Distributed Control of the Arago's Disc System with Gain Scheduler

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ABSTRACT

Arago's disk system consists of a speed controller of the DC motor (inner loop controller) and a position controller of the magnetic bar angle (main controller), which are implemented by the design of the PI and PID controller, respectively. First, we analyzed the nonlinear characteristics of the Arago disk system and found the operating point range of three locations as a result. In this paper, a gain scheduler method was applied to guarantee a constant control performance in the range of 0 ~ 130 °, and a structure to change the controller according to the control reference value based on the previously obtained operating points was experimentally implemented. The Distributed Control Systems (DCS) configuration using the Controller Area Network (CAN) was used to verify the proposed method by improving the operational efficiency of the entire experimental system. So, simplicity of the circuit and easy diagnosis were achieved through a single CAN bus communication.

Key Words : Gain Scheduler, Distributed Control System, Arago Disc System, Operating Points

1. Introduction

As an important drive configuration in the industry, in application ranging across speeds and powers as a result of its efficiency in control and excellent performance, DC motor has been of a great significance. Researches as equally shown that adopting mechanical or electrical approaches, both the speed and position control of DC motor can be accomplished[1]. Distributed Control system (DCSs) is adopted in this research due to its special features ranging from its redundancy design, improved control reliability, performance and diagnostic capabilities. Besides, it also provides greater flexibility to control both the distributed field devices (sensors and actuators) and its operating points. These field devices of discrete types are interfaces to input and output controller modules via communication bus. Through a networked-based distributed control system, there is a minimum in wiring, installation, maintenance and repair cost reduction resulting to a flexible structure in the entire control system [2].

Gain scheduling approach is used in design related to nonlinear control. Though several control techniques are regarded to be gain scheduling, their design procedure is of a divide and conquer type where the nonlinear control design task is broken into linear sub systems. This approach is the main reason behind the popularity of gain scheduling technique as it enables linear design methods to be well established and applied to nonlinear task [3, 4].

2. Theoretical Study

2.1 Concept of Gain Scheduling and Controller

Gain Scheduling is a controller design methodology whereby controller coefficients are varied in accordance to the present value of scheduling signals which may be either external or internal to the system. It is also a PID (Proportional- Integral- Derivative) enhancing factor that facilitates the control of a system with time and gains

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constant varying in accordance to the current value of the process variable. The gain scheduler is executed within the controller's microprocessor by monitoring the process variable in order to determine when the process has entered a new operating point. After this, the controller is then updated with a predetermined set of tuning parameters designed to optimize the closed-loop performance in that range [3, 4]. As shown in Fig. 1, the dynamics of a plant/ system in most instances vary with operating conditions. This change accounts for the known nonlinearities. Therefore, changing the controller parameters is possible through monitoring the system's operating conditions. Hence the scheme was to help accommodate changes in the process gain only [5].

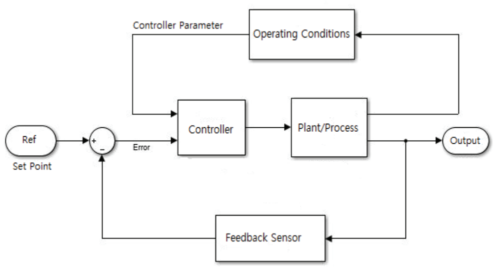

Fig. 1. Schematic diagram of gain scheduling control system.

Gain scheduling implementation is quite easy in computer-controlled systems. In the course of changing the parameter variables, feedback gains are adjusted. When scheduling variables have been deformed, the controller parameters are calculated at a number of operating conditions using some suitable design approach. The controller is tuned for each operating condition. The stability and performance of the system are evaluated at different operating conditions [5].

