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Motion Control in Mechatronics Devices

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Abstract

This paper describes motion control system applied to mechatronics devices. It is pointed out that a new approach is necessary to realize a good performance motion control. At first, a motion controller of mechatronics devices is introduced. The controller is constructed from four layer of hierarchical structure. After that two practical examples are presented to introduce the new approach to advanced motion control exactly.

1. Introduction

The term of "Mechatronics" was coined out in 1971 as a registered brand name by Yaskawa Electric and became familiar to us from about ten years ago. Through various kinds of its use, the term seems to have fully gained much recognition as a term indicating an engineering category of today's high technologies in Japan. Moreover, it is an undoubted fact that both numerical control machine tools and industrial robots have significantly big weights in one field of mechatronics technology.

Meanwhile, motion control is an important baisic technology in this engineering category of mechatronics. It is widely known to us that this motion control covers a wide range of engineering and that research and development effort has been made in a variety of fields relating to this technology.

In this motion control, however, the main targets of research seems to relate to one actuator, a power circuit to drive the actuator, and its control circuit and control system, all of which are individually mounted to realize a desired operation. When it comes to general industrial machinery, mechanisms composed of multiple axes for straight or rotational movement, and it is rather seldom that the motion control for these axes is applied indipendently. When applying the motion control to a multi-axis machine, a control unit is usually employed to automatically and smoothly perform complex machining operation. In this context this control unit is defined as the motion controller in the mechatronics devices control. The final goal of the motion control in mechatronics devices is to realize a specified operation automatically at a desired accuracy and in a specified process time, and therefore various technologies to achieve the final goal will become truly important as the future mechatronics devices control technology.

From such a point of view, this article first describes the motion controller in the mechatronics devices control technology and then the structural concepts of numerical control of machine tools and control units of industrial robot, which are typical products of mechatronics devices, followed by examples of the motion control of today.

2. Configuration of Motion Controller

With respect to motion controllers including numerical control units for machine tools as well as control units for industrial robots, various kinds of control funtions, which are conventionally employed in micro, middle-sized, and large-sized computers, have been utilized one after another. For example the industrial motion controllers recently have incorporated multi-CPU (Central Processing Unit) mainly 32-bit CPUs. Multi-task processing has been introduced to a group of servo actuators to perform the group control. And, general purpose real-time OS (Operating System) has been adopted. These introduction and adoption are realizing high speed and high accuracy tool-path control. In adittion,much effort is being made to respond to the demands for realization of composite and highly functional operations.

Meanwhile,the configurations of the motion controllers mentioned above seems to have various differences when their hardware and software are picked up for comparison.In accordance with the types of operation,such as turning,boring, grinding,welding,or coating operation,some differences are seen in the procedure of manual operation and automatic operation,as well as the screen display function. It can be said,however,that the basic functions of these controllers consist of,by and large,four layers in a hierarchical structure.

That is to say,given some differences in contents,an operator intervences within the structure,programs for the operation are created automatically or semiautomatically,and thereby the cutting tools and peripheral devices are controlled to perform a specified operation automatically.In acordance with the foregoing concept,a controller is chosen to satisfy the target work mentioned above.Figure 1 shows a conceptual configuration of a motion controller based upon such a concept.The upper portion of the structure is referred to as the sensitivity layer,and by citing the term pertaining to biological genes and by taking each role inside the controller into consideration,the subsequent three layers are respectively referred to as the structural layer,the regulatory layer and the operator layer.

The uppermost sensitivity layer is the area in which various function relating to human interface are performed.And,the interrelation with the external environment(various communication components for building the CIM and FA system)is also carried out through this area.The role of this layer is important in that it determines efficient machine operation without errors.

The functional increase in this area has recently become tremendous in comparison with other layers from the viewpoints of the volume of created software and various types of humann-interface hardware to be connected.

The next-coming structural layer is the area in which the functional structure of controller is determined. The hardware configuration of this area has some differences,depending on whether or not the operational control is implemented by inputing numeric values,how the language system for operational instruction is established,or whether or not the operational control is performed by instruction and regeneration.The software configuration is becoming more remarkably different.

The difference between the present numerical control units for machine tools and the control units for industrial robots seems to lie in the difference in applicable languages,and this difference in the languages makes the configurating system of the structural layer conspicuously different.In the case of more versatile mechatronics devices control,it is regarded as important to give this structural layer a versatile configuration.

