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Development of a servo system having opto-fluid converter

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ABSTRACT

We developed the control system having opto-fluid converter.
This system is composed by opto-fluid converter, 4 stage cascades of Laminar Proportional Amplifier (LPA) which amplify the pressure difference from optical-fluid converter, and the pneumatic servo valve which sends the actual working air pressure to an actuator of a robot arm. By isolating an electric signal processing part and an optical signal processing part using the optical fiber, the control system which is not influenced by an electromagnetic noise can been realized. The optical signal is changed into the fluid pressure signal, without an intermediary electric signal, and can control the robot arm. The system can work under the severe environment where the radioactivity or an electromagnetic noise influences it, and an activity can be expected at medical spots, a nuclear reactor, etc. In this report, we have an analyzed the characteristics of the opto-fluid converter in order to design the high-speed response and optimize the converter.

KEY WORDS

Laminar Proportional Amplifier, opto-fluidic converter, pneumatic servo valve.

NOMENCLATURE

Input A : Input pressure A
Input B : Input pressure B
A port : Output pressure port A
B port : Output pressure port B
P : Supply pressure port

INTRODUCTION

The control system using optical signal is realizable with opto-fluid converter which changes the optical signal into the fluid pressure signal without the electric signal.
The opto- fluid conversion system which converts the optical analog signal into the fluid pressure signal comes from a Laminar Proportional Amplifier (LPA).
The rotary encoder attaching a pneumatic rotary

actuator which does not use an electric signal was developed. This system makes them. The environment where is influenced by the electromagnetic noise, radioactivity, and thunderbolt, and the action of this s system can be secured from them. This is the best feature of the system. Furthermore, the characteristic of the converter is analyzed in order to optimize and design the high-speed response of a system.
In addition in this research used an air pressure servo valve as an input control pressure. This is the analog servo valve functioning alike the opto-fluid conversion system.

CONSTITUTION OF THE SYSTEM

Scheme of system

Experimental set up of this system is shown in Fig.1. The analog signal sent by computer is inputted into a laser diode controller, the optical intensity of a laser diode is decided, and it becomes an optical control signal. The optical signal is inputted into opto-fluid converter, and it is changed into a pneumatic pressure signal. The output pressure is amplified with a 4 stage cascades of LPA, and the boosted signal is inputted into the pneumatic servo valve. The spool inside the pneumatic servo valve is driven by the pressure signal, and the output flow rate and pressure of the pneumatic servo valve are determined by the spool position. The output from the pneumatic servo valve is inputted into the rotary actuator attached to the shoulder portion of the robot arm, and the robot arm drive. The optical rotary encoder detects the drive angle, and feedback control carries out the angle of the arm.