2.2 Distributed Control System (DCSs) & CAN (Controller Area Network) Protocol

The distributed control method was known to be useful for a complicated control system configuration. Arago's disc system using a gain scheduling approach is complex in configuration. So, in this paper, the distributed control method will be used to ensure a performance of this control system at all operating points under investigation. This control system has sensor subsystems which read data from the plant/system to be controlled. The controller subsystems process this data and derives the control action needed. The actuator subsystem performs the action implied by the controller on the plant/system. Hence, there should be a communication network between all nodes of a distributed control system. For implementation of the system via the distributed control, we will use the CAN (Controller Area Network) which supports many requirements such as simple protocol and high transmission reliability for a fieldbus. This fieldbus will also drastically influence the architecture of distributed control system. Generally, the use of a normal hardware structure shows lots of I/O ports being used to interface each device to the microcontroller making all design looking clumsy and cumbersome. Using CAN, substituting this with just a single two-twisted wire, a lot of advantages comes into place ranging from complex wiring replacement, ease of device installation to BUS, ease of error detection, a robust noise immunity etc[6-9].

As shown in Fig.2, Arago's Disc System has five essential nodes which are required. There are two sensor nodes, one actuator node, and two control nodes each with a distinct function [8]. With well-defined software written in C programming language and a design of a single CAN BUS, the communication between nodes are achieved.

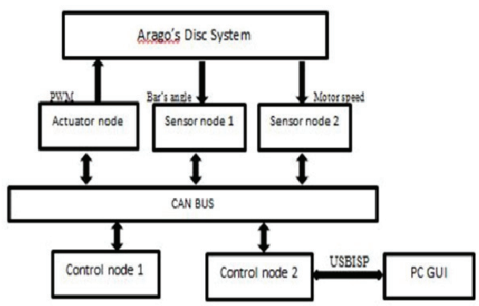

Fig. 2. Structure of a distributed control system with Arago Disc System.

CAN have a multi-master bus topology that has been proven to be an effective technique in fault tolerance and error detections is employed. In order to control the Arago disc system using a distributed control approach, the analog signal input/output value converted by CAN protocol requires a device that can transmit and receive. In this paper, an on-chip CAN module is contained on the DVK90CAN1 development board which has an AT90CAN128 micro-controller chip also being embedded. With this design type, adequate distribution of control over the entire CAN BUS will be achieved [9, 10].

3. Experimental Setup and Result

3.1 System Hardware Implementation & System Constituents

In this paper, the AT90CAN128 AVR microcontroller is used which provides a highly flexible and cost effective solution to many embedded control applications. The H-bridge L298 motor driver (DCMD-25-D) was also used, providing the system with the control of the direction of rotation of DC motor and as well control of motor via PWM (Pulse Width Modulation) technique. Tamagawa TS3881N1E187 type DC motor with 7V/1000rpm tacho-generator was used. This tacho-generator serves as the feedback sensor being used to measure the speed of the motor. The system constituent also consist of a potentiometer serving as the feedback sensor being used to measure the angle of the magnetic bar in the Arago part of the Arago's disc system.

Fig. 3 below illustrates the block diagram consisting of both the DC motor speed control and the position control of the magnetic bar’s angle of the Arago’s disc system

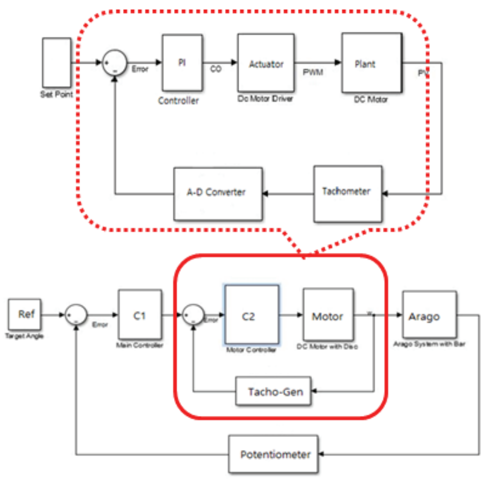

Fig. 3. A block diagram for explaining the inner (sub, speed) and main (position) controller.

respectively. From the diagram, it is deduced that the control of the Arago’s disc system is composed of speed controller (Inner loop controller) mark with a dotted lines and position controller (main controller) each with different configuration[6-10].

