtreme Fast Control Technology) Beckhoff presents a new, fast control solution: XFC is based on an optimized control and communication architecture comprising an advanced Industrial PC, ultra-fast I/O terminals with extended real-time characteristics, the EtherCAT high-speed Ethernet system, and the TwinCAT automation software. With XFC it is possible to realize I/O response times ≤ 100 µs. This technology opens up new process optimization options for the user that were not possible in the past due to technical limitations.

XFC – eXtreme Fast Control Technology

XFC represents a control technology that enables very fast and highly deterministic responses. It includes all hardware and software components involved in control applications: optimized input and output components that can detect signals with high accuracy or initiate tasks; EtherCAT as very fast communication network; high-performance Industrial PCs; and TwinCAT, the automation software that links all system components. Not long ago, control cycle times around 10 – 20 ms were normal. The communications interface was free-running, with corresponding inaccuracy of the determinism associated with responses to process signals.

The increased availability of high-performance Industrial PC controllers enabled a reduction in cycle times down to 1 – 2 ms, i.e. by about a factor of 10. Many special control loops could

thus be moved to the central machine controller, resulting in cost savings and greater flexibility in the application of intelligent algorithms.
XFC offers a further reduction of response times by a factor of 10, and enables cycle times of 100 µs, without having to give up central intelligence and associated high-performance algorithms. XFC also includes additional technologies that not only improve cycle times, but also temporal accuracy and resolution.
Users benefit from entirely new options for enhancing the quality of their machines and reducing response times. Measuring tasks such as preventive maintenance measures, monitoring of idle times or documentation of parts quality can simply be integrated in the machine control without additional, costly special devices.
In a practical automation solution, not everything has to be extremely fast and accurate – many tasks can still be handled with "normal" solutions. XFC technology is therefore fully compatible with existing solutions and can be used simultaneously with the same hardware and software.



The I/O response time includes all hardware processing times (IPC, EtherCAT and I/O system), ranging from physical input event to output response. With an I/O response time of ≤ 100 µs, PLC programmers have access to performance that in the past was only available in servo controllers with digital signal processors.

XFC performance data

Extreme short control cycle time

- 100 µs (min. 50 µs)
- new performance class for PLC application: control loops with 100 µs

Extreme fast I/O response time

- 85 µs (min. ~ 50 µs)
- Deterministic synchronized input and output signal conversion leads to low process timing jitter.
- Process timing jitter is independent of communication and CPU jitter.

Signal oversampling

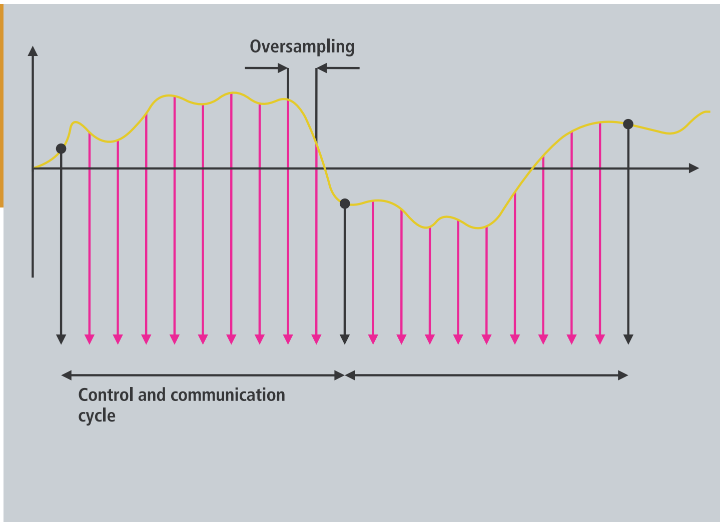
- multiple signal conversion in one control cycle
- hard time synchronization through distributed clocks
- for digital input/output signals
- for analog input/output signals
- support of analog I/O EtherCAT Terminals
  - up to 200 kHz signal conversion
  - down to 5 µs resolution
- application
  - fast signal monitoring
  - fast function generator output
  - signal sampling independent of cycle time
  - fast loop control