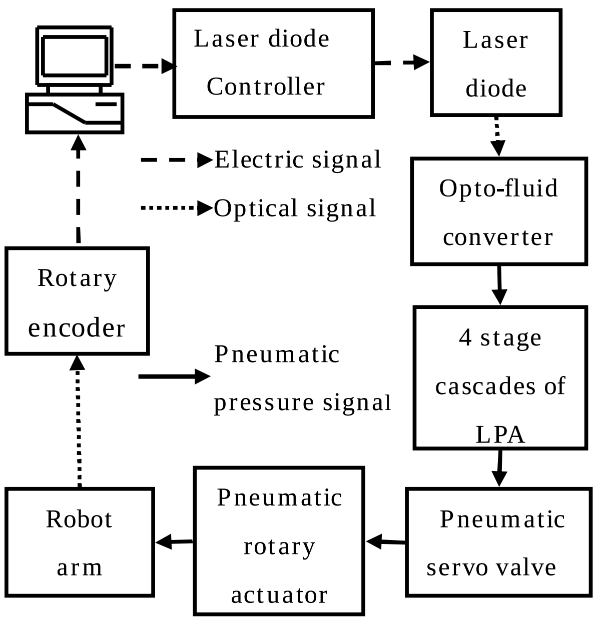

Fig.1 System components and configuration

Opto-fluid converter

This research proposes the way of changing a optical signal into a fluid signal without a mechanical device.
The optical fiber which coated the optical absorber at the edge is set in the supply nozzle side of LPA. The optical energy is changed into the heat energy by irradiating the optical signal there, the temperature distribution of the main jet boundary layer changes, and the jet deflects. A schematic view of opto-fluid conversion element is shown in Fig.2.
Since the output of this conversion element is weak, two stages of LPA amplify follow the output of converter. The aspect ratio of nozzle of conversion element stage and the first stage of LPA is 1.3 and the one of second stage is 0.66. The schematic view is shown in Fig.3.

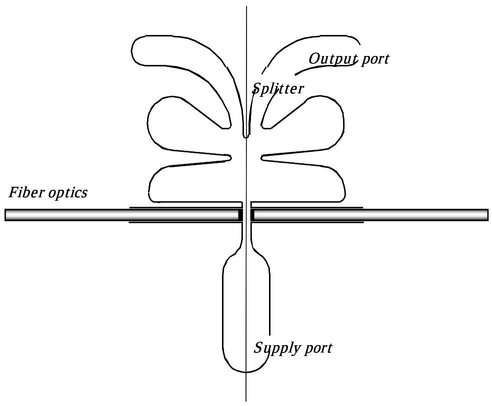

Fig.2 Opto-fluid conversion element

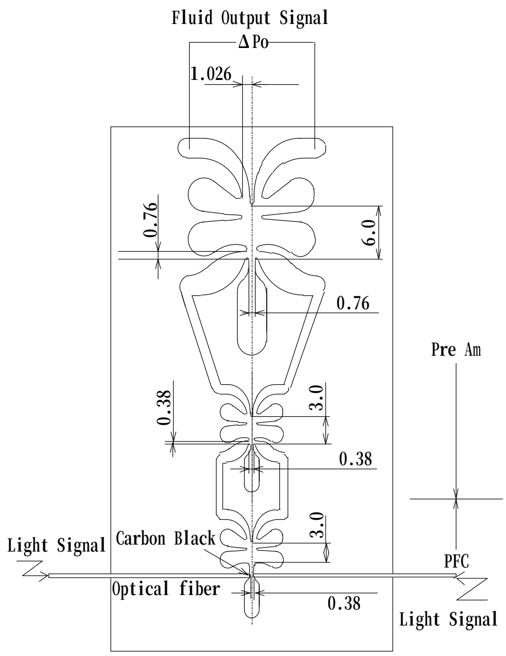

Fig.3 Opto-fluid converter

4 stage cascades of LPA
The output from opto-fluid converter does not have enough power to drive the spool of the pneumatic servo valve. Therefore, the output pressure is amplified with more 4 stage cascades of LPA. The 4 stage cascades of LPA are serial connection of the same shape LPA, and the first and the second stage are the parallel stacked LPA having the thickness is 1.574 [mm], the third is 2.361 [mm], and the fourth is 3.935 [mm], in each stage. The outputs of these LPAs are laminar flow and both pressure and flow rate are boosted by the cascades.

Air pressure drive type Pneumatic servo valve
A usual servo valve is driven by the input of an electrical signal. On the other hand, the proposed pneumatic servo valve is driven by pilot air pressure, the spool in the pneumatic servo valve moves to right or left according to the input-pressure difference on either input side, the crossectional area of flow of the output port is adjusted by the displacement of the spool. The schematic view is shown in Fig.4

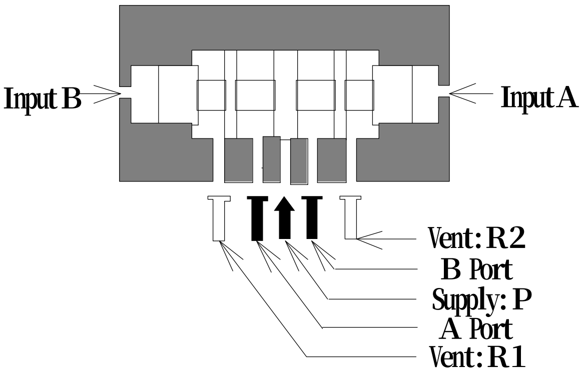

Fig.4 Air pressure drive type Pneumatic servo valve

Robot arm
The robot has one link arm driven with the air pressure rotary actuator. The rotary actuator is commercial product of the size of the diameter 50 [mm] and length 60 [mm]. The arm is made from aluminum and length and weight are 260 [mm] and 600 [g] respectively. The rotary encoder is embedded into the shoulder portion in order to detect the angle.

