New Automation Technology

XFC | eXtreme Fast Control Technology

Mr. Patrick Gielis
Beckhoff Automation
The new class of Control Performance

I/O Response Time < 100 μs
XFC - eXtreme Fast Control Technology

Control cycle = 100 µs

XFC - eXtreme Fast Control Technology

I/O Response Time 85 µs*

* Best case, because the Input signal comes asynchronous to the internal cycle.
1. XFC components
2. XFC technologies
XFC components
XFC components

EtherCAT | eXtreme fast control communication technology

Optimised control and communication architecture for highest performance

- 1,000 distributed digital I/Os in 30 μs
- EtherCAT down to the individual I/O terminals, no sub bus required
- Optimised use of standard Ethernet controllers, e.g. Intel® PC chipset architecture
- Advanced real-time feature based on distributed clocks: synchronisation, time stamping, oversampling
XFC components

EtherCAT | eXtreme fast due to unique Functional Principle

- Efficient: Typically only one Ethernet Frame per Cycle
- Ideal Bandwidth Utilization for maximum Performance
Optimised control and communication architecture for highest performance

- full range I/O line for all signal types
- high-speed digital and analog I/Os
- Time stamping and oversampling features allow extreme high timing resolution (down to 10 ns).
XFC components

IPC | eXtreme fast control CPU

Optimised control and communication architecture for highest performance

- Industrial PC based on high performance real-time motherboards
- compact form factors optimised for control applications
XFC components

TwinCAT | eXtreme fast real-time control software

Optimised control and communication architecture for highest performance

- real-time under Microsoft Windows down to 50 μs cycle time
- standard IEC 61131-3 programming in XFC real-time tasks
- Standard features of Windows and TwinCAT are XFC-compliant.
1. XFC components
2. XFC technologies
XFC technologies

- Time stamp
- Distributed clocks
- Oversampling
- Fast I/O
XFC technologies

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

- Fast I/O with short conversion time

![Diagram showing reaction times](image)

- Input: EL1202
- Output: EL2202
- Minimum reaction time: 85 µs
- Time delay: 185 µs
XFC technologies

Time stamp terminals

- Exact time resolution with DC
- Synchronised responses

![Signal diagram showing exact reaction time between input EL1252 and output EL2252.](image)
XFC technologies

Oversampling terminals

- Fast signal sampling with oversampling
- Output of short pulses

Diagram showing:
- Bus cycle
- Samples
- Digital Input (EL1262)
- Digital Output (EL2262)
- Analog Input (EL37xx)
- Analog Output (EL47xx)

Key points:
- 100 μs
- 10 μs
**Distributed clocks**

- Shifting accuracy to the I/O level
- Distributed absolute system synchronization
  - CPU
  - I/O
  - drive devices
- Resolution: 10 ns
- Accuracy: < 100 ns
Distributed clocks: Accuracy

- Long Term Scope View of two separated devices
- 300 Nodes in between, 120m Cable Length

- Jitter: ~ +/-20 ns
- Simultaneousness: ~15 ns

Interrupt Node 1
Interrupt Node 300
XFC technologies

XFC verified!

File  Vertical  Timebase  Trigger  Display  Cursors  Measure  Math  Analysis  Utilities  Help

Measure
value
mean
min
max
sdev
num
status

C1
20.0 V/div
30.00 V offset

C2
20.0 V/div
0.00 V offset

C3
20.0 V/div
-35.00 V offset

C4
20.0 V/div
72.00 V offset

LeCroy

Timestamp Input (EL1262)

Fast Output (EL2202)

Timestamp Output (EL2262)

Oversampling Output (EL2262)

11/24/2006 2:34:39 PM

Timebase -200 µs
100 µs/div
250 kS

Trigger C1 DC
Normal 10.0 V
Edge Positive

New Automation Technology
XFC performance data

- **System performance**
  - cycle time: 100 µs (min. 50 µs)
  - I/O response time: 85 µs ... 185 µs

- **Distributed clocks**
  - resolution: 10 ns
  - accuracy: < 100 ns

- **Signal oversampling**
  - sample rate: 1 MHz
  - time resolution: 1 µs
  - accuracy: < 100 ns

- **Time stamping resolution**
  - resolution: 10 ns
  - accuracy: < 100 ns
XFC in practice

Printer position control

Digital cam

Glue application

Closed-loop control

Linear path control

Part tracking

BECKHOFF New Automation Technology
Timing – Synchronous with telegram

Position Signal = x

Sample Point

Velocity = x'

EtherCAT

Gradient = velocity

~4 µs Master Jitter

100 µs Cycle Time

108 µs

94 µs

101 µs

104 µs

Error due to sample deviation

Sampling error because of jitter

equidistant

Not in sync with IN

D/A

A/D

Calc.

Out

In

Calc.

Outlet

Calc.

Out

Calc.

Out

Calc.

Out

Calc.

Out

Calc.

Out

Calc.

Out

Calc.

