High Precision Drive Synchronisation with CANopen

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For many users and suppliers CAN is the first choice for drive communication – due to its reliability, efficiency and flexibility paired with low hardware costs. CANopen provides a synchronisation mechanism, which uses the cyclic transmission of a SNYC message. However, the medium access method of CAN cannot guarantee absolute deterministic data delivery. Therefore specifically designed drive fieldbus systems had to be used for applications which require high precision drive synchronisation such as printing machines, machine tools, packaging machines or robots.
The deterministic behaviour of the CANopen SYNC telegram is limited to one frame length and may jitter with 130µs at 1 Mbit/s. This paper introduces a synchronisation method that uses the standard CANopen SYNC but achieves distributed simultaneous drive control which jitters less than 2 µs. A phase locked loop mechanism that tolerates the jitter of a single SYNC frame is superimposed and provides the timing information for the position or velocity control data.
The bus system capacity is discussed for various applications and it is shown that CAN and CANopen is suitable even for demanding real-time requirements.

1. Introduction

Digital intelligent drives offer maximum precision and speeds while minimizing equipment costs. For some applications the performance and accuracy of the digital drive interface itself is not crucial, as the drive internal capabilities allow one to send a command without hard timing requirements whilst the high speed control loops are closed locally in real time fashion. In most cases though a high accuracy digital interface is required to make full use of the advantages that the digital drive offers – especially when several axis work in a synchronised manner (Fig 1).

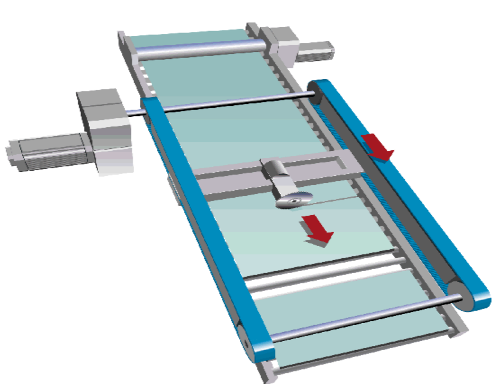

Fig.1: flying saw application

Examples are automatic supply machinery that transports and positions materials and products, grinding, drilling and polishing applications, handling devices that extract and palletise, etc. In all these cases several drives are involved and have to be mutually co-ordinated in their varying dependencies by NC or continuous path control systems.

2. System description

Servo drive applications can be classified in two categories:
- in most cases a central positioning or NC controller is used for set point generation, interpolation, path co-ordination and drive synchronisation. The control unit typically provides or connects the user interface, and is able to control the motion path depending on external conditions like complex sensor information, varying geometries or user input. Proper drive synchronisation is crucial.
- For very simple tasks local control may be sufficient. A locally executed drive control program that repeats the motion path is adequate especially when no interaction with other drives or external conditions is required.

The Beckhoff TwinCAT Software System acts as central drive controller. It turns any compatible PC into a real-time controller with a multi-PLC system, NC axis control, programming environment and operating station. TwinCAT NC offers 3D interpolation, an integrated PLC with an NC interface and can communicate via all major fieldbus systems. The CANopen master functionality is provided by the FC5101 PCI card, which is available with two CANopen channels (FC5202) as well. The CANopen implementation was specifically designed for high performance applications whilst supporting the full range of CANopen features.

Lenze's intelligent drives are designed both for central drive control and for local drive control. The drives integrate the CAN bus with the standardised communication profile CANopen DS301. The drive can make full use of CANs multi-master capabilities by, for example, enhancing the input range with external CANopen I/O modules like the ones offered by Beckhoff.

As each drive carries its own CPU, the computing performance and I/O capacity hence increases in networked drives with every additional controller.

Another supported CAN bus function is the synchronisation of control algorithms in a drive group. Chronologically equidistant angular information is needed to avoid irregularities that might arise using control algorithms that function asynchronously.
Such angular information is needed to ensure angularly synchronised running of individually driven axes and for spatially coordinated movement/s (continuous path control system/s) via bus system/s.

Unlike drives with analogue (+/-10V) interface, digital drives not only close the torque and speed control loops locally, but are able to perform fine interpolation and position control with very short cycle times. TwinCATs interpolator and NC calculates position command values (set points) cyclically for each machine axis at identical, short intervals. With its own position control, each axis follows the cyclical position command values supplied by the interpolator, with a high dynamic response and high precision.
Thus control is exercised where the information relevant to this level of the control system is captured without any delays caused by the communication system. The fast control cycles in the drive are used to damp out interference. The position set points, transmitted at slower cycle times, are fine interpolated by the fast controller/s in the drive/s for that purpose.
Please not that this distribution of the control cascade (Fig 2) is not CAN specific, but typical for digital drives. Dedicated drive control systems like SERCOS favour the same approach.