In this paper, for using a method of the distributed control system (section 2.2 and Fig.2), this system is implemented via communication among five nodes viz; two sensor nodes, one actuator node, and two (main & sub) control nodes.

The sensor node consist of the sensor node 1 (System's Angle Node) designed to read the value of the magnetic bar's angle via a communication with the potentiometer. This value or data is transmitted to main controller (control node 1) whenever there is a request of data. Sensor node 2 (tacho node) reads the current/present value of the rotational speed of the Arago's disc. Consequently, the speed data is transmitted to the motor controller (sub, control node 2) whenever there is a request by it via the CAN BUS. Appropriate PWM waveform is generated in the actuator node which drives the DC motor via the motor driver. Thus, it plays a role to change the speed of the Arago's disc in accordance with the instruction of the motor controller.

In the control nodes, PI and PID controllers are executed to control the inner loop and main loop of the system respectively. While the motor controller is designed to take responsibility of the appropriate calculation using PI controller which changes the speed of the Arago's disc in accordance with the speed command. The main controller controls the entire system. It generates a control value needed to rotate the disc based on the magnetic bar's angle value read from sensor node 1. This control value is conveyed to motor controller where the value and the current DC motor rotational speed value are compared making it possible to rotate the disc at a required or target speed. For communication of the main and motor controllers, the length of the packet data was analyzed with each operating at a control period of 20msec and 4msec respectively. The reason why, to attain a good performance and high stability of the system, it was ensured that the inner loop control was faster than the main loop control. To avoid occurrence of data confliction in the distributed control implementation, controllers were designed to have different operating sampling time. With the use of a single

CAN BUS, the simplicity of the CAN architecture was achieved and also easy diagnosis in case there is a breakdown of any node.

Fig. 4 is the overall system's experimental setup which has the Arago's disc system to the left part, the interface unit in the middle and the system nodes to the right. It shows the five system nodes consisting of actuator node, potentiometer sensor node, tacho sensor node, motor controller node, main controller node all connected to a single CAN bus with two twisted wire each.

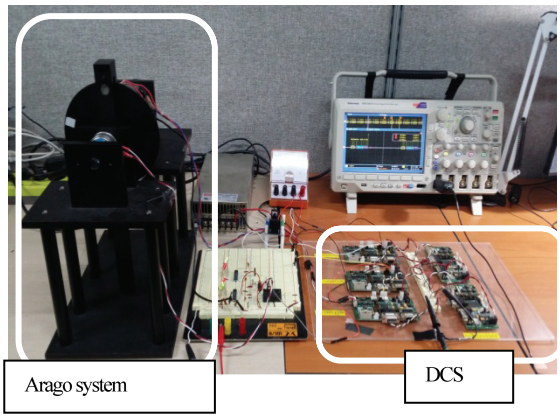

Fig. 4. Experimental setup.

3.2 Experimental Result and Discussion

The PI controller gain of K_P=25, K_I=2 was obtained via tuning in the speed control of the system having ensured the effect of overshoot, damping, steady state error characteristics of the system..

In this paper, operating points were selected based on nonlinearity characteristics of the Arago's disc system [11]. The magnetic bar's angle in relation to its stability range was the basis of choosing these operating points. Magnetic bar's angle below 90^0 is at a stable region, at 90^0; it is marginally stable while above 90^0; it is unstable. Therefore, a control over the range of 0^0~130^0 was experimented. In order to control each operating points of the Arago's disc system, the gain scheduling PID controller used has different K_P, K_I, K_D gain value which were determined through tuning under the experiment. Table 1. shows the PID controller gain obtained by manual tuning of each control function. To achieve a desired result, a trial and error means of tuning was carried out by manually adding proportional (P), integral (I) and derivative (D) term in succession. . Proportional gain value (K_P) is increased until a best response is achieved. P term is decreased slightly while adding I term gradually to improve steady state error. It is ensured that much increase of I term will increase overshoot and oscillation and finally D term is added to improve transient response. This method describes the Zeigler-Nichols method of tuning the parameters of PID controllers which is probably the most common for use [12].

