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Servo Drives
State of the Art in Industrial Applications – A Survey

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ABSTRACT

Servo drives with microcomputer control provide the possibility of using modern and sophisticated control algorithms. As an additional feature it is possible to implement parallel and/or redundant software and hardware structures to realise safe motion or similar security functions Unfortunately microcomputer control also has some impact on the behaviour of servo drives. Control algorithm, cycle time, sensors and interface have to be perfectly synchronised. Special control schemes are necessary on the line side (power supply) to meet the actual requirements concerning EMC. This contribution presents experiences and results obtained from a modern digital drive system pointing out the influences of low and high accuracy position sensors and the interdependencies mentioned above.

Key Words: Servo drives, control synchronization, smooth motion, encoder resolution, encoder accuracy, EMC

1. Introduction

Recently several servo drive manufacturers presented new servo drives which use really a new generation of servo drives[11]. The main features of these drives are:

- Digital control of position, speed and current Since 1987, when first industrial servo drives with completely digital control had been presented [1], the performance of these drives has improved more and more and today is better than the behaviour of analogue controlled drives[9].
- Identical inverter hardware and software for asynchronous as well as for synchronous and even synchronous reluctance motors An „electronic name plate" inside the motor (patent pending) is the most progressive solution to transfer all data necessary to operate the drive. An optimization by technical staff is possible but not necessary any more.
- High resolution encoder systems for simultaneous sensing of position and speed providing a resolution of several million positions per revolution A significant reduction of encoder costs introduced even multi-turn absolute encoders to a wide field of applications.
- Digital interfaces (e g. SERCOS interface [2], CAN, ...). Full access to all data inside the servo drive provides highest flexibility in adapting the drive to any application.
- Intelligent start-up and installation tools Detailed text messages via digital interface support diagnostics and service; use of sophisticated service equipment – e g PCs – give access to all parameters and data of the servo drives and assist the customer's optimisations and adjustments [6]
- Power supply with reduced line harmonics [3]. Viewing the mains as an electrical machine with very special characteristics enables the use of the same field oriented control as on the drive side of the inverter, current control provides very low harmonics in the mains.
- Voltage control in the DC link (providing a voltage

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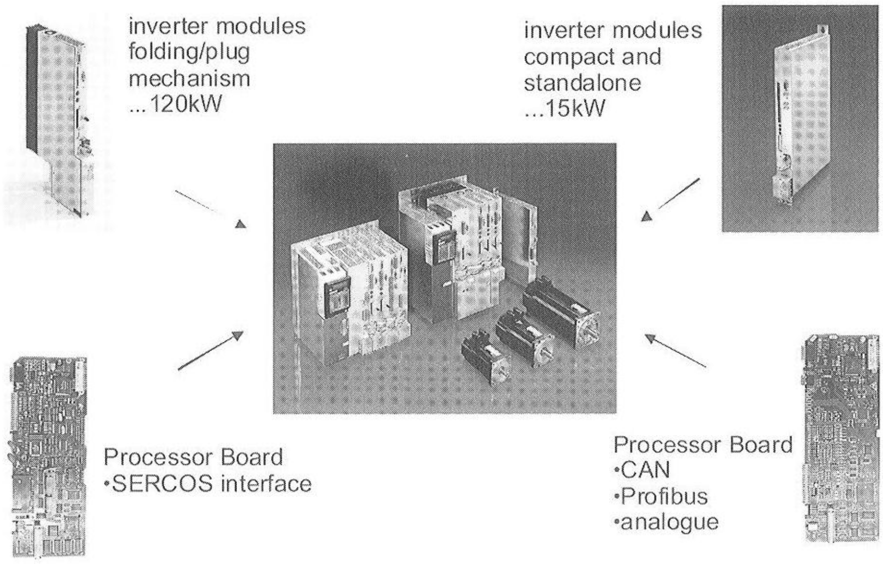


Fig. 1. Modular Servo Drive System.

tolerance of about 1% leads to a better design of the electrical machines, as it is not necessary to consider big tolerances in the operation point; narrow tolerances and a high DC link voltage lead to better drive efficiencies and better use of field weakening ranges of asynchronous machines).

