Development and Implementation of AC Servo Motion System

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Abstract — **After reviewing the development of servo motor in China, the concept of ac servo motion system is put forward and introduced in this paper. Then the control structure of ac servo motion system is divided and compared. In order to speed up the development of sinusoidal-current-excited permanent magnetic synchronous motor (PMSM) servo system, the technology routine suitable to China is explored and the research emphasises are presented. Finally a design example of PMSM servo motion system is given.**

I. Introduction

AC servo motion system evolves from the ac servo system. AC servo system is the core of ac servo motion system. In addition to the ac servo motor and its driver, the ac servo motion system consists of the controller and the sensor. Its research object is the characteristic of the system and not the one of certain part, but the research of the ac servo system purely focuses on the speed, position, acceleration/deceleration and torque of the motor. Unlike general adjustable frequency system, ac servo motion system concerns not only the speed control, but also the position control. Moreover the dynamic characteristics of the ac servo motion system are superior to the general adjustable frequency system.

The large-scale production of the ac servo motor in China dates from the middle of 1980s of the 20th century. First, the variable-reluctance, permanent magnetic and hybrid stepping motors were produced. They can satisfy the open-loop control of the speed and the position and are used in the application of frequent start/stop. The subsequent developed switched reluctance motor (SRM) accomplished the close-loop control by means of detecting the position of the magnetic poles. In 1990s, the square-wave or trapezoidal-wave brushless DC motor (BLDCM) was rapidly developed. Similar to the SRM, the excitation state is determined by the sensor of the magnetic poles or the sensorless algorithm. The operation range and torque ability of the BLDC and SRM are superior to that of the stepping motor, but their position resolution is lower. From the end of last century to now, the sinusoidal-current-excited permanent magnetic synchronous motor (PMSM) and its control technology have attracted the attention of the researchers and manufacturers. Due to its outstanding performances such as high resolution, lower torque ripple and wide operation range, the sinusoidal-current-excited PMSM is an ideal choice in the servo applications. Up to now, the China stepping motors have been mature, their performance and price can be a match for that of other countries' motors. They are widely used in the simple numerical controlled machine tools, embroidery machines and carving machines. The noise at high speed limits the application area of SRM. The speed response of square-wave BLDCMs is faster than that of the induction motors, so they are used as the main axis motors of above mentioned machines. Due to the same cause, BLDCMs are also employed in the gymnastic equipments and motor bicycles. In China, the development of PMSM and its system is at initial stage, it will take at least several years to follow the other kinds of ac servo motors [1].

The development of PMSM servo system is more difficulty than other servo system. Some industries have adopted the strategy of integrating the PMSM, driver, controller and sensor, and remarkable successes have been achieved. These resulted from the concept of ac servo motion system. However the designers often feel puzzled how to determine technology requirement, system structure, software function and hardware distribution. In this paper, the control structure of ac servo motion system is first discussed, and the function of the controller is compared in two types of control structures. Then the technology routine suitable to China is explored and the research emphasises are presented. Finally a design example of the PMSM servo motion system is given.

II. Control Structurs

The driver generally consists of power devices and microcontroller such as digital signal processor (DSP). The function difference between the controller and the microcontroller results in two types of control structures: the concentrated control structure and the distributed control structure, as shown in Figs. 1 and 2.

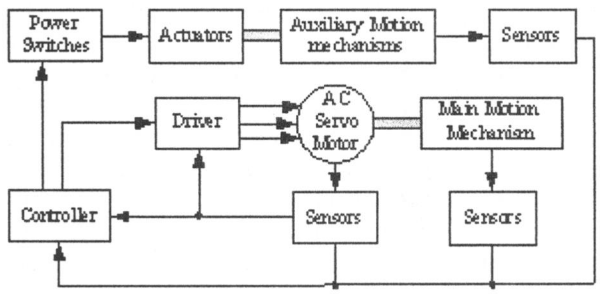


Fig. 1. Concentrated control structure.