Table 1. PID Controller Gain

PID Gain	45 Degree	90 Degree	120 Degree
K_P	11	90	200
K_I	0.052	0.001	5
K_D	4	13.5	10

Fig. 5(a)~5(c) below shows the experimental output waveform results of the operating position obtained when the reference angles of the magnetic bar was set to 45^0, 90^0 and 120^0 respectively. It can be inferred that, the test input signals used was a step input control enabling both the transient and steady state response characteristics be analyzed. These specifications are analyzed and indicated on each input signals output waveform diagram below.

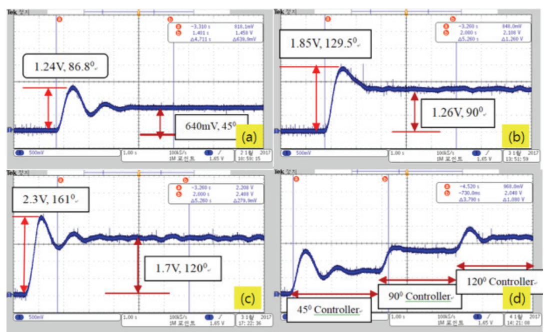

Fig. 5. Magnetic bar's angle of Arago's disc controlled at 45^0(a), 90^0(b), 120^0(c), and change controllers with time(d).

At 45^0, (Fig.5(a)) the maximum overshoot at transient response was 1.24V at 86.8^0. There was no either oscillation or damping. When the set point of the magnetic bar was changed to 90^0, (Fig.5(b)) the output voltage of the potentiometer was 1.26V as seen from the waveform above. There was a maximum overshoot of 1.85V at approximately 129.5^0 but steady state was reach without oscillation. In Fig.5(c), though little oscillation occurred at steady state response, the voltage value at 120^0 was 1.7V. These can be shown that, though overshoot occurs at rising period in the three (3) input signals but no significant steady state error exist. Hence, the stability of the three operating angles was achieved. Fig.5(d) shows the magnetic bar's angle of the system when there was a change in each controller of the operating point with respect to time.

The experiment for the Arago's disc system was carried out when the reference angle is changed continuously from 0^0~130^0 with respect to no change in the controllers of the operating angles (i.e. 45^0, 90^0 and 120^0). The corresponding output waveforms for each operating angles controller are shown in Fig. 6(a), 6(b) and 6(c) respectively.

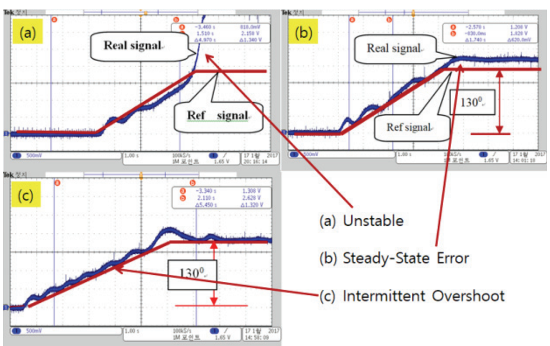

Fig. 6. Using the 45^0(a), 90^0(b) and 120^0(c) controller respectively, at reference angle change from 1^0 ~ 130^0.

