Advanced Digital Motion Control Using SERCOS-based Torque Drives

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Abstract

This paper presents a survey of the applications of real-time network control technology to advanced digital motion control. A DSP-based digital ac servo drive with SERCOS interface has been constructed. Realization issues of a fully digital controlled multi-axis servo system has been discussed. A windows-based interactive development environment has been developed for the design of multiple-axis motion control system.

Keywords: SERCOS, real-time network, digital motion control, digital motor control.

I. INTRODUCTION

Advances in microelectronics and information technology have brought significant changes in motion control technology. The development of high-speed digital signal processors (DSP) paves the way to software servo for motor control. High-speed single-chip DSP controller with processing speed higher than 20 MIPS and unit price lower than ten dollars initiates the age of digital motor control.

Digital PWM control of the power converters and digital current regulation of the motor drives enable the feasibility of developing universal motor drives using software control techniques. Successful application of digital motor drives needs computer interface with higher transmission rate and high-level motion and motor control protocols.

During the past ten years, development of internet has made a tremendous progress in computer communication technology. The application of microprocessors,

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information technology, and local network in factory automation motivates the development of computer integrated manufacturing (CIM) systems.

This paper presents the design and implementation of an advanced digital motion control system using SERCOS-based torque drives. A digital motion control algorithm has been developed for the synchronization control of multiple servo axes. The designed motion control system is based on a digital torque drive for ac servo motors with SERCOS interface. Digital torque commands are generated from a PC-based motion controller. The digital motion controller is realized on a personal computer under a Windows based real-time kernel.

II. SERCOS FOR MOTION AND MOTOR CONTROL

The backbone of this fully digital motion control system is SERCOS which is a high-speed communication protocol specifically designed for fast response distributed control systems. SERCOS stands for SErial Real-time COmmunication System. It's an open digital drive interface specification (IEC 1491) designed for high-speed serial communication of standardized motion control data in real time using a fiber-optic cable.

Multiple-axis motion control in a distributed architecture requires a bus protocol that supports high-speed synchronous transmission of digital data to perform contouring, interpolation, electronic gearing, and cam profiling. Fig. 1 shows the structure of a distributed digital motion control system using SERCOS interface. SERCOS was created in 1986 by a consortium of machine-tool, industrial-drive, and numerical-control manufacturers that were looking for an open communications system for the future development of intelligent drive technology. SERCOS became a European Preliminary Standard in 1991, and in 1995 was approved by the IEC. It is now published as IEC 1491, an international standard. Drive manufacturers wishing to put their products on the SERCOS ring can access to this specification, either through the IEC or the American National Standards Institution (ANSI, New York), by requesting IEC 1491.

The concept of synchronization not only applies to the bus of a computer system, it also plays an important role in the synchronization control of electric drives. If synchronization can not be maintained, a “beat frequency” in motion profile occurs, which could result larger contouring errors. Real-time communication using SERCOS for coordinated motion control via a ringed fiber-optic cable can not only handle the synchronization of all elements connected, but saves the user’s cost by reducing the number of electrical connections.

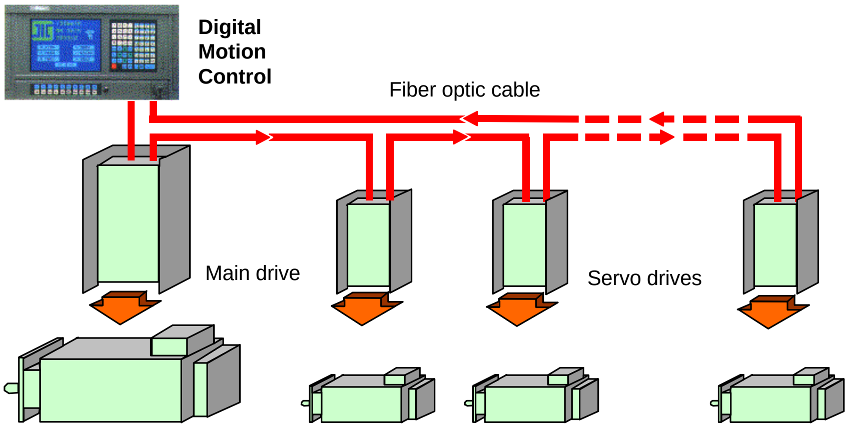

Fig. 1. SERCOS interface for digital motion control.