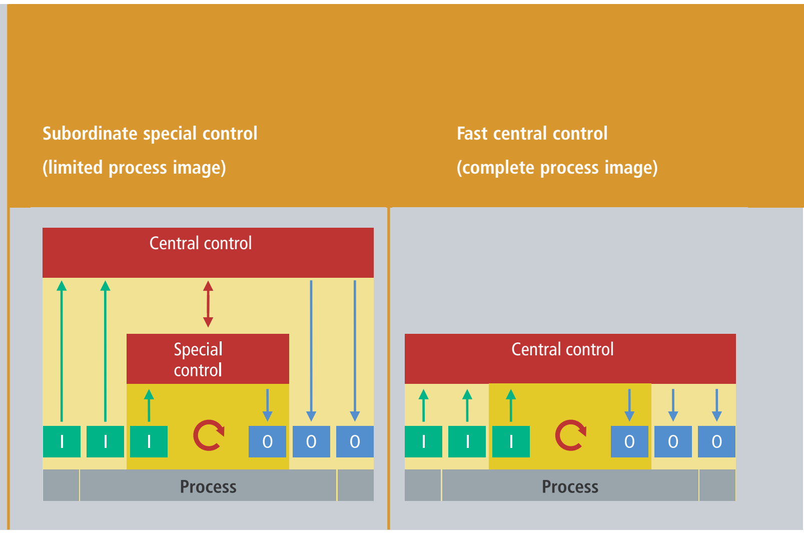
Signal time stamping (10 ns resolution)

- extreme time measurement for digital single shot events: resolution: 10 ns, accuracy: < 100 ns
- exact time measurement of rising or falling edges of distributed digital inputs
  - exact timing of distributed output signals, independent of control cycle
  - time stamping data: resolution 10 ns, accuracy < 100 ns

Distributed-Clocks

- distributed absolute system synchronization for CPU, I/O and drive devices
- resolution: 10 ns
- accuracy: < 100 ns





XFC technologies

Distributed clocks – Shifting accuracy to the I/O level

In a normal, discrete control loop, actual value acquisition occurs at a certain time (input component), the result is transferred to the control system (communication component), the response is calculated (control component), the result is communicated to the set value output module (output component) and issued to the process (controlled system).

The crucial factors for the control process are: minimum response time, deterministic actual value acquisition (i.e. exact temporal calculation must be possible), and corresponding deterministic set value output. At what point in time the communication and calculation occurs in the meantime is irrelevant, as long as the results are available in the output unit in time for the next output, i.e. temporal precision is required in the I/O components, but not in the communication or the calculation unit.

The distributed EtherCAT clocks therefore represent a basic XFC technology and are a general component of EtherCAT communication. All EtherCAT devices have their own local clocks, which are automatically and continuously synchronized with all other clocks via the EtherCAT communication. Different communication run-times are compensated, so that the maximum deviation between all clocks is generally less than 100 nanoseconds. The current time of the distributed clocks is therefore also referred to as system time, because it is always available across the whole system.

Time stamp data types

Process data is usually transferred in its respective data format (e.g. one bit for a digital value or one word for an analog value). The temporal relevance of the process record is therefore inherent in the communication cycle during which the record is transferred. However, this also means that the temporal resolution and accuracy is limited to the communication cycle.

Time stamped data types contain a time stamp in addition to their user data. This time stamp – naturally expressed in the ubiquitous system time – enables provision of temporal information with significantly higher precision for the process record. Time stamps can be used for inputs (e. g. to identify the time of an event occurred) and outputs (e.g. timing of a response).

Oversampling data types

Process data is usually transferred exactly once per communication cycle. Conversely, the temporal resolution of a process record directly depends on the communication cycle time. Higher temporal resolution is only possible through a reduction in cycle time – with associated practical limits.

Oversampling data types enable multiple sampling of a process record within a communication cycle and subsequent (inputs) or prior (outputs) transfer of all data contained in an array. The oversampling factor describes the number of samples within a communication cycle and is therefore a multiple of one. Sampling rates of 200 kHz can easily be achieved, even with moderate communication cycle times.