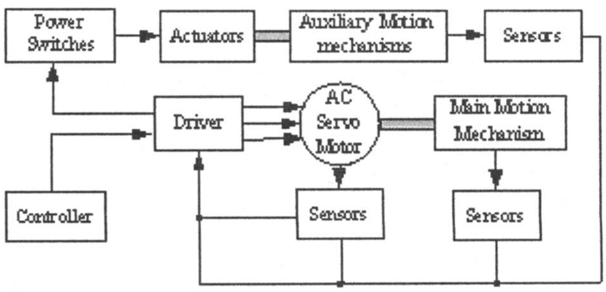


Fig. 2. Distributed control structure.

In Figs. 1 and 2, the sensors of the ac servo motor detect the current, position, speed and temperature. Their outputs serve as the inputs of the motor control algorithm. The sensors of the motion mechanism are determined by the process technology, they can be the position, temperature, pressure, tension, flow or light sensors. The solenoids, valve or other types of the motors can be used as the actuators. The controller can be the industrial computer, programmable logic controller (PLC) or single chip microcontroller such as DSP and ARM. The keyboard, button, disk and communication interface are employed to receive the operation commands. The process or run parameters can be displayed. The light and sound devices can be for the purpose of the monitor and alarm.

In the concentrated control structure, the controller is responsible for the calculation and analysis of the received commands and sensor signals, then controlling the driver and power devices. All control signals come from the controller, the technology software is also stored in the controller. The power devices and driver are controlled separately and are subsystems of the controller. In the distributed control structure, the controller only functions as the input and display. The microcontroller in the driver plays the main controller's role. It controls not only the ac servo motor, but also the power devices and other drivers. Some parts of technology software are stored in the microcontroller. The controller and microcontroller are often connected with the communication interface.

For the mature ac servo system, its performance is universal and entire, so the concentrated control structure is the ideal choice. As long as the suitable ac servo system is selected, the development period of the application system will be shorten. The system designers focus on only the controller. This control structure requires the controller to have strong ability of numerical operation, ample input/output ports, adequate interrupts and timers. The distributed control structure is more suitable to the special or new type systems. The control task can be flexibly distributed between the controller and the microcontroller. The requirements on the controller decrease, but the performance of the microcontroller should be stronger than that in the concentrated control system. This control structure is compact, its cost is low. Once the development is successful, the intellectual property right will be owned. It can be found that the distributed control structure is fit for the development of PMSM servo motion system at initial stage.

III. Key Technologies

In China, the degree of difficulty in developing ac servo motion system are the controller (less difficult), motor, sensor and driver (most difficult). Some key technologies are as follows [2]:

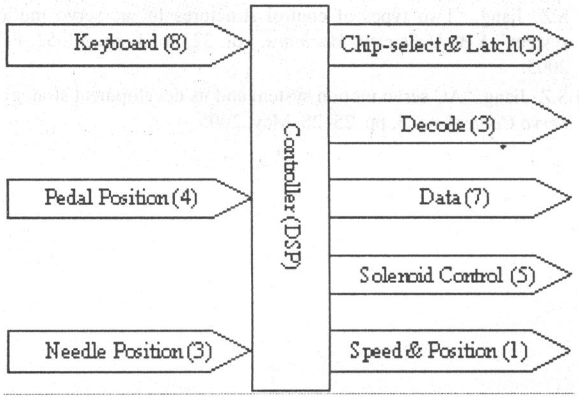
- Controller: Its hardware is maturest and its fulfillment is easiest. The hardware obstacle is how to replace the current expensive PLC with cheap and reliable single chip microcontroller. The software task is to set a standard and open development platform which is easy to use like the PLC development platform.
- Motor: Stepping motor, SRM and square-wave BLDCM has been mature, PMSM is in development stage. The design ability in China doesn't fall behind. The main difficulties are the manufacturing technology level and materials. At initial stage, those PMSMs for special applications such as low speed large torque, large inertia and potential energy load should be developed to satisfy the market demands.
- Sensor: The types of the sensor are manifold. Some of them are imported and are expensive. These sensors should be made domestically. For new types of sensor, they are should be researched and developed as fast as possible.
- Driver: It's the main obstacle to industrialize PMSM servo system. There are three reasons: devices, mathematical model and the management of research group. The popularization of high speed DSP and application-specific intelligent power module (ASIPM) alleviates the device difficulty. In view of the sensorless control, low speed/step operation and fast response, precise mathematical model should be researched. At present, the researchers are scattered. How to organize and optimize the research sources is worthy of thinking seriously.