III. MULTIPLE-AXIS CONTROL

Fig. 2 illustrates the architecture of a SERCOS based digital motion control system. Fig. 3 shows the physical layer for the interface control of a motor drive. Coordinated motion control can be achieved by using a motion controller generated synchronized position, velocity, or torque commands. Conventional servo drives receive a synchronized pulse train for coordinated position control. Synchronization of motor drives in lower level can release the computation load for higher level control functions of the drives, lower MIPS microprocessor can be used to realize a digital torque drive. However, this structure also requires a higher communication rate interface to deliver the synchronized torque commands and it also needs a higher MIPS microprocessor to realize motion control algorithms as well as servo loop control functions.

Fig. 4 shows the proposed control structure of a SERCOS based digital motion control system for two-axis servo motor control. Digital ac servo drives with SERCOS interface have been employed in the construction of a distributed motion control system. A digital motion controller with SERCOS interface has been constructed based on a personal computer. Digital motion control algorithms and digital servo loop compensator are realized using high-level C language with floating arithmetic.

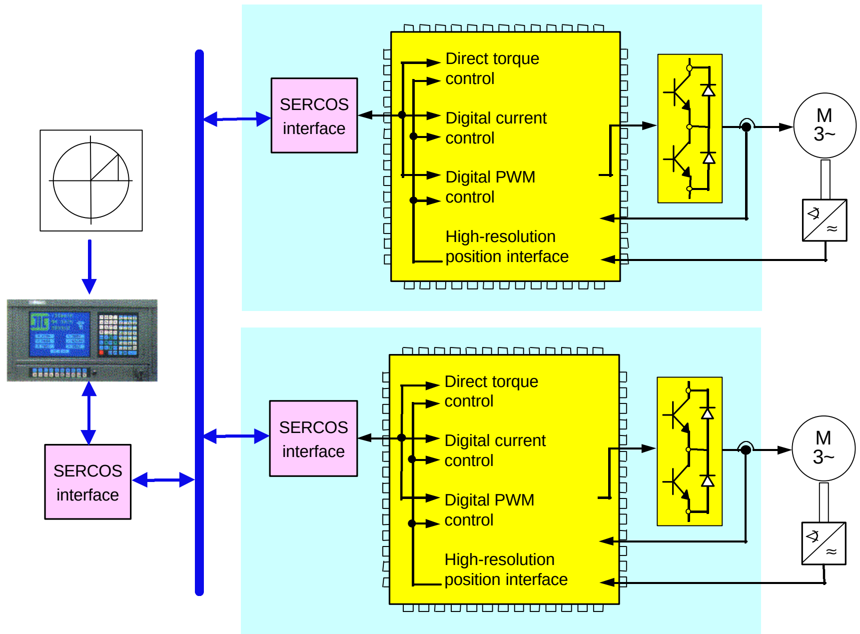

Fig. 2. Architecture of a SERCOS based digital motion control system.