Due to the features mentioned above, servo drives with analogue control are completely going to be replaced by digitally controlled drives[4, 5, 6]. However, besides the advantage of having the possibility to use modern and sophisticated control algorithms, servo drives with microcomputer control also have some disadvantages. Control algorithm, cycle time, microcomputer, sensors and interface have to be perfectly combined to achieve better performance as it is known by servo drives with analogue control. It is necessary to use special current, speed and position sensors as well as digital interfaces to transfer the reference and real values. Internal synchronization of all control parts is essential as well.

The following remarks deal with digital drive features becoming more important than in the past when using servo drives with analogue control.

2. Drive Control

The development of "digital" servo drives meant integrating microcomputers into inverter designs. This is possible today without negative interference between power stage and microcomputer. The new drive generation provides a modular mechanical structure by using identical power stages and control hardware for synchronous and asynchronous motors as well as for power supplies. Processor boards are only different with respect to different digital interfaces. Fig. 1 shows the possibility to combine inverters with power stages for different output powers and processor boards with different processor performance for any servo drive system. This concept saves cost and effort on the customer's side.

To control synchronous and asynchronous motors, servo drives use the same control structure in field orientation. Depending on the type of motor, the microcomputer activates some software-subroutines. A hardware or software change is not necessary. Even the power supply unit may be considered as a big synchronous machine and can be controlled by the same control algorithm (see paragraph 5 "EMC/EMI").

Enough performance should be left to calculate models of the electrical machine to support the drive's behaviour in safe operation conditions (see paragraph 6 "Safe Operation").

The servo drive's microcomputer must be able to handle at least 32-bit-operations to achieve results better than servo drives with analogue control. Only few processors are able to do this within acceptable cycle times When using servo drives with digital control remarkable improvements of the drive behaviour are obtained during operation. Due to the fact of digital signal processing and - what is even more important - digital sensing of speed and position there are no offsets and no drifts any more within the control loops. A command speed of 0 really leads to a standstill of the drive

Cost reductions have been achieved by shortening the time necessary for set-up operations of servo drives Besides the significantly reduced number of wiring and cables and consequently minimized installation effort the optimization procedure of "digital" servo drives is simplified by the use of data tables containing control parameters or - what is even more progressive - an "electronic name plate" A memory chip is integrated in the servo motor (or its encoder) The control microcontroller polls all information to adjust the drive control to that specific motor from the "electronic name plate" without any additional action from the operating staff. The set-up operation of a modern drive package for a machine tool needs less time than a working day.

3. Synchronization

As mentioned above, there are some disadvantages when using servo drives with microcomputer control Control algorithm, cycle time, microcomputer, sensors and interface have to be perfectly combined to achieve better performance than it is known by servo drives with analogue control. The application of digital current control has to consider the effects of control cycle time, inverter switching frequency and recovery time of the inverter switches It is necessary to implement internal synchronization of all control instances. Fig. 2 shows the current/torque ripple of a synchronous servo drive with identical control hardware and control algorithm with and without control synchronization [7].

When using several servo drives as a whole system for multidimensional motion control (e g. in machine tools), it is necessary to synchronize not only the components within each single drive but also between the drives taking part in the co-ordinated motion with each other This is possible by using a special synchronization interface or – what is more sophisticated – by using a digital interface

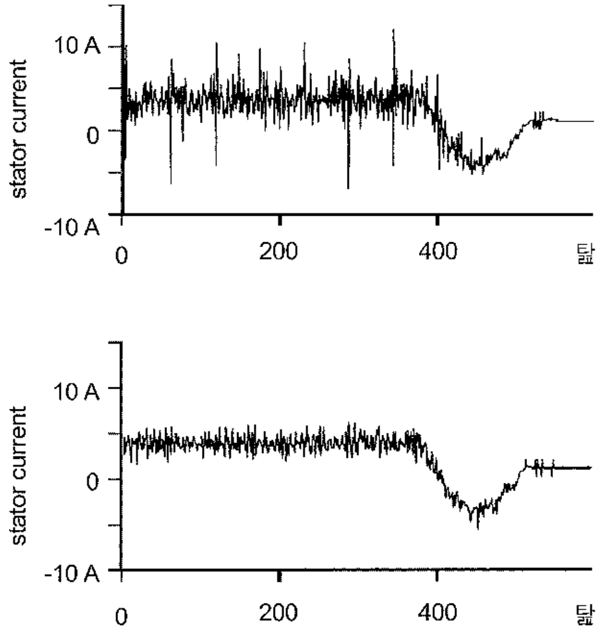


Fig 2 Current Ripple without (upper diagram) and with (lower diagram) synchronisation of control loops[7]

with integrated synchronization procedure (e g SERCOS interface[2])