Triggering of the sampling within the I/O components is controlled by the local clock (or the global system time), which enables associated temporal relationships between distributed signals across the whole network.

Very short cycle times – Optimized I/O communication

Very fast physical responses require suitably short control cycle times in the associated control system. A response can only take place once the control system has detected and processed an event.

The traditional approach for achieving cycle times in the 100 µs range relies on special separate controllers with their own, directly controlled I/Os. This approach has clear disadvantages, because the separate controller has only very limited information about the overall system and therefore cannot make higher-level decisions. Reparameterization options (e.g. for new workpieces) are also limited. Another significant disadvantage is the fixed I/O configuration, which generally cannot be expanded.

I/O component – EtherCAT Terminals with XFC technology

Communication component – EtherCAT fully utilized

Control component – High-performance Industrial PCs

Software component – TwinCAT

XFC components

Implementation of the XFC technologies described above requires full support for all hardware and software components involved in the control system, including fast, deterministic communication and I/O and control hardware. A significant part of XFC are the software components responsible for fast processing of the control algorithms and optimized configuration of the overall system.

Beckhoff offers a special XFC product range based primarily on four categories: EtherCAT as fieldbus, EtherCAT Terminals as I/O system, IPCs as hardware platform, and TwinCAT as higher-level software. All components are based on open standards, which means that any engineer or programmer can develop very fast control solutions with high performance based on standard components (i.e. without special hardware).

I/O component – EtherCAT Terminals with XFC technology

Standard EtherCAT Terminals already offer full support for XFC technology. Synchronization of the I/O conversion with the communication or – more precisely – with the distributed clocks is already standard in EtherCAT and is therefore supported by all terminals. Newly developed XFC terminals offer additional special features that make them particularly suitable for fast or high-precision applications:

- digital EtherCAT Terminals with very short T_{ON}/T_{OFF} times, or analog terminals with particularly short conversion times
- EtherCAT Terminals with time stamp latching at the exact system time at which digital or analog events occur. Output of digital or analog values can occur at exactly predefined times.
- Terminals with oversampling enable actual value acquisition or set value output with significantly higher resolution than the communication cycle time.

XFC EtherCAT Terminals

The EtherCAT I/O system provides a wide range with different signal terminals. Standard EtherCAT Terminals already offer full support for XFC technology. Synchronization of the I/O conversion with the communication or – more precisely – with the distributed clocks is already standard in EtherCAT and is therefore supported by all terminals. Further developed XFC terminals offer additional special features that make them particularly suitable for fast or high-precision applications.

Communication component – EtherCAT fully utilized

With high communication speed and usable data rates EtherCAT offers the basic prerequisites for XFC. However, speed is not everything. The option of using the bus to exchange several independent process images arranged according to the control application enables parallel application of XFC and standard control technology. The central control system is relieved of time-consuming copying and mapping tasks and can fully utilize the available computing power for the control algorithms.

The distributed EtherCAT clocks that form the temporal backbone of the XFC technologies are available in all communication devices without significant additional effort. The crucial point of XFC is the option of integrating all I/O components directly in the EtherCAT communication, so that no subordinate communication systems (sub bus) are required. In many XFC terminals the AD or DA converter is connected directly to the EtherCAT chip, so that delays are avoided.

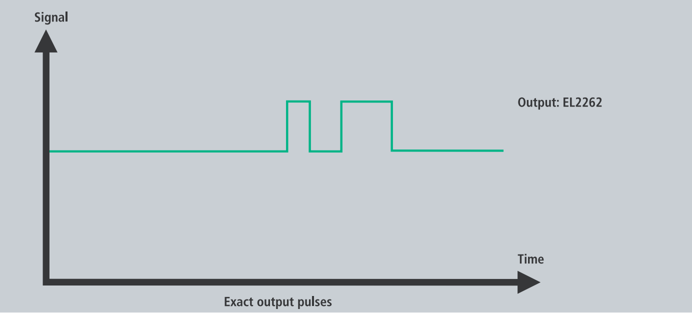
Control component – High-performance Industrial PCs

Central control technology can be particularly advantageous if it can run faster and more powerful control algorithms than would be the case with many distributed small controllers. Modern Industrial PCs offer significantly more processing power and memory at lower cost than the sum of a large number of small controllers.