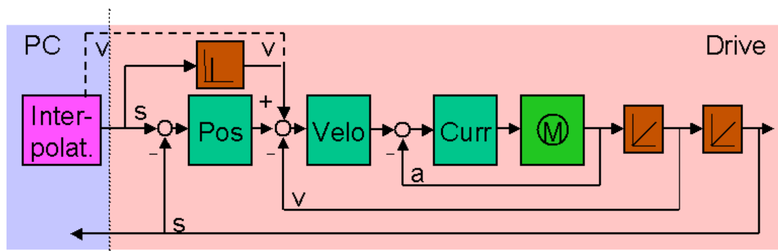

Fig 2: control cascade with digital drive system

3. Synchronisation Method

Best drive accuracy is achieved when the drives are precisely synchronised with the superimposed continuous path control system. This permits controller processing of the set points exactly simultaneously.
A phase error of about 2 degrees due to the internal position control phase offset is caused, for example, by a deviation of a mere 100 µs in synchronisation precision at a speed of 3,000 RPM.

Only standard features of the CANopen specification DS301 are used for the drive synchronisation method. DS301 includes the definition of a mode for synchronous cyclic data transmission. Periodically the SYNC telegram is transmitted by the SYNC producer. On reception of the SYNC the consuming device actuates based on the contents of the synchronous process data object (PDO) received before the SYNC. The reception of a SYNC also prompts a device to sample its feedback data and transmit a synchronous PDO with an actual value as soon as possible afterwards (Fig 3).

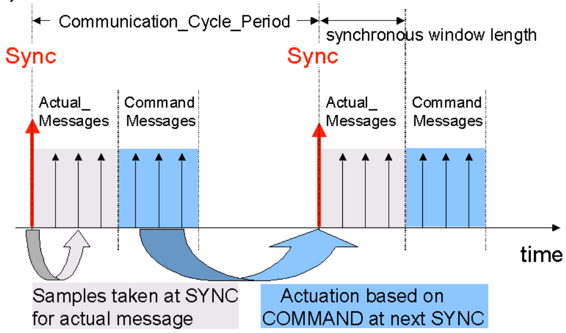

Fig 3: CANopen sync mechanism

This mechanism works fine but has some limitations: As the SYNC message cannot interrupt a CAN frame currently being transmitted on the bus, the SYNC delivery may jitter by several hundred microseconds – at least the time it takes to transmit a CAN frame with maximum length, but maybe even by another higher priority frame like a network management telegram. Furthermore, the quality of the SYNC mechanism very much depends on the software implementation. In many cases only the CANopen communication is synchronised, but not the application running on another CPU.

The high precision distributed synchronisation control (dsc) used for the drive synchronization makes use the CANopen SYNC mechanism with an enhanced application synchronisation method. It permits exact synchronisation of the chronological basis of the individual controllers. The synchronisation telegram must be transmitted cyclically with several milliseconds (1-13) and in the median with quartz precision. This is achieved by the CANopen PCI card FC5101, which also precisely synchronises the NC task with the CANopen cycle. It is as well possible to synchronise several CANopen channels on one or several cards.

As described above, the single telegram fluctuation, however, may be several hundred µs. The drive application uses a phased locked loop (PLL) mechanism to synchronise with the SYNC telegrams and thus synchronises with the overall accuracy of the SYNC cycle. A single jitter has no influence. No further means of parallel transmission of a synchronisation tact are needed and this functionality can therefore be achieved with standard CAN hardware.

The assumption that accurate cyclic behaviour cannot be realised with the CAN bus is proven wrong by the results illustrated below.

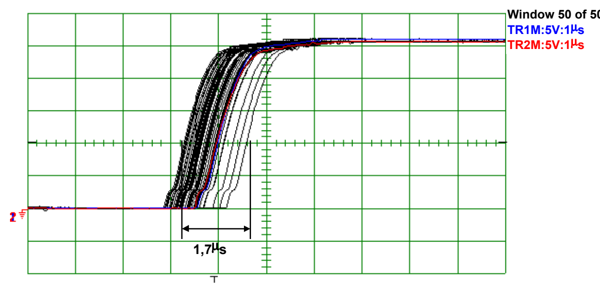

Fig 4: synchronisation jitter of 2 9300 servo inverters.