4. High Resolution

Improvements concerning accuracy and resolution of optical sensors provided a dramatic increase of positioning accuracy In combination with high resolution microcontrollers or -processors very smooth speed operation as well as accurate positioning can be achieved

Fig 3 shows the comparison between a modern optical encoder and a well-known magnetic resolver concerning accuracy of position angle. The deviation of the position error is a measure for the ability of smooth operation at very low speeds To operate a servo drive with the speed of the hour hand of a clock – which is not unusual – an encoder resolution of several million positions per revolution is necessary to guarantee really smooth operation Of course, it is nearly impossible to design encoders like this Today's compromise is to use optical encoders with rather high line numbers (e. g. 5000) with sinusoidal output signals and to interpolate the signals in the drive's electronics by an additional factor (e g 2048). The use of more or less sinusoidal signals produces a better speed behaviour without better physical conditions

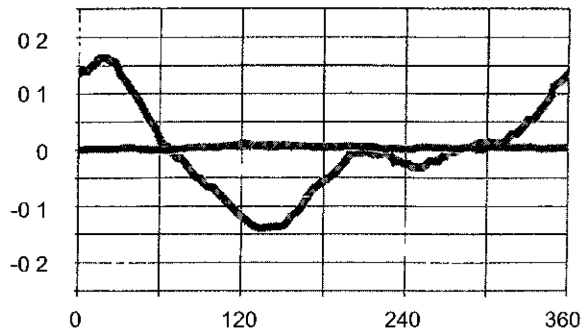
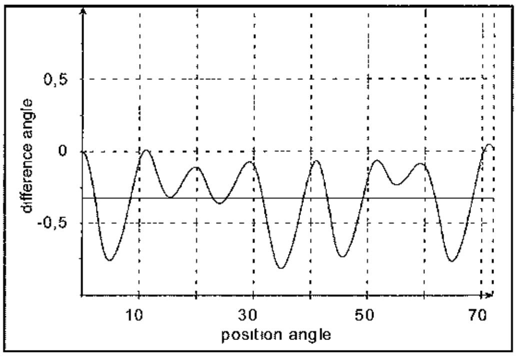
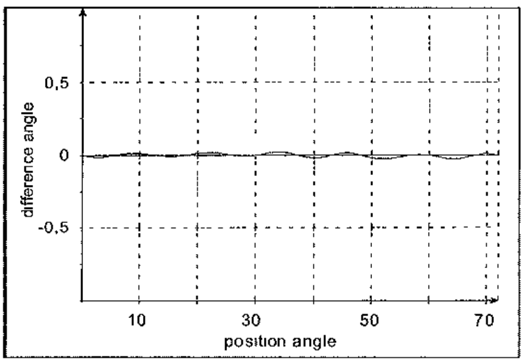


Fig 3 Comparison of position accuracies when using magnetic or optical sensors in servo drives[12] {horizontal axis position angle in ° (degrees), vertical axis difference angle in ° (degrees)}



(a) brushless DC tacho



(b) high resolution optical encoder

Fig 4 Comparison of smoothness in speed control

within the sensor. These devices are available on market for reasonable prices today Consequently, the smooth operation behaviour of servo drives with digital control has improved significantly in spite of some drawbacks in comparison with analogue tachogenerators