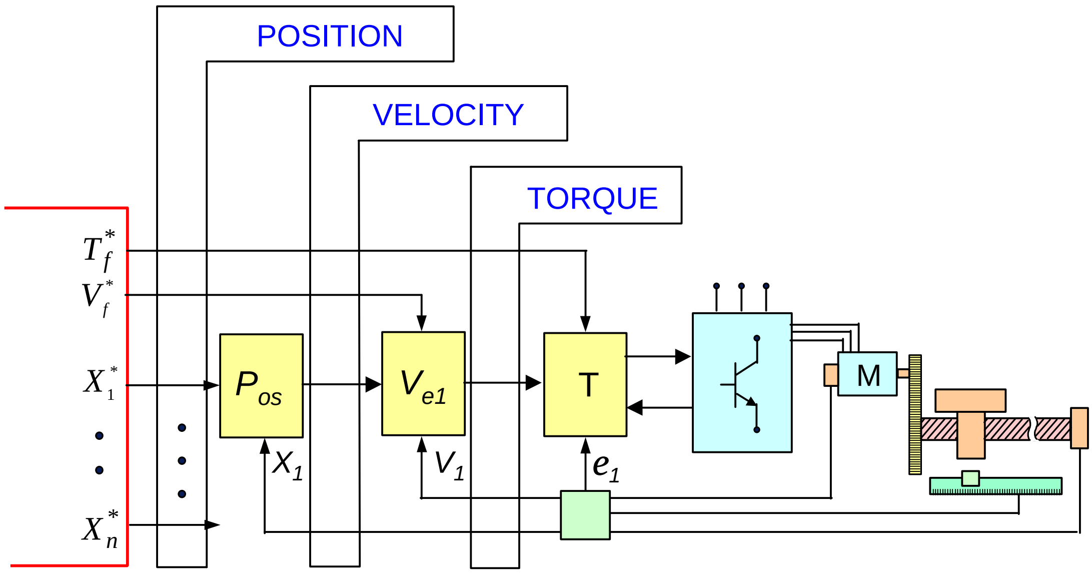

Fig. 3. Physical layer for the interface control of a motor drive.

In a multiple-axis motion control system, the maximum tolerance of following error at a given maximum ramping speed of a positioning servo system defines its minimum required position loop gain. The position loop gain determines the closed-loop bandwidth of a position servo. In general, a higher position loop gain can achieve a wider bandwidth of the position servo. However, a higher position loop gain also requires a higher bandwidth of the corresponding velocity loop bandwidth. For CNC machine tools, typical position loop gain of its feed drives ranges from 3~100 sec^{-1}. Appropriate bandwidth of the corresponding velocity loop of the position servo typically ranges from 3.5 ~ 5.0 times of its position loop gain. When a position servo drive has been tuned to its maximum extent, for example, 100 sec^{-1}, a velocity loop bandwidth of 500 sec^{-1} would be required, this corresponds to about 80 Hz.

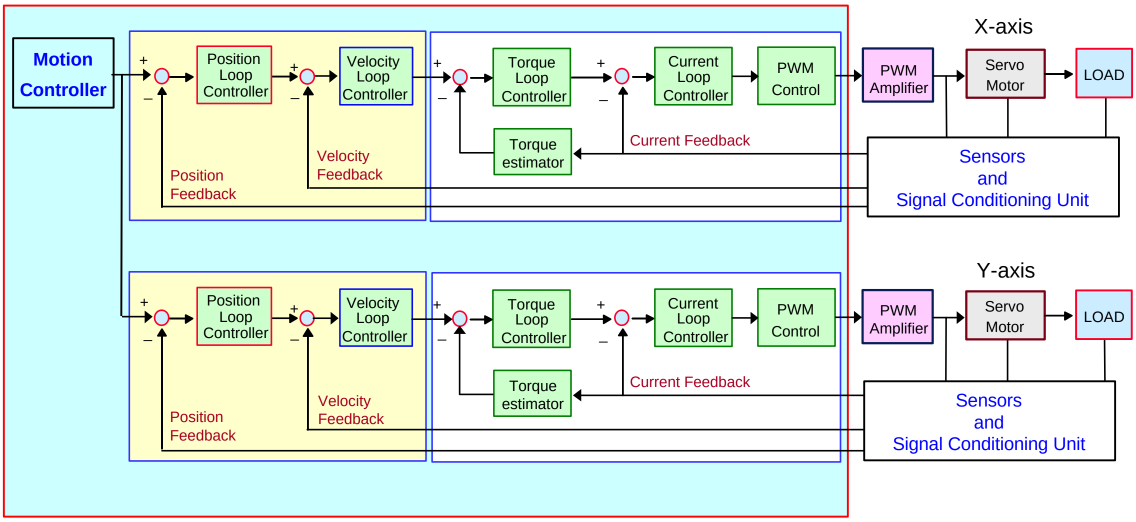

Fig. 4. Control structure of a multiple-axis motion control system.