The third layer is the regulatory layer.In general,various machine tools need controls not only to execute the main operation with cutting tools but also to hold and fix the work-pieces and to change their position.And,in the case of executing a trial operation,basically required is an overlapping function with which the control is automatically carried out along with an operational program while an operational command can be added by the operator.Moreover,the recent machine tools are required to provide independent or synchronized motion of two or three cutting tools.

The role of this regulatory layer is to regulate and/or adjust an integrated motion of a machine tool through surveillance,mutual restriction,and cooperation of such complicated motion.This layer includes a sequence-control section for peripheral devices,a monitoring section for operational integration,a motion profile generating and processing section,a failure diagnosing and monitoring section,and an external sensor signal processing section.These sections must interchange information closely with one another and operate smoothly the devices to be controlled.

The lowermost layer is the operator layer.This layer is the area in which respective devices(various actuators)are operated in accordance with the commands that are issued from the regulatory layer.The machine tools and industrial robots incorporate control system for servo-actuators and servo-drives as the main control systems.Accompanying to these motions,control of actuators and relays is needed and included in the operator layer so as to perform on/off operation.Also digital I/O handling sections are included in order to interchange signals with external devices.

Generally speaking,when it comes to the motion control in mechatronics,improvement of characteristics in the operator layer mentioned above tends to occupy the central topic of discussion,but when seem from the viewpoint of the motion control for accomplishment of opration,it should be pointed out that it will become more and more important to create ingenious motions as much as possible through interaction between the regulatory layer and the operator layer.

3. Function of Motion Control

The servo-actuator that is generally employed as a motion control unit for present mechatronics devices is mainly based on a position control system which incorporates torque(current) minor loop and a velocity minor loop.

PTP(Point To Point) control or CP(Continuous Path) control is implemented by giving those loops proper commands of time function.

The actuator employed for machine tool spindle is mainly used as a velocity control system.But recently,it also has begun to be used as a position control system for various kinds of work.Figure 2 showes a configuration of the position control system as a software servo system.

What is demanded for these performances of the motion control are quick response and good regulation as well as the robust property against disturvance in pursuit of high speed and high accuracy in many kinds of operations.

Meanwhile, in the present motion control system, each one actuator is used for each straightforward motion or rotational motion, and the axis control system (shown Figure 2) composed individually and independently. And, in regard to a space trajectory control by combined control of multiple axes, or a synchronized control of two axes, commands of positions in which each axis must be operated are determined as the time function for each axis by means of multi-axis interpolation in the regulatory layer, then these commands are given to each axis through the operator layer as the operational motion reference input to perform the servo-system control function.

4. New Approach to Motion Control --Advanced Motion control--

Recent strong demands for various kinds of operations are centered around high speed and high accuracy, and development to satisfy these demands are being reported through various activities in the field of machine tools. However, no observation of approach is not made from the aspect of the motion controller.

From a viewpoint to satisfy these demands, it is necessary to expand the scope of concept from the motion control for a single axis to the entire motion control system including the mechanism configuration. In this chapter, hereafter, two examples are cited to explain the necessaity of concept expansion. The first example is a cutting operation to provide the surface of a cylindrical part with dents of a trapezoidal pattern (Figure 3).

As regards an ordinary configuration of a machine tool, machining operation is performed with the biaxial system shown in figure 3(a). The first axis rotates a part, and this rotation is timed to the second axis and then the second axis cuts the pattern shown on the right side of the Figure as much as ΔL (L_2/N and N arepr ovided in advance) and N times of cutting gives the final and desired pattern.

In order to shorten the machining time in such an operation, it is needed to speed up the rotation of the first axis. In order to maintain the machining accuracy (straightness or surface roughness of the trapezoidal pattern) in the speed gaining process, the response characteristics of the second axis must be improved in conformity with the speed of rotation. In the general case of the biaxial configuration however, the moment of inertia of the second axis is considerably large, and it is accordingly very difficult to drastically improve the response characteristics.

In this connection, adoption of the triaxial system that is shown in Figure 3 (b) enable to obtain a very good finishing accuracy in terms of the high speed operation of the first axis. The second axis perform a repetitive motion over the length of L_1 at a low speed. At this time, if the third low-inertia axis holding the cutting tool only performs a repetitive motion of the same pattern over the length of L_2 at a high speed for N times, it becomes possible to create a desired shape. It may be understood easily that, in comparison with the biaxial system, the triaxial system excels the former in the controlling performance of the cutting tool control system as far as the high speed and high accuracy motion is concerned.