Optical rotary encoder
The constitution of the rotary encoder is shown in Fig.5. We thought, this rotary encoder must have the stout characteristic against the influence by the electromagnetic noise, we want. So, the electric circuit of the electrical-signal processing part is split up the slit plate of the optical-signal processing part.

The light of LED is let by the optical fiber to the slit plate, and the optical pulse signal caused by rotation of slit is transmitted to a Photo-Transistor (called as PT) by the optical fiber. At this time, the PT produces an electric signal in the area apart from the robot arm, where is secured from noises. The signal flow is shown in Fig.6. The LED and the PT are put on the place distant from the robot arm using the optical fiber as previous shown. The arm can be driving only optically and pneumatically control part without any electric part.

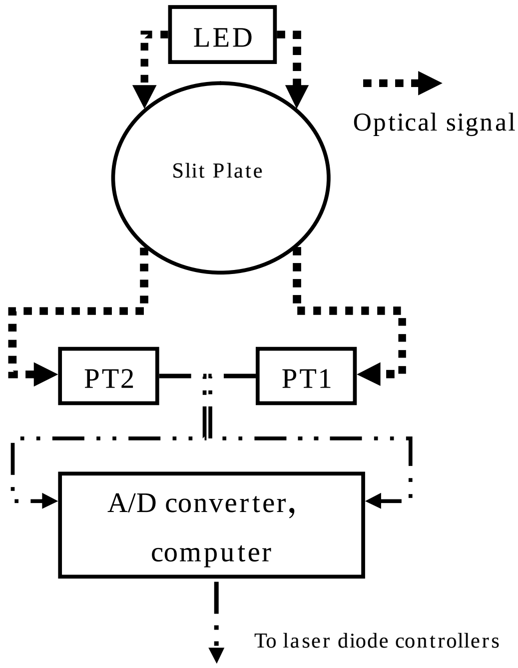

Fig.5 Constitution of a rotary encoder

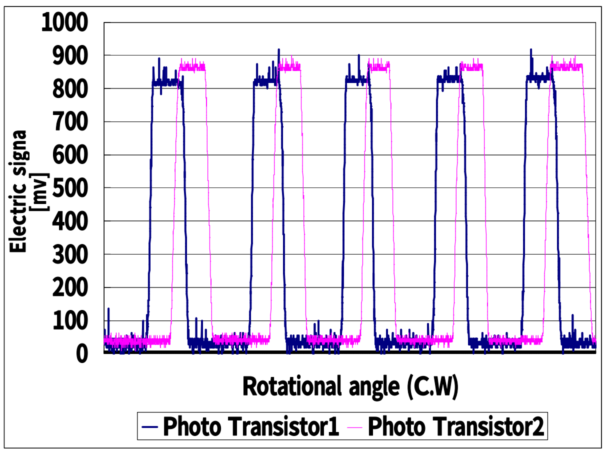

Fig.6 Voltage waveforms of the encoder, case of Right

COMPACTION OF THE SYSTEM

The system made the loss of pressure and flow rate. We thought decrease the loss for the purpose of improvement the response. So the design and improvement of equipment were carried out in the following points.

First, we cut the tube lengths in the 4 stage cascades of LPA. Those tubes were connecting the LPAs. In the result, the LPAs are combined as unity module.