IV. Implementation Of System

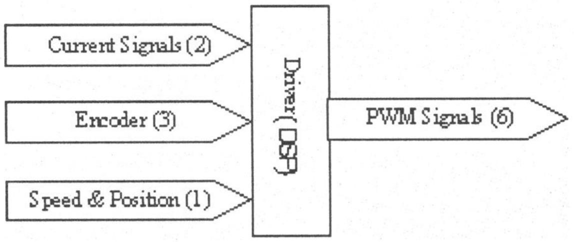
In recent years, a large amount of industrial sewing machines has been produced in China. Only in 2004, 470 million sewing machines were manufactured, but less than ten percent of them employed the PMSMs. The characteristics of servo system in sewing machines are [3]:

- Wide operation range: from 200 rpm to 6000 rpm;
- Fast speed response: 100 ms start time from start to 4500 rpm at full load;
- Lower position resolution: less than $\pm 3°$;
- Zero electromagnetic torque at still.

For the lockstitch sewing machines, the PMSM drives the needle mechanism to reciprocate. According to needle position, the corresponding solenoid is triggered to finish expected motion. Fig. 3 shows the functions of the controller and microcontroller in the concentrated control structure. In Fig. 3(a), the keyboard is 4×4 array and occupies 8 input ports. The 16 control states of the pedal are obtained by 4 bits binary input signals. The needle position signal (3 bits wide) comes from the optical encode on the motor's shaft end, two of the 3 bits signals are quadrature pulses. The chip-select and latch signals need 3 output ports. Another 3 bits output signals are decoded into 8 bits signals to latch the 7 bits wide display data for 8 7-segment light emitting diodes (LEDs). Five solenoids are controlled by 5 output ports. The controller outputs the pulse signal to control the speed and position of the PMSM. In Fig. 3(b), the DSP fulfills the field-oriented control of three-phase PMSM. 2 current sensor signals and 3 encoder signals are the inputs and 6 pulse width modulation (PWM) signals are used to control the three-phase inverter. The speed and position commands come from the controller. Fig. 4 shows the design scheme of distributed control structure. The DSP in the driver carries out some functions of the DSP in the controller in Fig. 3(a). The burden of the DSP in Fig. 4(a) reduces and it only serves as reading the keyboard, displaying and communicating.

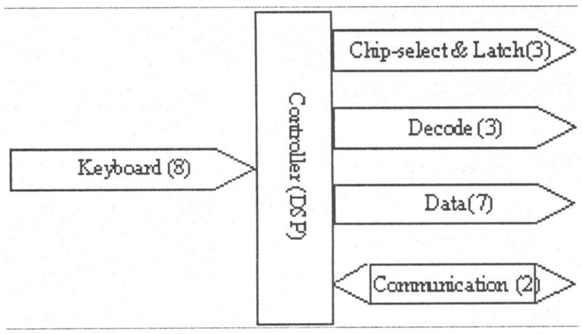


(a). The function of the controller

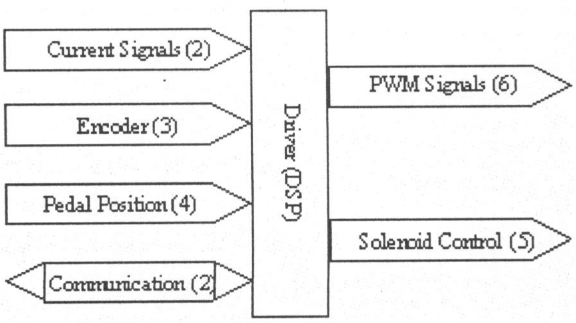


(b). The function of the driver

Fig. 3. DSP-based concentrated control structure.