On the other hand, when adopting the above mentioned triaxial system, realizing these controls only with the operator layer will demand the control system to provide special shapes only to the axes relating to these motion and, in consequence, the configuration is forced to become complicated as a whole.

Therfore, it is desired that control for synchronization among three axes or for timing of start up should be carried out via the upper regulatory layer and that the motion control section should devote itself to the performance of high speed and high accuracy response.

And, as is easily known from the motion of biaxial system and the triaxial system, the biaxial system changes its motion starting point little by little every time. However, in the case of the triaxial system, the third axis is to always repeat the repetitive motion of the diatance L_2 on the second axis. Therfore it becomes available to apply a method of repetitive control to the third axis without difficulty, and it is accordingly possible to remarkably improve its response characteristics.

The second example explains tapping (screw forming) operation by rotation and straightforward motion. In performing the tapping operation, it is needed to finish the screw pitch and the screw length to a satisfactory level of accuracy. Moreover, it is required to execute position synchronizing control between two axes at a good timing because the control is accompanied by the rotational motion and the straightforward motion. Figure 4 shows a configuration of the control system to accurately perform the position synchronizing control between the two axes.

The X_1 and X_2 in the Figure show both a rotatioal angle and distance, respectively. G_{s1} and G_{s2} show system dynamics of the rotational axis and the straightforward axis, and G_{11}, G_{12}, G_{21} and G_{22} show controllers for axis position and velocity loops, respectively. The area surrounded with broken lines shows the compensating control section for the position synchronizing control between the two axes.

M_1 and M_2 are the blocks to calculate the distance over which the second axis must actually move in accordance with the command values previously calculated and given from the upper computer individually for the first and second axes. G_{c1} and G_{c2} are the blocks to perform compensating calculation for control of these values.

When configurating such a control system, it is by any means indispensable for the compensating control block to secure not only the command values for the two axes but also information on the state of the counterpart axis (the first axis in this connection) to be synchronized.

As to the motion control of a machine composed of multiple axes (5 to 10 axes) in which composite machining is required, the two axes with which the synchronized control is desired are not always limited to two specified axes. It is often the case with such a machine that any two axes are picked up among the multiple axes as the target of synchronized control. It is, however, difficult to realize synchronized control between these optionally chosen two axes, by using the operator layer only.

The solution can be found in making a compensating control section for the synchronized control of two axes incorporated in the regulatory layer, and thereby it becomes possible to give excellent flexibility towards synchronized control for the arbitrary two axes.

5. Conclusion

Thus, with respect to the concept of advanced motion control in the mechatronics technology, the multi-axis coorperated-motion needs motion control method developed in consideration of both the configuration of the mechanism itself and the configuration of the control system. Moreover, in the case of a certain type of motion control, it is basically necessary to integrate two axes motion into one control system as a "MIMO"(Multi-Input and Multi-Output).

Also, in oder to practically realize these necessities, it is not the point to pay attention to the single axis motion control alone, but it is important to configurate a control system which involves multiple axes and the upper layers for the advanced motion control function.