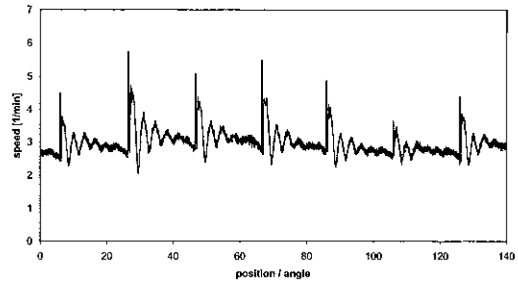


Fig 5 Speed behaviour of a servo drive with brushless tachogenerator

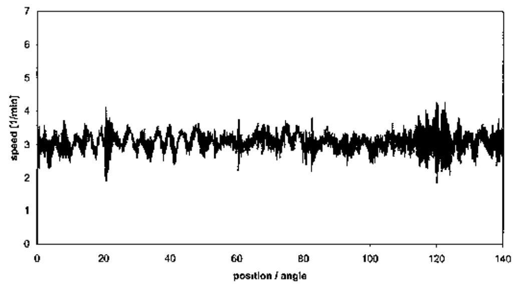


Fig 6 Speed behaviour of a servo drive with resolver

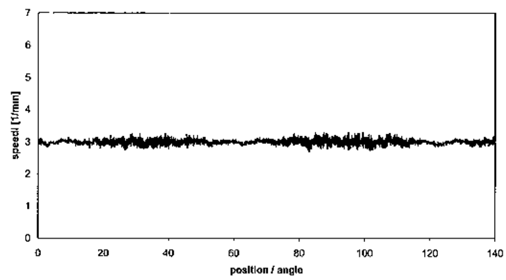


Fig 7 Speed behaviour of a servo drive with high resolution optical encoder

Fig 4 compares the smooth operation of two servo drives, one is equipped with a brushless tachogenerator and analogue control, the other one with a high resolution optical encoder and digital control The commutation of the brushless tachogenerator produces significant speed deviations which cannot be compensated by the drive control, because the tachogenerator is a component of the feedback loop An optical encoder improves the smooth operation by more than factor 10 in comparison to brushless tachogenerators, which are commonly used in combination with analogue drive control.

Fig. 5, Fig 6 and Fig 7 compare the smooth operation of servo drives equipped with a brushless tachogenerator, with a resolver and with an optical encoder Even with a low resolution resolver there is an improvement of about factor 2 compared with a brushless tachogenerator. An optical encoder improves the smooth operation at least by factor 8 – 10 in comparison to brushless tachogenerators, which are commonly used with analogue drive control.

5. DC Link Voltage Control and EMC/EMI

The new servo drive generation shows an improved EMC behaviour concerning the power supply, an improved drive efficiency by controlling the DC link voltage and an improved torque-speed-characteristic

The basic idea leading to these improvements is to transfer control principles from the inverter supplying the electrical machine to the inverter of power supply [3]. The electrical mains can be viewn as a very big and very special synchronous machine controlled by the power supply inverter. If the servo drive needs power, the power supply intends to decelerate the electrical network – hopefully without success If the servo drive regenerates power, the power supply tries – not successfully, of course – to accelerate the synchronous machine behind the electrical network. Consequently the same control strategy can be used for both the electrical machine and the power supply of a servo drive system

All ideas aiming to a reduction of ripple currents in inverter supplied electrical machines can be used similarly for line currents. As a result, the 5th harmonic can be easily reduced by a factor 8 to 10[3]

A further improvement is the control of the DC link voltage superimposed on the current control like the speed control on the motor side. The efficiency of the whole servo drives is increased by reduced tolerances of DC link and motor voltages The tolerances of the DC link voltages can be limited so far that the rated values of the servo motors do not need to consider voltage variations any more. The design of the electrical machines can be adjusted much closer to the rated values, (e g ± 1% instead of ± 10%) saving weight and cost. Even when the line voltage has tolerances of 20% and more, the DC link voltage is controlled with much higher accuracy (e.g 1%) on a higher voltage level than with diode rectifiers. This provides an improved torque-speed-characteristic of servo drives – especially of asynchronous motors in the field weakening range.