The synchronisation tact was dictated to two intelligent drives of the 9300 series by the superimposed NC control system. The diagram shows the beginnings of the control algorithms of both controllers, whereby the first channel serves as trigger point. Statistical recording of 50 incoming signals shows the quality of synchronisation, the jitter range being below 2 µs (Fig 4).

4. Bus system capacity

The bus system capacity is discussed using several typical applications.

4.1 Angularly synchronous individual drives (used instead of vertical shaft)

The CAN bus is pre-destined for use as a transmission medium in angularly synchronous individual drives because of its multicast capabilities. A virtual master sends the set point with one process data object cyclically and a further SYNC message for system synchronisation. All drives thus receive the same information at the same time. In angularly synchronous individual applications, average distance of up to 100 m bus extension must be allowed as a rule. As this is related to the data transmission speed, a baud rate of 500 Kb is realistic in this particular case. At this rate, the data transmission time is about 400 µs for both objects. Given a cycle time of 1 ms, the bus system is thus about 40% used. Adequate reserve therefore remains for transmitting control and status information and/or other service data objects (SDO). The number of axes connected is only limited by the bus physics and thus by the CAN transceivers.

In sum and depending on the physical transmission limits, the capacity of angularly synchronous individual axes is as follows.

Cycle time	1ms
Baud rate	500KBaud
max. no. of drives	63*
max. bus extension (500 KBaud)	100m

* depends on CAN Transceivers used

4.2 6-axis handling robot as example

In general the electronic components of handling robots are close together so that the data can be transmitted with 1 Mbaud. A CAN object has a max. of 8 data bytes. Two controllers with 32-bit cyclic position set point can hence be controlled per object. Three cyclic process data objects for the position set points plus one SYNC object are therefore needed for a 6-axis handling robot.

The control information can be summarised in a single broadcast object for all the drives and transmitted event-controlled. The information is thus irrelevant where bus load calculation is concerned. Status information for each controller are e.g. exchanged in total every 24 ms alternately. Bus loading for a cycle time of 1 ms can then be calculated as follows.

3 cyclic position set point objects * 130µs	390µs
1 SYNC object	70µs
_ status information object (1 object per 2ms)	65µs
Σ	525µs

This equals a bus load of around 53%. There is adequate reserve for exchanging further data such as e.g. service data objects.

6 axes can thus be controlled in 1ms with 32-bit position set points each.

4.3 System capacity with a cycle time of 4 ms

Position set point updates within a 4 ms cycle time are sufficient for over 90% of all applications.

32-Bit set point updates with a cycle time of 4 ms referenced to the number of drives and bus expansion is given in the table below. It is assumed that less than 75% of the bandwidth is available for cyclic drive communication.

Bus length	Baud rate	No. of axes
25 m	1000 kbit/s	16
100 m	500 kbit/s	8
250 m	250 kbit/s	4
500 m	125 kbit/s	2

The number of axis can be further e n-hanced by not sending each actual position in each cycle, but spreading the feedback in a way that there is only one actual position value sent in each cycle. As the position control loop is closed locally, this is sufficient.

5. Effects of data transmission on drive characteristics

It is necessary to examine the drive characteristics of a single controller to obtain valid data on this. For this purpose, the contouring error of a series 9300 servo position controller with high-resolution feedback system (sine/cosine encoder) was measured over a speed range of 0 to 4,000 RPM in idle.

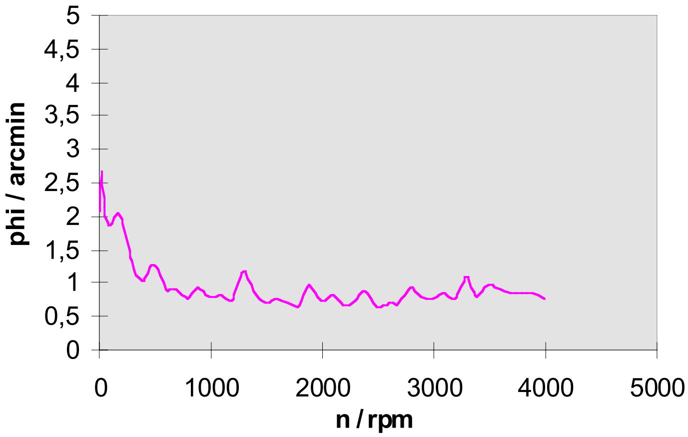

Fig. 5: contouring error of a 9300 series position controller with high-resolution feedback system, idling

Measurements results show deviations of less than 2 angular minutes over the entire speed range.

