

Motion control system options utilizing EtherCAT® Technology

Karl A. Meier

Overview

This document describes the evolution of motion and control system architectures and what benefits are realized today when using EtherCAT[®], whether for a large number of axes or simple systems using just a few. OEMs have many choices available and naturally gravitate to a given architecture to speed development and reduce costs. Machine systems, and mainly motion control, are normalized to meet the requirements of the application.

Highlighted too is not only the rise and acceptance for network connected motion control applications but also why they are here to stay. In fact, the continued demand for servo solutions like those provided by EtherCAT-based systems will grow faster than most others and come at lowered system costs to implement.

Servo drive technology continually pushes power densities to decrease the size envelope. The realization of these achievements brings added benefits for cost reductions not only of the hardware but also the need for separate housing enclosures and complications of the wiring involved. Better solutions at lower costs, solutions that everyone can agree on.

Differentiation of Motion Control Solution Types

Motion control solutions come in many different varieties and are usually dependent on these major factors: 1.) the type of motion required to sufficiently satisfy the application, 2.) the machine / equipment in which the application is operating and 3.) the expected interoperability the application has with other equipment or personnel, both locally and globally. Of course, there are many additional factors particular to an application needed to be taken into account and prioritized based on all of the specific needs where motion control plays a major role.

Traditionally, servo-based motion control systems have been categorized into two types: centralized or distributed. Initially, there was only one method for motion control - centralized. Although still prevalent today, the shift toward distributed control is undeniable and directly attributed to the emergence of digital networks from advantages these bring to future designs.

In a centralized control scheme, the controller is responsible for motion and machine control. Motion profiling and planning is covered by calculating trajectories on all axes by generating commands for each drive involved, historically +/-10V. All I/O required and event handling within the system coexists with the motion. Motion Control solutions of this type have been contained within a dedicated motion control card, usually indicating a non-standard specific programming language. The drives would normally operate in Current Mode to provide the appropriate motor torque or force based on application orientation. However, since the servo drives current loops are typically 'closed' within 50 μ sec or faster, the controller must send trajectory commands at least once for every two times of current loop closure, or 100 μ sec,

to maintain smooth performance. Depending on the number of axes involved, updating the servo loops places an ever-increasing burden on the processing power of the DSP. Among just some of the tasks at hand, the controller takes into account all axes velocities and/or positions, all I/O operations, makes updated profile movements by comparing the trajectories to the feedback, all while running complicated programs that dictate the motion specified.

It can easily be shown that many applications quickly become unmanageable simply due to scalability. The controllers' DSP needs to take into account any maximum case scenario and is selected and priced as such. With limitations such as this, there must be better solutions.

The next evolution for motion was distributed control. In these schemes, controllers simply focus on motion profiling and planning as well as associated I/O. Generation of the commands is somewhat more simplified since it would be over a network where existing open standards are readily available, such as CANopen with comprehensive command structures describing all motion types. Additionally, motion commands are less complicated as the drives close the velocity and/or position loops internally. With DSP's incorporated into drive designs, closing the servo loops is already achieved.

The benefit is reduced network traffic as trajectory calculations are made for each respective axis by the drives. Many operating modes are available giving increased flexibility at both controller and drive levels enabling even more controller performance and freeing processing power for other operations. The main control now is a communications master, such as CANopen controller, performing motion and I/O functions with a main program taking into account the machine's

functionality. However, some limitations arise here too as communications speed may be the limiter of some specific motion and machine requirements. Even though the system can be made to be deterministic, the ability to keep up with demand can also be challenging, even for simple machine tools.

in each slave node addressed to it while being forwarded to the next device. Similarly, input data is inserted while the frame passes through and therefore only delayed by a few nanoseconds. Performance is not only maintained but greatly improved.

Why not a hybrid solution where the best of both centralized and distributed control solutions brings increased scalability while still providing even greater flexibility?

Enter the Age of Motion Control via EtherCAT

The latest evolution in motion and machine control is EtherCAT, taking into account centralizing machine control but leaving motion control distributed. This brings together the best of both worlds. In fact, CANopen over EtherCAT is easily implemented. Since the EtherCAT interface is based on Ethernet, the worldwide hardware standard, it is provided at lowest cost possible. Even though the network has a master, configurability is much easier, including thousands of I/O points if needed, and completely scalable from one axis to hundreds of axes. This is the best of both worlds indeed.