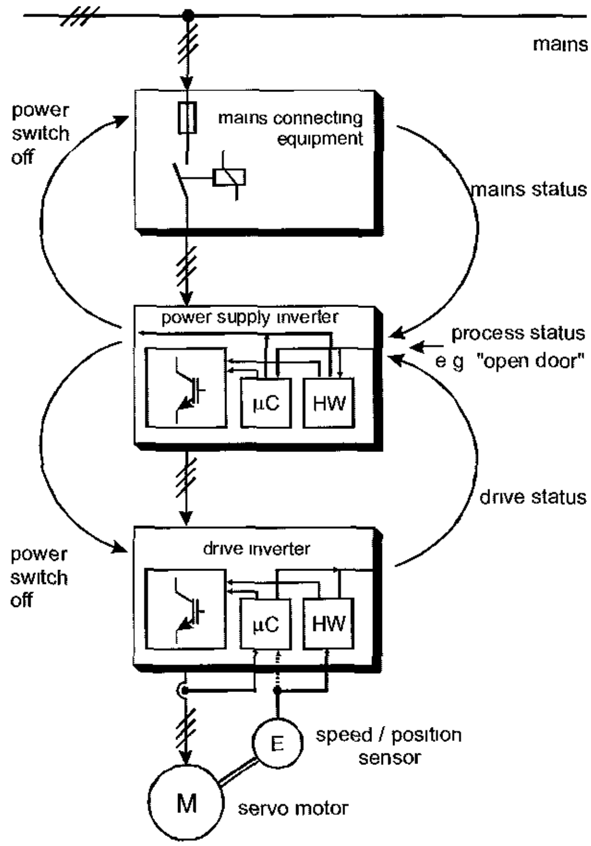


Fig 8 Redundant structure for safe operation

6. Safe Operation

The most interesting highlight of the new servo drive generation is the possibility to realize safe operation (i.e. safe standstill or safe motion) in robots or machine tools under direct access to the machinery without danger even when the electrical power is still active

The digital drive system provides safe operation by internal redundant channels with different hardware The servo motor itself is used as a speed/position sensor by the microprocessor without considering any information from the encoder. (For control purposes, of course, the information of the encoder is used by the processor.) When using a processor independent encoder hardware to define the drive's position and/or speed, this second (redundant) channel is used for supervising safe operation of the servo drive (Fig. 8). Both channels – the encoder hardware as well as the microcomputer – compare the real speeds/positions with each other. In the case of a difference, both channels switch off the drive – this type of emergency action is also performed by two independent channels: the encoder hardware as well as the microcomputer shut down the inverter and – via a second (redundant) channel – switch off the main switch of the drive system.

Due to this feature, one of the new generation drives was certified by a Swiss safety agency as a safety related component (according to the machinery directive of EU). Using this product a manufacturer of machine tools or similar safety critical machinery has much less problems than in the past.

7. Conclusions

Servo drives fullfill nearly all requirements of the market today – therefore further development is not a very big issue in industry research at the moment. Some years in the future, when further progress in servo drive performance will be required, the resolution of the encoders will appear as the technical narrow-gap in servo drives.

Servo drives of the newest generation are a good basis to make further development in control techniques. Processing power is high enough to implement self optimization and self adjustment schemes for drive controls – the main requirement when replacing the well-known cascade control by more modern control schemes[10].

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In 1983 he started his industrial career as a Development Engineer for servo drives with Robert BOSCH GmbH. Later he became Group Manager and finally Department Manager in the same development department. Until 1997 he was responsible for all developments concerning servo drives in the Robert BOSCH GmbH. In 1997 he changed to the Automotive Division of the same company at Bühlertal, Germany, as Department Manager for Advanced Development of electrical drives.

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Gerhard Kobs received his diploma degree from the Technical University of Braunschweig, Germany. From 1985 he developed microcomputer controlled drives with Robert BOSCH GmbH at Erbach, Germany. Later he became group manager for main spindle drives in machine tools. In 1994 he took over responsibility as a product manager for servo drives. In this position he introduced the new servo drive generation SERVODYN-D with digital control to the market.

Rupert Weber received his diploma degree in electrical engineering in 1977. From 1977 to 1980 he worked in developing industrial power supplies and battery chargers. In 1980 he joined Robert BOSCH GmbH at Erbach for developing electrical drives. He was project manager for the development of the digital drives family SERVODYN-D. Since 1998 he is head of the servo drives development at Robert BOSCH GmbH, Erbach, Germany.