Two controllers were then set up using the synchronisation mechanism described above to obtain data on the influence of data transmission on drive characteristics. The angular deviation of the two rotating motor shafts relative to one another were then measured.

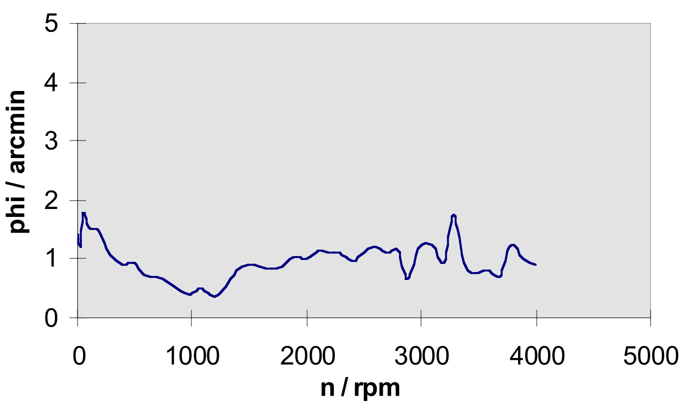

Fig 6: angularly synchronous running; phase difference of 2 9300 servo inverters, idling

The measurements show that here again precision of less than 2 angular minutes is achieved over the entire setting range. The phase offset is thus always of similar dimensions to the contouring errors of the individual controllers.

The bus (CAN with CANopen) used for the Beckhoff TwinCAT / Lenze communication with distributed synchronisation control (dsc) has no negative influence on the system and is optimally suited for multi-axis-coordinated movement sequences.

Dynamic and static drive characteristics measurements under load conditions and conditions of higher data flow due to further asynchronous bus participants led to the same result/s.

6. Field experience

TwinCAT NC can perform significantly faster control cycles than the CAN bandwidth allows to communicate. Field experience though shows, that in combination with intelligent digital drives and high precision synchronisation, CAN easily meets most application demands. For handling systems, for example, a cycle time of 4 ms is adequate in more than 90% of the applications. The deviations in synchronicity of less than 2 angular minutes (1 / 10800th of a shaft revolution) can usually be disregarded by comparison with mechanical imprecision (torsion in the mechanical shafts, gearing tooth face change, etc.) .

Applications that have been successfully solved with the CANopen digital drive interface include:

- 3-axis precision cutting machine (Fig 7)
- 9-axis special handling device
- Handling robot for extracting injected plastics parts
- Engraving steel blocks in the steel industry
- Printing machinery without shafts
- Blister packaging machinery for the pharmaceutical industry
- Bookbinding machinery

- Wire pulling machinery
- Foil covering plants
- etc.

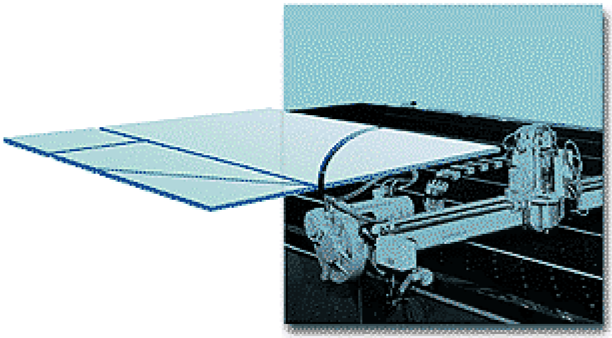

Fig 7: Glass cutting machine

7. Why CAN and CANopen?

What are the advantages of CAN and CANopen compared with dedicated drive control systems like SERCOS?
Low costs and versatility. As CAN adds only little cost to a drive hardware, Lenze and many other drives come with a CAN interface by default whilst other fieldbus interface cards are optional. And CANopen is not only supported by drives and I/Os, but by all kinds of devices.
In most cases the available bandwidth allows one to combine drives, controllers and other devices on the same CAN network – and if the bandwidth is not sufficient, a second CAN network is available at little costs with the Beckhoff two channel CANopen card.

8. Summary and outlook

CAN and CANopen is suitable for many drive engineering applications due to its multi-master and multi-cast capabilities. It is therefore used by Lenze as the system bus for integrating systems and expanding them and supported by Beckhoffs TwinCAT NC and PLC system.

This bus is pre-destined to exchange data within intelligent sub-systems that are networked via standard fieldbus systems to superimposed control computers.

Development of the distributed synchronisation control (dsc) shows that CANopen is suitable even for demanding real-time uses. The cost advantages, including networking without extra cost as CANopen is default whilst other bus systems are optional, combined with the robustness and the versatile use of this system will lead to further increasing acceptance.

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