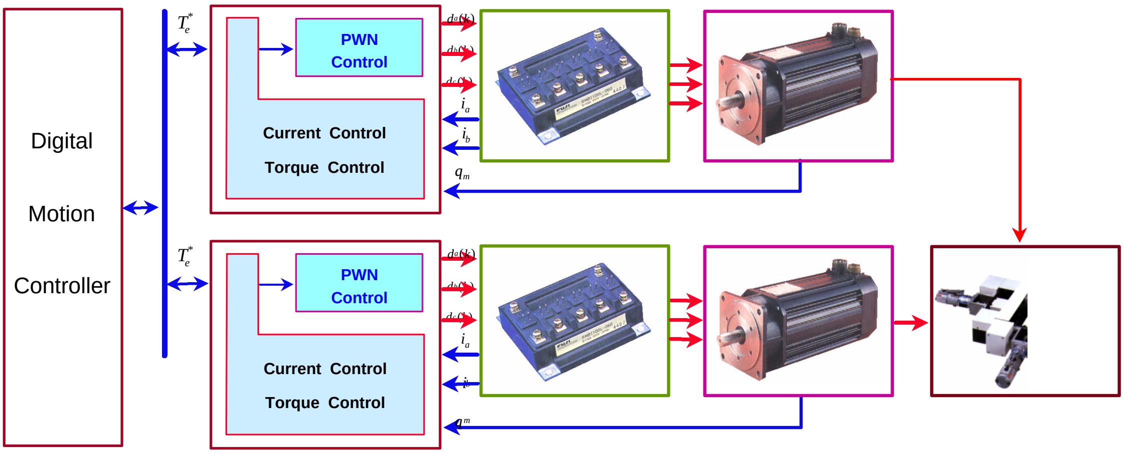

Fig. 5. Block diagram of multiple-axis digital motion control using SERCOS based torque drive.

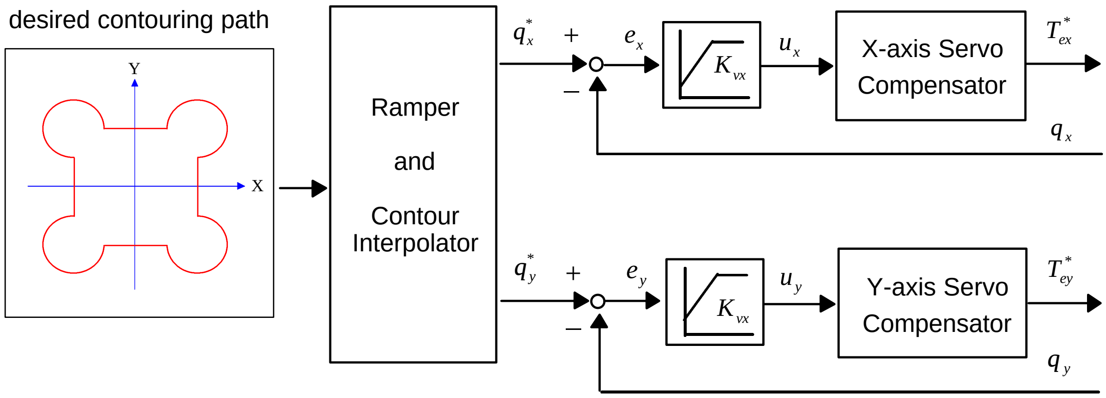

Fig. 6. Simplified position loops for coordinated 2-axis motion controller.

In a digital incremental motion control system, selection of sampling rate of its corresponding loop plays an important role in designing of its loop compensator. The ratio of sampling rate to loop bandwidth typically ranges from 6 to 40. In general, digitizing an analog system requires a higher sampling rate. The sampling rate of a velocity loop with bandwidth of 80 Hz can range from 480 to 3200 Hz. This illustrates that a digital torque drive may need to update its torque command within 312.5 μsec for a typical application. SERCOS as a real-time communication protocol dedicated designed for motion control systems provides transmission rates of 2, 4, or 10 Mbps [7]. SERCOS provides communication protocols for cyclic transmission of process data and noncyclic transmission of diagnostic data. Synchronization of servo drives can be achieved by a master motion controller linked with salve servo drives via cyclic transmission. For a 4 Mbps transmission rate, selectable cycle rates include 0.0625 msec, 0.125 msec, 0.25 msec, 0.5 msec, 1 msec, or any multiple of 1 msec.