(a). The function of the controller



(b). The function of the driver

Fig. 4. DSP-based distributed control structure.

Fig. 5 shows the printed circuit board of the controller in Fig. 4(a). For convenience of comparing the two control structures, DSP is still selected. On the board, there are 4×4 array keyboard, 8 LEDs and 232 standard serial communication interface. It's noted that if the keyboard names are renamed, the board can be used in other applications. Fig. 6 shows the printed circuit board of the microcontroller in Fig. 4(b). In addition to the 2-channel current sensor signals, 3-channal encoder interfaces and 6 PWM outputs, there are 4 digital inputs, 5 digital outputs and a communication interface. The 375 W and 550 W PMSMs are shown in Fig. 7.

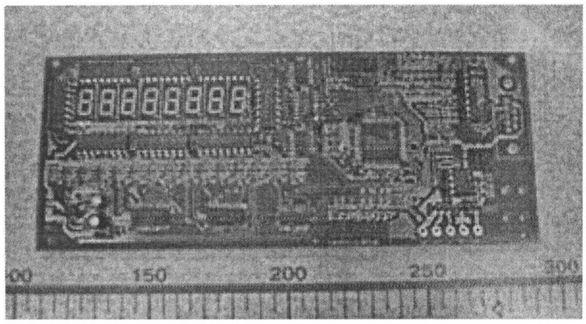


Fig. 5. The board of DSP-based controller.

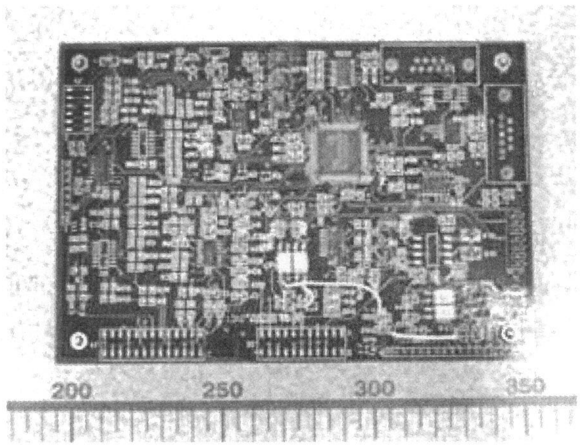


Fig. 6. The board of DSP-based microcontroller for the driver.

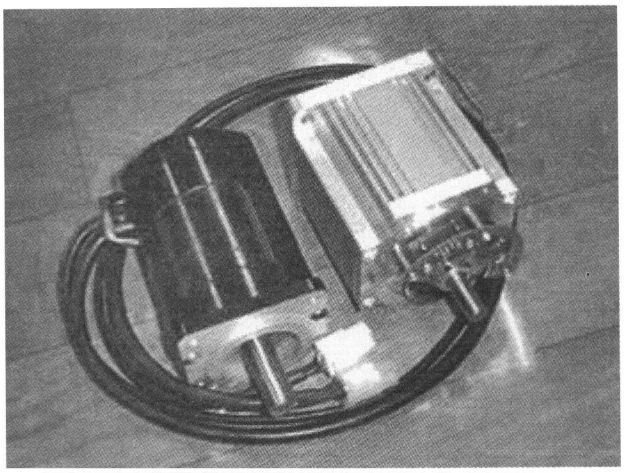


Fig. 7. 375 W (left) and 550 W (right) PMSMs.

V. Conclusion

The concept of ac servo motion system is put forward and introduced. The concentrated and distributed control structures are compared. Some key technologies are given. All of these aim to speed up the research and application of PMSM servo motion system in China. The object is to manufacture universal PMSM servo system. It's particularly indicated that the distributed control structure is ideal choice at initial developing stage of PMSM servo system. In this way, the PMSM servo products can go into the market as soon as possible. The given design scheme can also be applied in the similar applications.

References

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