To the next, we design the optimal location of the 4 stage cascades of LPA, the pneumatic servo valve and the opto-fluid converter. In the previous, the 4 stage cascades of LPA and the pneumatic servo valve were placed in rather long distance. Therefore the design of compaction rearranges both equipments near the opto-fluid converter, in this report. As the result, the tube length connecting the opto-fluid converter and the 4 stage cascades of LPA was reduced about 91.9%, and it connecting the 4 stage cascades of LPA and the pneumatic servo valve was reduced about 63.6%.

THE CHARACTERISTIC OF THE SYSTEM

The response of the pneumatic servo valve to the supply pressure of the 4 stage cascades of LPA

Measuring method

In this experiment, the 5 port type air pressure servo valve is used to generate precise the input signal of 4 stage cascades of LPA, instead of the opto- fluid converter. The electrical signal sends to the air pressure servo valve from CPU, changes the output pressure difference of air pressure servo valve from 50 [Pa] to -50 [Pa] or from -50 [Pa] to 50 [Pa]. Then, the pressure difference is amplified with the 4 stage cascades of LPA and inputted into servo valve and the spool displacement generates the powerful output.

The output pressure of the pneumatic servo valve is measured with a pressure sensor. The response time of 4 stage cascades of LPA and pneumatic servo valve are measured by connecting an oscilloscope.

As the supply pressure of the 4 stage cascades of LPA, the pressure of 1st stage is changed from 0.8 [Pa] to 2.0 [Pa], and the pressures of each stages are set as follow. The 2nd is twice magnitude of 1st, the 3rd is 4 times and 4th is 10 times. The supply pressure of the pneumatic servo valve is set as 50 [kPa] constant.

The measurement result and consideration

The response time when the output pressure difference of the air pressure servo valve changed from 50 [Pa] to -50 [Pa] is shown in Fig.7, changed from -50 [Pa] to 50 [Pa] is shown in Fig.8.

First, by comparing Fig.7 with Fig.8, it is shown that the response changing from 50 [Pa] to -50 [Pa] is rather better. The effects of improvement by reducing the tube length are compared. When the output pressure difference is changed from 50 [Pa] to -50 [Pa], about 0.07 [sec] reduction is shown, where the supply pressures of the 4 stage cascades of LPA are 1.5[kPa], 3.0[kPa], 6.0[kPa], and 15.0 [kPa] , respectively. These combinations of supply pressure are the optimal conditions in the former research. When the output pressure difference is changed from -50 [Pa] to 50 [Pa], about 0.05 [sec] reduction has been shown. As the result, reducing pressure loss and flow loss can be done by having compact the system.

Next, the optimal supply pressures of the 4 stage cascades of LPA are specified as 1.3 [kPa], 2.6 [kPa], 5.2 [kPa], and 13.0 [kPa], to each stage, respectively, and the result are shown in Fig.7 and Fig.8. The delay time decreases until the pressure of the 1st stage becomes by 1.3 [kpa]. The delay time does not almost change above 1.3 [kPa] ranges. It will be thought that the pressure and flow loss occurred by the leak of air in this range.

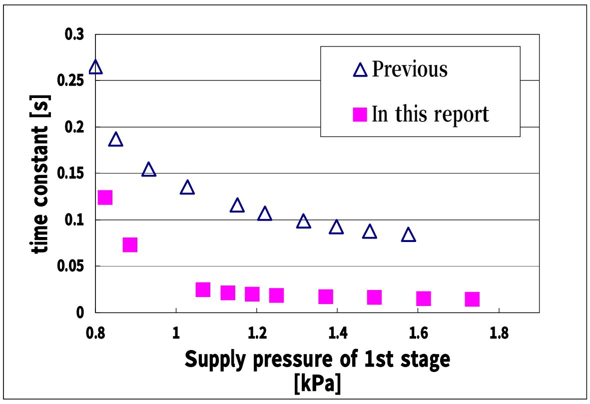

Fig.7 The air pressure servo valve (-50 [Pa]→50 [Pa])