Fig. 5 shows the functional block diagram of a multiple-axis digital motion control system using SERCOS based torque drive. The torque drives receive torque command from higher level motion control unit and regulate the motor developed torque by closing control of its voltage and/or current. The torque control of a motor heavily depends on its motor dynamics and parameters. Essentially, an ac motor under well tuned decoupling control behaves just like an externally excited dc motor with torque proportional to its armature current and magnetic flux density proportional to its field current. The field current is usually kept constant and set at a maximum magnetic flux density. Fig. 6 shows the simplified position loops for coordinated 2-axis motion controller. Fig. 7 shows the proposed digital control scheme for the DSP controlled PM ac servo drive and Fig. 8 is the block diagram of the proposed digital servo compensator. Proportional derivative with feed forward (PDFF) control scheme has been employed for the velocity loop regulation. Digital speed estimation algorithm has been developed for speed estimation when operating in low-speed range. Fig. 9 shows a typical operating frame of the constructed Windows-based user's interface for digital motion control.

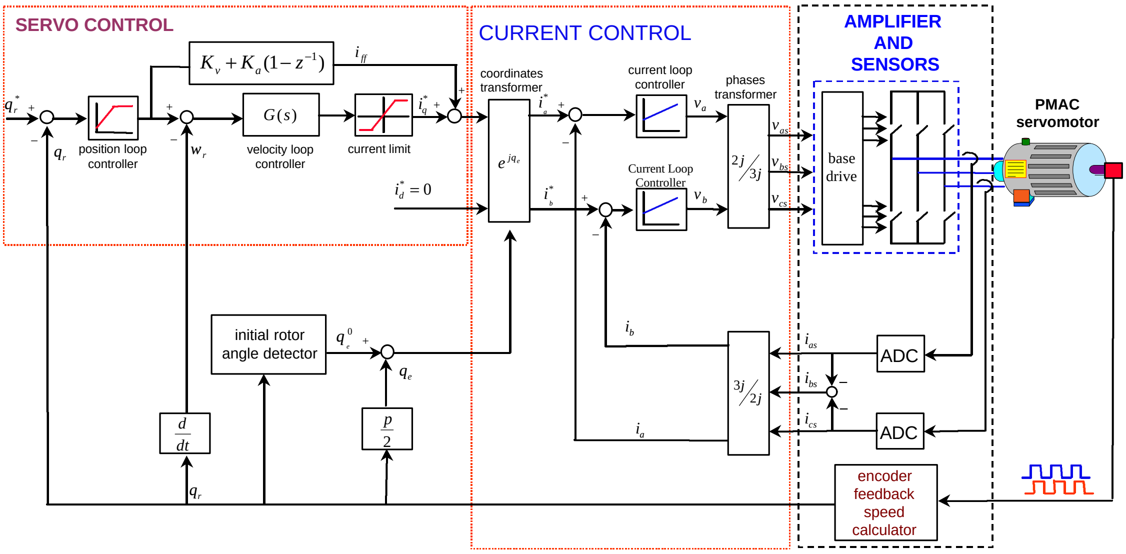

Fig. 7. Digital control scheme for a PM ac servo motor.