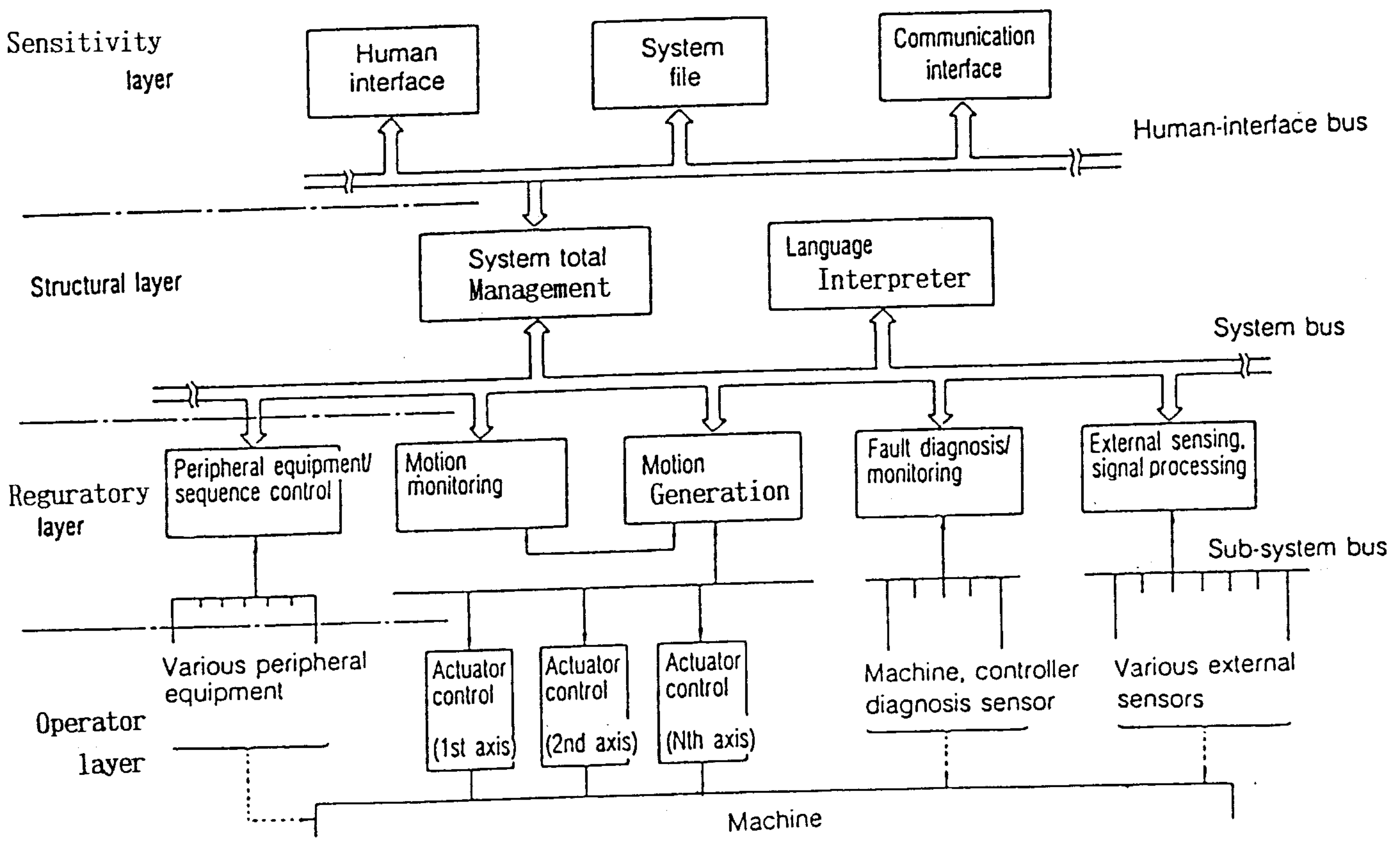


Fig.1 Hierarchical Structure of Motion Controller