Enabling Performance with EtherCAT

EtherCAT is an Ethernet-based solution that processes Ethernet frames 'on the fly' (Figure 1). This overcomes Ethernet's system limitations as the data packet is no longer delayed at every node. Packets are processed

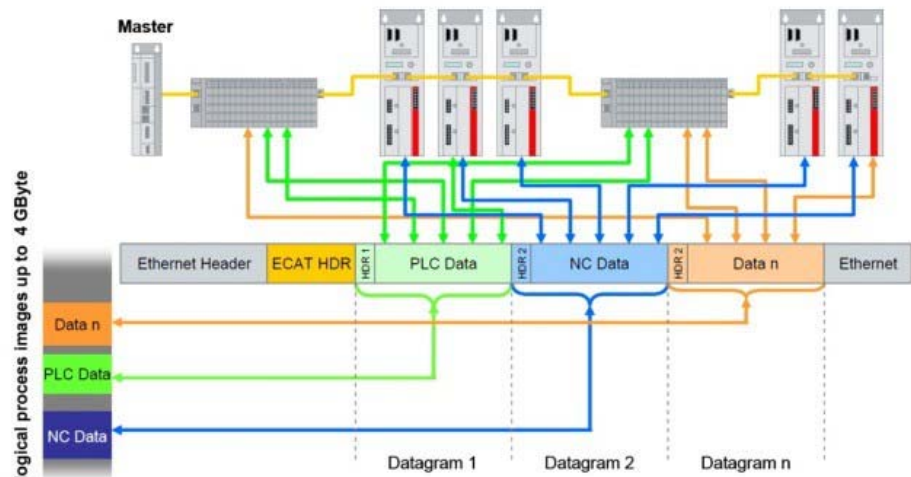


Figure 1 - Example EtherCAT data frame of up to 4 GB with multiple datagrams.

Note: slave node order is not important and data consists of several parts

Data transfer to the master controller is via direct memory access (DMA) so no processor capacity is consumed for network access. EtherCAT protocol allows for transport of control data directly within the Ethernet frame without redefining the standard. The frame may consist of several parts, each serving a particular memory area of the logical process that can be up to 4 gigabytes in size. Most importantly, node addressing can be in any order because the data sequence is independent of the physical order. EtherCAT network configurations support almost any topology while being completely flexible - line, tree, star or variations of each (forming stubs or branches) are not a problem (Figure 2). In fact, provision for cable lengths of up to 100 m between devices is possible and

network size is almost unlimited (up to 65535 devices can be connected).

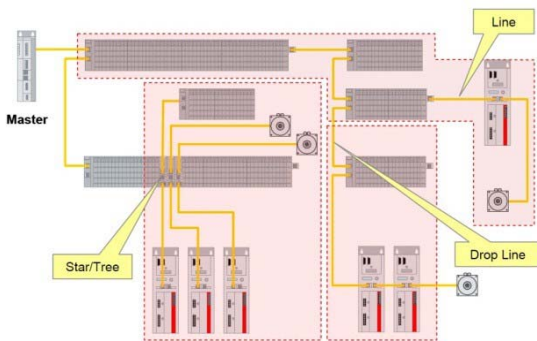


Figure 2 - EtherCAT's support of multiple connection topologies

Additionally, broadcast, multicast and direct communication between servo drives (slaves) is also possible. Direct transfer within the Ethernet frame is used in cases where EtherCAT components are operated in the same subnet as the master controller and where the control software has direct access to the Ethernet controller. Many system variations can exist and response times of the EtherCAT network itself are hardly restricted at all.

EtherCAT data exchange is completely hardware based on a 'master timekeeper', which is selectable as any of the nodes' clock on the network and not necessarily the controller. All others would then be 'local' clocks (slave nodes), within the system. Each clock can simply and accurately determine the other clocks run-time offset because the communication utilizes a full-duplex Ethernet physical ring structure and the distributed clocks are adjusted based on the established value. This foundation provides a very precise network-wide time-base with jitter of significantly less than 1 µsec.

Another factor that propels EtherCAT ahead of other networks as the one of choice is 'hot

connect' (Figure 3). This function enables parts of the network to be linked, decoupled or reconfigured as it operates. There may be instances where a change in I/O configuration during operation is required, i.e. sensor-equipped tooled systems or transfer devices with intelligent, flexible work piece carriers. The protocol structure of EtherCAT accounts for changing configurations.

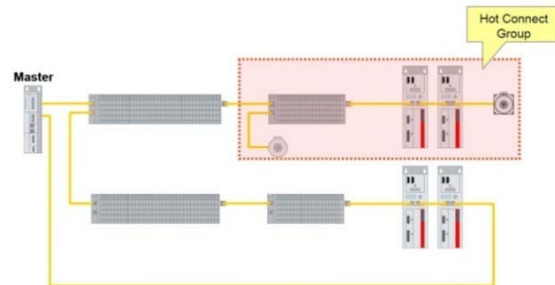


Figure 3 - "Hot swapping / connecting" of nodes or node groups completely possible

Accurate synchronization is particularly important in cases where widely distributed processes require simultaneous action. Applications where several servo axes carry out coordinated movements simultaneously, i.e. continuous web printing or processing web lines, synchronization is a minimal requirement for expected performance. In contrast, in a 'fully synchronous only' system, quality suffers immediately in the event of a communication fault whereas distributed aligned clocks have a high degree of tolerance from potential fault-related delays within the communications network system.