The latest general PC technology innovations can also be used to good effect for control technology. Fast dual core processors are ideal for running the operator interface of the machine in parallel with the control tasks. Large caches available with modern CPUs are ideal for XFC technology, because fast algorithms run in the cache and can therefore be processed even faster.

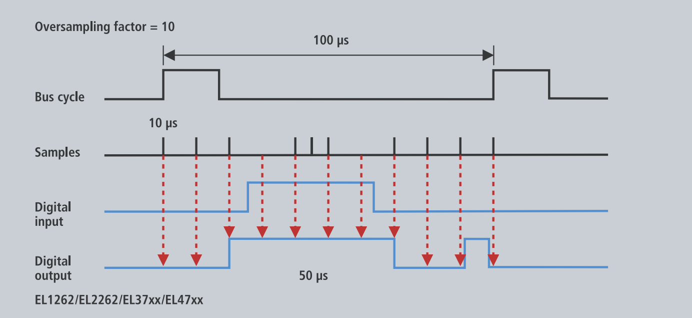
An important factor for short XFC cycle times is the fact that the CPU is not burdened with complex process data copying tasks needed by traditional fieldbuses with their DPRAM-based central boards. EtherCAT process data communication can be handled entirely by the integrated Ethernet controller (NIC with bus master DMA).

Oversampling terminals



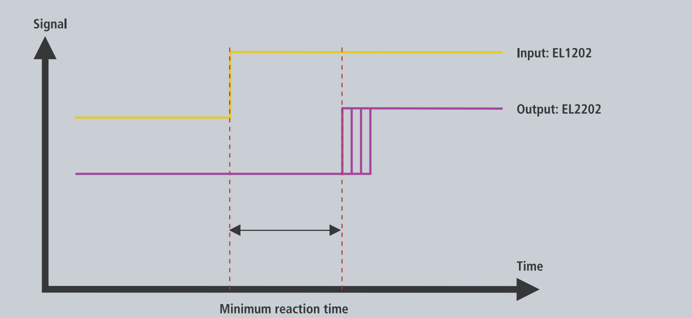
With the digital EL2262 oversampling output terminal, outputs can be switched on and off within a 10 µs time frame, which is ideal for high-precision dosing applications, for example.

Oversampling terminals



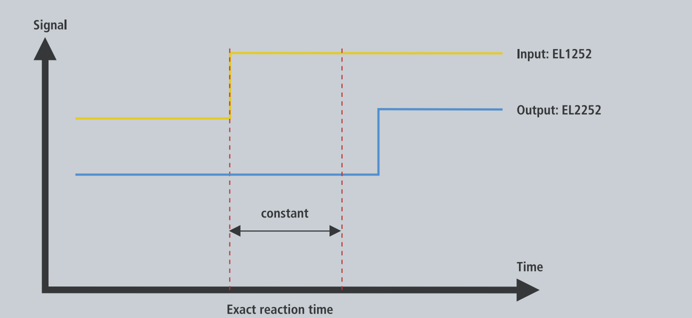
The digital EL1262 oversampling input terminal offers an input signal sampling rate that is better than the bus cycle time by a factor of 10 (configurable), enabling even short signals to be recorded, measured or counted exactly.

Fast I/O terminals 1 µs T_{ON}/T_{OFF}



With the EL1202 and EL2202 XFC terminals, delays in the terminal hardware are reduced down to < 1 µs and therefore become negligible. Input and output data are forwarded with maximum speed.

Time stamp terminals



Synchronized responses can be realized with time stamp input and output terminals; in the past, precision of < 1 µs was impossible with bus systems. The new XFC technology replaces hardware wiring.