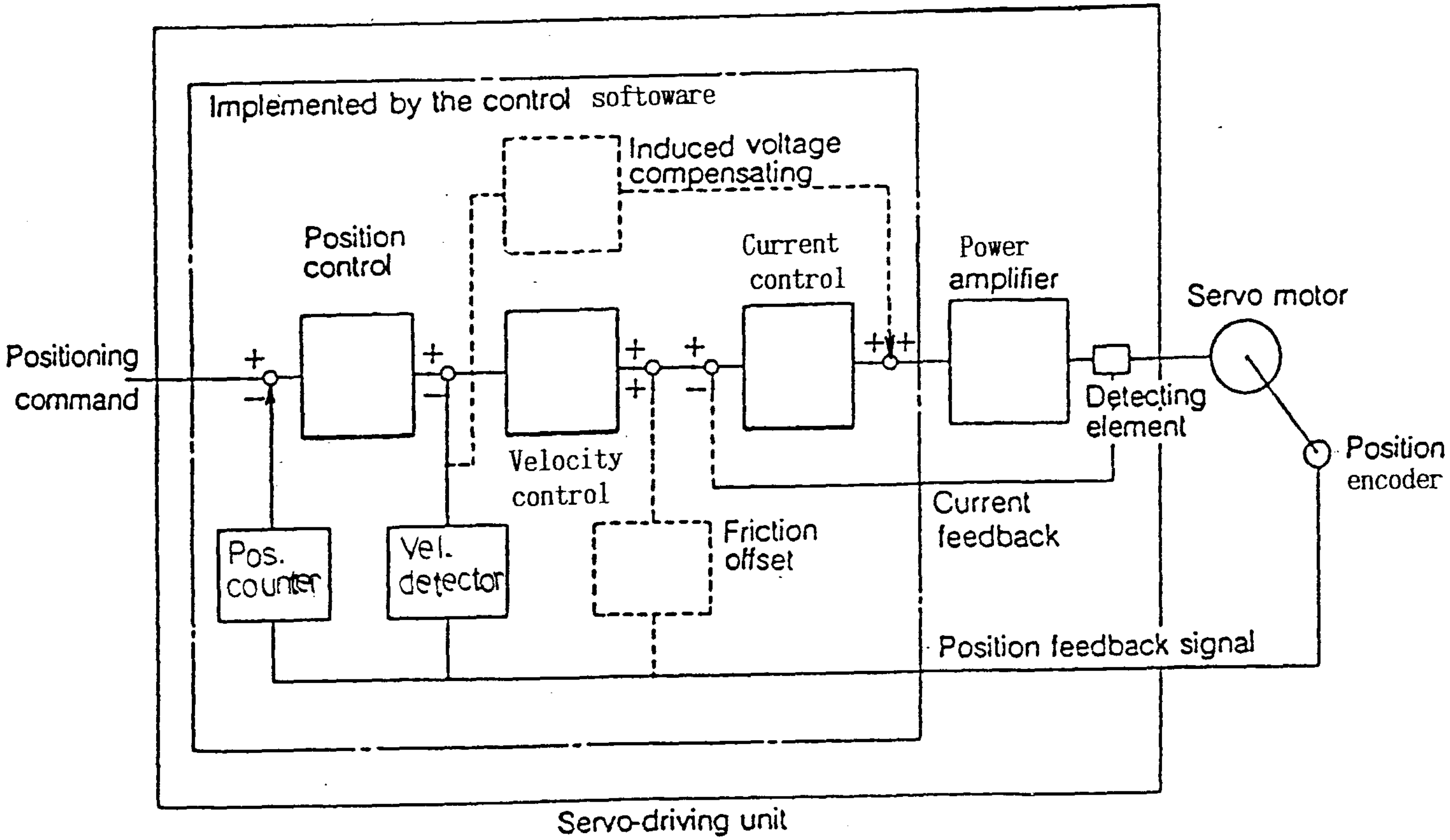
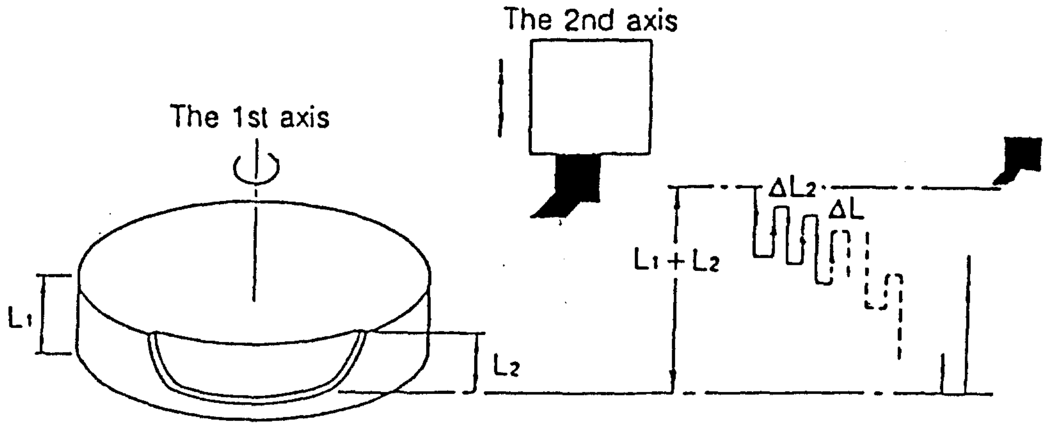
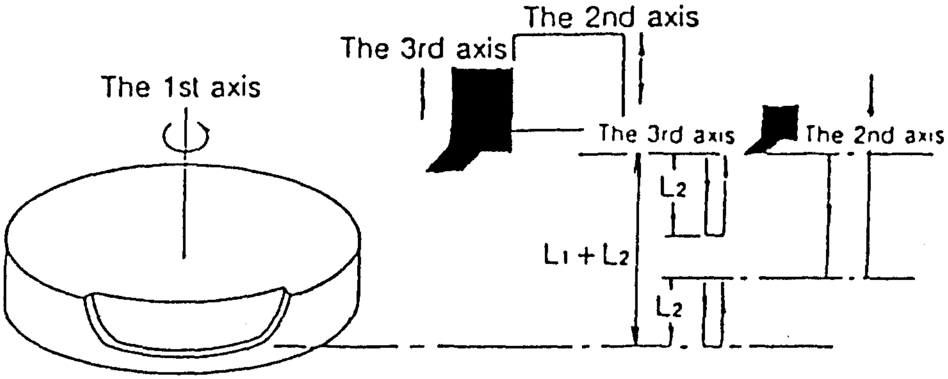