EtherCAT's expanded data types (timestamp data type, oversampling data type) provide local time to be linked to the measured value with a resolution of up to 10 nsec. For example, control systems frequently calculate velocities from sequentially measured positions. With very short sample times, even a small amount of jitter can lead to large step changes in velocity. The accuracy of velocity calculation is now no longer dependent

on network communications jitter and orders of magnitude better. Again, almost all servo applications would exceed the established requirements with this type of performance.

Given all of this, EtherCAT achieves network performance not realized by other networks. Properly configured, complete protocol processing takes place within hardware and is thus independent of the run-time of protocol stacks, CPU performance or software implementation. The update time for 1,000 distributed I/O points is only 30 μ s. Up to 1,486 bytes of process data can be exchanged with a single Ethernet frame - this is equivalent to almost 12,000 digital inputs and outputs. The transfer of this data quantity only takes 300 μ s. If that wasn't fast enough, now comes the amazing part - communication with 100 servo axes only takes 100 μ s, faster than most centralized control systems for a single axis! During this time, all servos can be provided with set values and control data, report their actual position and internal drive status. The distributed clock technique enables the axes to be synchronized with a deviation of less than 1 μ sec.

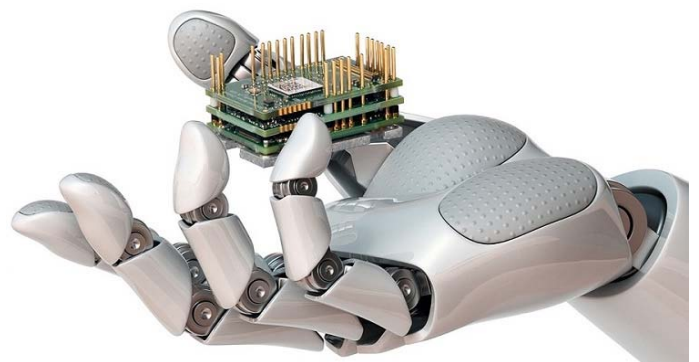
The EtherCAT Technology Group (ETG) organization ensures that each interested party can implement and use the network. EtherCAT is an open, international standard where communications technology is readily available, matches the superior computing capacity of PC's today, can be deployed in system configurations/topologies in a variety of methods, provides for more than sufficient number of I/O points and can be completely compliant to many servo axes necessary to provide machine and motion control with ease. I/O's are processed faster than what is possible with most centralized local I/O interfaces and servo motion control

methodology is accurate and seamless, regardless of operating mode or profiles selected.

ADVANCED Motion Controls® Delivers New Solutions for Motion Control Systems with EtherCAT



As amazing as EtherCAT is, *ADVANCED* Motion Controls has taken further steps to achieve yet new levels of capabilities. By leveraging the latest advancements in power electronics and ultra-small SMD components our recently introduced FlexPro™ servo drives can deliver 50A peak and 25A continuous in a servo drive within the footprint of 1/3 the size of a standard business card (Figure 4)!



**Figure 4 - New, exclusive FlexPro™ technology from
ADVANCED Motion Controls**

The servo drives themselves are an embedded, plug-in module form factor family known as 'PCB Mount' Drives (Figures 5 & 6) for highest installed density and available over a wide power range. This unique form factor significantly lowers system costs and covers a majority of possible OEM applications.

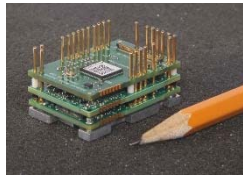


Figure 5
FlexPro, EtherCAT
plug-in servo drive



Figure 6 DZE, EtherCAT
plug-in servo drive

Typically, EtherCAT systems have been on larger machines such as printing presses, packaging lines and large in-place robotic systems that can accommodate sizeable control systems enclosures. With *ADVANCED* Motion Controls' technologies (Figures 7 & 8 respectively), application solutions can now be available for smaller machinery and desktop equipment like water jet cutters, routers, lab automation equipment, biotech processing equipment, smaller mobile robots etc. where panel space is a premium or not at all available with the added benefit of a major wiring reduction.



Figure 7 – Four plug-in servo drives mounted to create
a 4-axis servo drive module



Figure 8 – FD060-25-EM development board with one
FlexPro plug-in servo drive

Today, extremely high performance of EtherCAT technology enables control concepts that could not be realized with most other fieldbus systems. EtherCAT-based systems can now not only deal with velocity and position profiling/control, but also with current loop control of servo drives in a distributed nature with quantities not previously possible. The tremendous network bandwidth enables status information to be transferred with each data item. Traffic across the bus system no longer is the bottleneck of the overall control concept.

With the centralized/distributed hybrid control, low-cost, fast implementation approach by *ADVANCED* Motion Controls, EtherCAT is now a solution that also covers new market segments. Not only this, but scalability and future expansion is built-in and can be made with complete ease.

About the author – Karl A. Meier has worked in the controls industry for over 30 years and has a BS in Electrical Engineering with an MS in Computer Science. Contributions for the article also come from the EtherCAT Technology Group (ETG). Visit www.a-m-c.com and www.ethercat.org for more information. Updated by Rene Ymzon

Version History:
Updated June 2020 to reflect current products
Originally Published June 2013