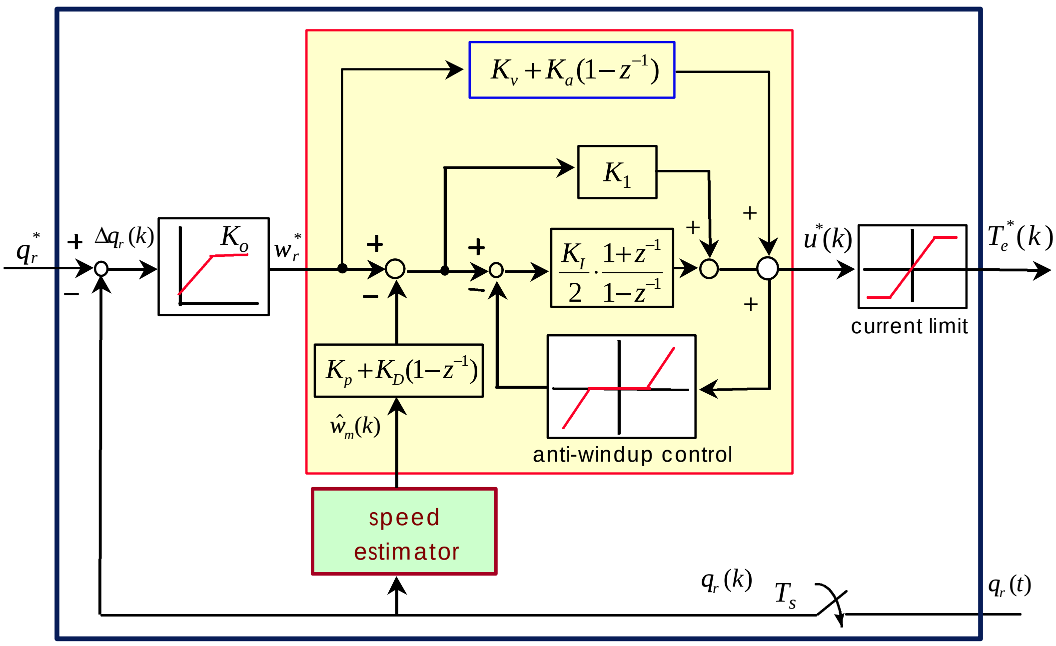

Fig. 8. Block diagram of the digital servo compensator.

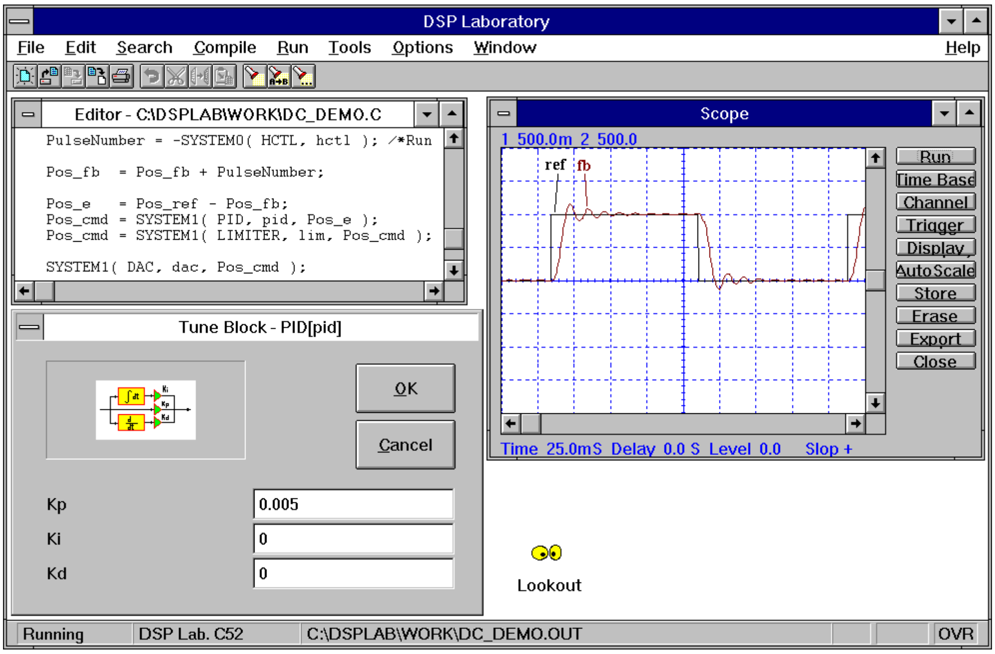

Fig. 9. Windows based user's interface for digital motion control.

Experimental results shows the developed digital torque drive can achieve fast dynamic response within accepted following errors. Control parameters can be interactively tuned via a user friendly interface. By employing SERCOS as a communication protocol for motion control systems, advanced software control algorithms can be developed based on the PC platform with real-time kernel. The SERCOS protocol can transform most of the control tasks of a motion control system to the development of control software under an open architecture environment. The design of a Windows-based development environment for digital motion control system can significantly ease the design tasks for motion and servo design.

IV. Conclusion

This paper proposes a SERCOS-based digital control structure for multiple-axis motion control systems. SERCOS-based torque drive plays a key component in such a distributed, coordinated, and real-time controlled multiple-axis motion control system. The torque drive features a standard torque interface based on the SERCOS protocol, which means it is independent of the servo motors been used. PC based motion controller initiates the development of digital motion and servo control based on a real-time multi-tasking operating system. The communication rate becomes a bottleneck when higher ramping speed control is required and more feed drives are to be synchronized. To enhance the application of SERCOS to advanced motion and power control systems, baud rate higher than 100Mbps needs to be developed.

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