Experimental result as seen from the signal waveform for 45^0 controller in Fig. 6(a) indicates that, control of the reference angle from 0^0~130^0 were impossible as stability of the system never occurs. This is clearly shown that, the real signal never come to a steady state giving rise to overshoot as compared to the reference signal. This invariable indicates that no stability of the system at any point above 45^0. For 90^0 controller in Fig. 6(b), stability of the control only occurs at an angle over the target point. There exists a steady state error. This can be seen when comparing the real signal with the reference signal. For 120^0 controller in Fig. 6(c), stability occurs for a change in reference angle range from 0^0~130^0. Though, intermittent overshoot occurred, the result shows control possibility.

It can be inferred from Fig. 6(a) ~ (c) that 45^0, 90^0, 120^0 controllers designed above cannot control all the operating conditions from 0^0~130^0. Therefore, an experiment of the Arago's disc system when there was a change in the three (3) controllers at each reference angle range was performed using a gain scheduler approach. Table 2 below was created to design a gain scheduling controller to establish the selection of the operating points to proof that below 90^0, at 90^0 and above 90^0 in operating range of 0^0~130^0. The corresponding experimental output waveform result is shown in Fig.7 and Fig.8 for increment and increment/ decrement respectively.

Table 2. Reference angle range with respect to operating controller

Reference Angle Range	Operating Controller
00 ~ 800	450
800 ~ 1100	900
1100 ~ 1300	1200

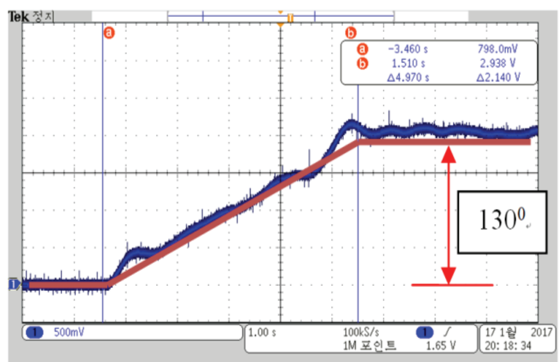

Fig. 7. Waveform output at a change controller with reference angle range in increment.

Comparing Fig.6 with the waveform output of Fig. 7, it can be shown that, with gain scheduler approach, the controllers for each operating point were able to accommodate the reference angle range of the magnetic bar accordingly with no occurrence of overshoot as compared to Fig.6(c) with intermittent overshoot. Hence, the desired performance was robust and maintained stability throughout the entire operating range of 0^0~130^0. Further experiment was conducted with the result shown in Fig.8 below to verify the result obtained in Fig.7.

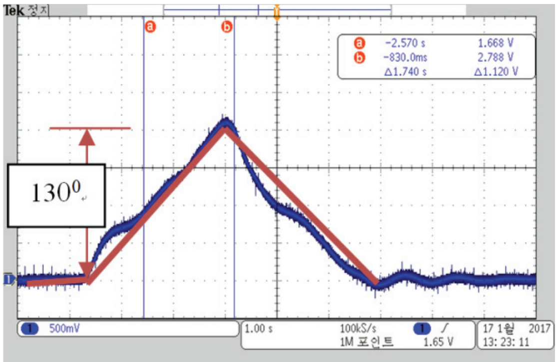

Fig. 8. Waveform output at a change controller with reference angle range in increment/decrement.

In Fig.8, the experimental waveform implies that with gain scheduler, the system can be controller from 0^0~130^0 within a time range and back to rest (0^0) at the same time interval without oscillation and overshooting its target.

4. Conclusions

In this paper, the experimental control of the Arago's disc system at different operating point of 45^0 (stable region), 90^0 (marginally stable region) and 120^0 (unstable region), are carried out with implementation and design of a digital PID controllers. The hardware performance was improved from the optimized distributed control being constructed. The gain scheduler is designed on the basis of the system linearization at different operating positions of 45^0, 90^0, and 120^0. It is noted that the fundamental limitation of this approach for nonlinear system of this type is that the controller obtained is only valid in small neighborhood about a specific reference trajectory. Hence with this approach, good control performances at each specific point were achieved. The respective designed controllers were robust and maintained stability with a desired performance through the entire operating range as experimented.

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