Fig.2 Block Diagram of Position Control System



(a) The 2-axis system



(b) The 3-axis system

Fig.3 Mechanical Structure for High-Accuracy Machining

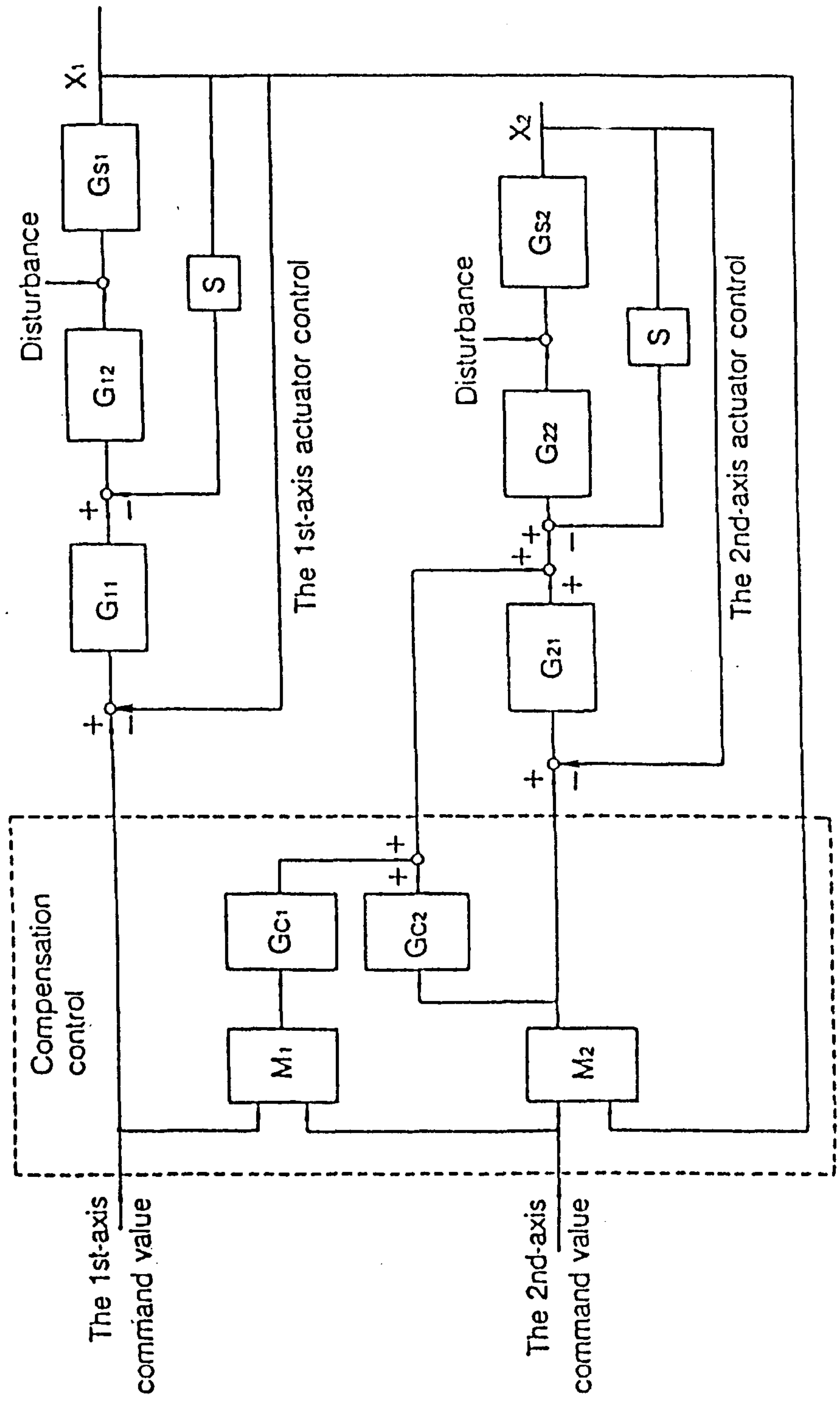


Fig.4 Coordinated 2-Axis Control System