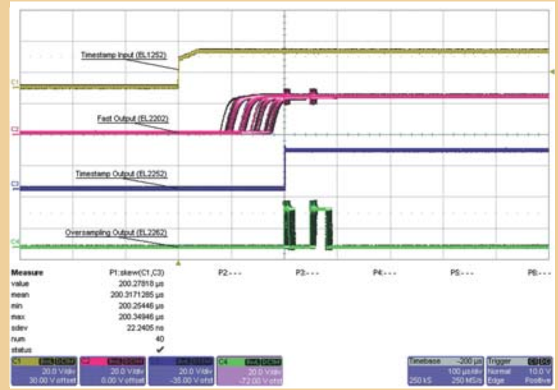
Software component – TwinCAT automation suite

TwinCAT as high-performance automation suite fully supports the XFC technologies while retaining all the familiar features. The real-time implementation of TwinCAT supports different tasks with different cycle times. Modern Industrial PCs can achieve cycle times of 100 µs or less without problem. Several (different) fieldbuses can be mixed. The associated allocations and communication cycles are optimized according to the fieldbus capabilities. The EtherCAT implementation in TwinCAT makes full use of the communication system and enables application of several independent time levels. It uses distributed clocks. Different time levels enable coexistence of XFC and normal control tasks in the same system, without the XFC requirements becoming a "bottleneck".

A new option specially designed for XFC enables inputs to be read during independent communication calls and outputs to be sent directly after the calculation. Due to the speed offered by EtherCAT the inputs are read "just" before the start of the control tasks, followed by immediate distribution of the outputs. The resulting response times are faster than the fieldbus cycle time in some cases.

Special TwinCAT extensions facilitate handling of the new XFC data types (time stamp and oversampling). PLC blocks enable simple analysis and calculation of the time stamps. The TwinCAT scope can display the data picked up via oversampling according to the allocated oversampling factor and enables precise data analyses.

→ www.beckhoff.com/XFC



XFC verified!

The oscilloscope recording shows application results for different digital XFC terminals. The control and communication cycle time is 100 µs. Inputs and outputs are exchanged in separate EtherCAT telegrams in order to minimize the response time. (The horizontal scaling of the oscilloscope recording is 100 µs.)

An external, unsynchronized input signal is acquired via a digital input terminal with time stamp (EL1252, yellow curve). The oscilloscope is set to trigger based on this input signal. The recording is therefore synchronous with the external event, but asynchronous with the control cycle. Several recordings are superimposed.

A fast, digital output terminal (EL2202, red curve) is instructed by the control system to respond to the recorded input signal as quickly as possible. In the fastest case a control response is available at the output after approx. 85 µs. Since the input signal is unsynchronized, in the worst case an edge can be recorded with a delay of one cycle time, i.e. if the event occurs right after the cycle and is therefore not transferred until the next cycle. As a result, the output signal appears to jitter within a range of one cycle time, i.e. between 85 µs and 185 µs.

Since the input event is recorded with time stamp, the control system can issue an output response with a constant time offset, independent of the communication cycle. To this end, the PLC for a digital output terminal with time stamp (EL2252, blue curve) is associated with an output response that is offset by 200 µs. Despite the unsynchronized control cycle, the response can thus be exactly deterministic. In addition, the oscilloscope is set to measure and analyze the temporal difference between the input signal and the response of the EL2252 over several cycles (in this example 40 cycles). The result is a minimum value of 200.254 µs and a maximum value of 200.349 µs, i.e. the difference between minimum and maximum value is less than 100 ns. The fact that 200 µs is not adhered to exactly is due to the (small, but nevertheless present) TON and TOFF times of the terminals, although these are constant and can therefore be accounted for. The green curve shows a digital output terminal with oversampling (EL2262). With an oversampling factor set to 10 and with a cycle time of 100 µs, output states can be issued every 10 µs. To illustrate this, in response to the input signal the PLC issued two pulses via the terminal, i.e. a short pulse followed by a slightly longer one. Here, too, a supposed jitter can be seen, although it is significantly lower (10 µs instead of 100 µs) – again caused by the unsynchronized input signal. When it comes to the response, the PLC can intervene much more precisely, according to the oversampling factor.