Out
Timing – Synchronous with telegram

Problems of this approach:

- I/O signal timing comes from Master
- Modern (multicore) CPU systems will always jitter in the range of 1..5 µs

→ Measuring error due to sample deviation

Conclusion

- IO-Signal timing must come from Distributed Clock System
  - Fully synchronized
  - Independent from System architecture
  - System wide synchronicity <100 ns
Timing – Synchronous with Distributed Clocks

Position Signal = x

Sample Point

Velocity = x'

EtherCAT

100 µs Cycle Time

DC Sync

100 µs equidistant

No sampling Error

Sync In  Sync Out


In  In  In  In  In

D/A  D/A  D/A  D/A  D/A

A/D  A/D  A/D  A/D  A/D

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Advantages of this approach:

- High precise synchronous signal-timing by DC
- No errors due to sample deviation
- All filter algorithms and factors in control loops run without errors

→ Equidistant signal latching with Distributed Clocks improves quality of measuring
Timing – Synchronous with DC, Oversampling

Position Signal = x

Sample Point

Velocity = x'

EtherCAT

Sync out

Telegram

Sync in

DC Sync

100 µs Cycle Time

100 µs

10 µs

100 µs

100 µs

100 µs

In /Out
Calc.
In /Out
Calc.
In /Out
Calc.
In /Out
Calc.
In /Out
Calc.
XFC Application: Standard Sequential Machine Control
Simple Pneumatic Cylinder, going back and forth

How does the communication and control system influence its performance?
XFC/Profibus: Standard Machine Test Application

EtherCAT

PROFIBUS

EK1100  EL2202  EL1252

BK3120  KL2134  KL1114

Out 1  Out 2  In 1  In 2

Y₁  Y₂

S₁  S₂

Pneumatic Cylinder

X₁  X₂
XFC/Profibus: Standard Machine Test Application

- Identical PLC program in all 4 Tasks
- Identical Mechanics + Sensors
## Efficiency Gain Demonstrator: Results

<table>
<thead>
<tr>
<th>PROFIBUS Cycle time (ms)</th>
<th>EtherCAT Cycle time (ms)</th>
<th>Efficiency Increase (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>1</td>
<td>11,7 %</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>5,7 %</td>
</tr>
<tr>
<td>2</td>
<td>0,1</td>
<td>1,17 %</td>
</tr>
</tbody>
</table>

- EtherCAT and XFC: Increase the Efficiency of each „Standard“ Machine
- Just by using an EtherCAT powered Control System:
  - No faster sensors / actuators needed
Machine Cycle Time Reduction in %
(= Increase in machine efficiency)

\[ T_{d\%} = \frac{N_{r2} \cdot T_{c2} - N_{r1} \cdot T_{c1}}{T_t} \]

\( T_{d\%} \) = Machine Cycle Time Reduction (%)

\( N_{r1} \) = Average Number of Control Cycles for I/O response of Control 1
\( N_{r2} \) = Average Number of Control Cycles for I/O response of Control 2
\( T_{c1} \) = Control Cycle Time 1 (shorter cycle time)
\( T_{c2} \) = Control Cycle Time 2 (longer cycle time)
\( T_t \) = Time between 2 control transitions
Cycle Time Reduction = Efficiency Increase

E.g.: 4 Trans/sec, from 2 ms Profibus to 0,1 ms EtherCAT:

2.4% Efficiency Gain

with: $N_{r1} = 3$, $N_{r2} = 1.5$, $T_{c2} = 0.1$ ms
Husky HyPAC Injection Molding Machine

Initially presented at Siemens Industrial Ethernet Symposium, Chicago, October 2006
(please find presentation at http://www.ethercat.org/pdf/english/Speed_without_Haste_Chris_Choi_IIES_2006.pdf)
Husky (Canada): HyPAC Injection Molding Machine
XFC Example: Raw Material Reduction @ Plastics Machine

Transition Pressure Control Plastics Machine

Source: Husky Injection Molding Systems Ltd.
XFC Example: Raw Material Reduction @ Plastics Machine

Due to EtherCAT >100t Material Saving / Year
And Energy Saving accordingly…
I/O Oversampling: Improving Timing, Resolution and Reaction Signal Analysis with up to 500 kSamples
Analog Input with Oversampling

Oversampling:
- Up to 500kSamples/sec
- Oversampling Factor from 2 - 100
Oversampling: Usage for Critical Threshold Detection

Simplified pressure curve during filling phase of injection molding machines
Oversampling for Critical Threshold Detection and Reaction

Exact threshold detection with 10us timing resolution!
Intelligent signal algorithms (filtering, …) freely programmable on the PC!
Very short and exact reaction with 200us delay and 100ns jitter
XFC: Summary

- XFC provides a new class of control performance
- It de-couples the process from the control cycle time
- Required Ingredients:
  - EtherCAT
  - XFC I/O Terminals from Beckhoff
  - PC based Control Performance
  - TwinCAT, the Automation Software Suite
- XFC accelerates your Application!