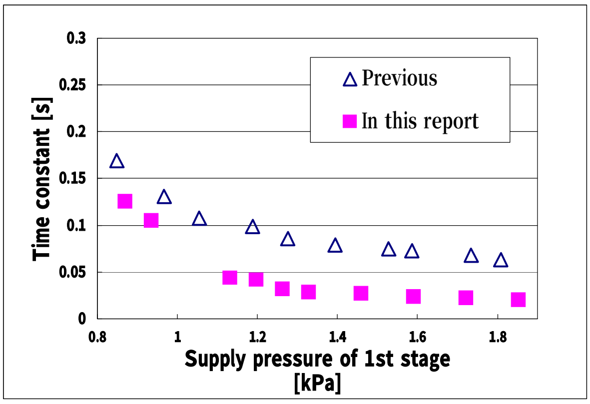

Fig.8 The air pressure servo valve (50 [Pa]→-50 [Pa])

The pressure characteristic to the input-pressure difference of the 4 stage cascades of LPA

Measuring method

The output pressure difference (i.e., input-pressure difference of the 4 stage cascades of LPA) of the air pressure servo valve is changed from -50 [Pa] to 50 [Pa]. The output pressure difference of the 4 stage cascades of LPA in the previous is measured with a pressure sensor. Those which was improved the tube length is measured in the same way. The supply pressure of the 4 stage cascades of LPA is set to 1.5 [kPa], 3.0 [kPa], 6.0 [kPa], and 15.0 [kPa], respectively.

The measurement result and consideration

The measurement result of the output pressure difference of the 4 stage cascades of LPA is shown in Fig.9. The effect of improvement by reducing the tube length is compared. The proportional working area of linearity becomes wide and the sensitivity becomes large in this improvement. The maximum pressure difference becomes about 0.3 [kPa]. This is considered to reduce the pressure loss by making the compact system.

The control range is between -10 [Pa] and 10 [Pa]. The result of this range, because the supply pressure of the 4 stage cascades of LPA is larger than the input-pressure difference. The effects of improvement by reducing the tube length change the gain of the output pressure difference vs. the input-pressure difference of the 4 stage cascades of LPA are shown in the control range from 195.0 to 267.1, the gain is progressed about 37.0%.

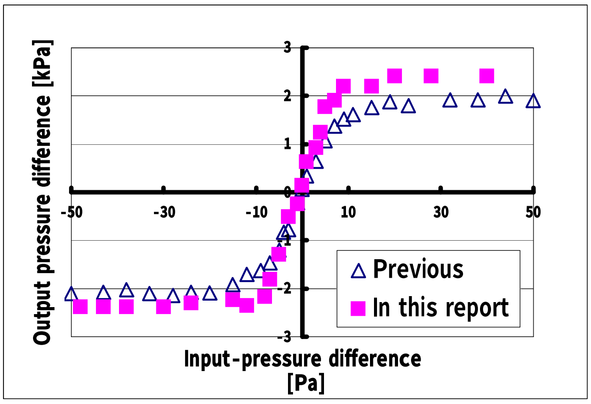

Fig.9 The pressure characteristic to the input-pressure difference of the 4 stage cascades of LPA

The flow characteristic to the input-pressure difference of the 4 stage cascades of LPA.

Measuring method

When the input-pressure difference of the 4 stage cascades of LPA is changed from -50 [Pa] to 50 [Pa], the output flow rate difference of the 4 stage cascades of LPA is measured with a flow sensor. The supply pressure of the 4 stage cascades of LPA is set to 1.5 [kPa], 3.0 [kPa], 6.0 [kPa], and 15.0 [kPa], respectively.

The measurement result and consideration

The measurement result of the output flow rate difference of the 4 stage cascades of LPA is shown in Fig.10.The output flow rate difference of improvement by reducing the tube length is compared. In the range of the input-pressure difference is between 20 [Pa] and 50 [Pa], the flow characteristics are increased about 0.45 [l/min], and between -20 [Pa] and -50 [Pa] in the range of about 0.35 [l/min].

The flow rate tends to be influenced by friction in the tube. So I consider that the frictional loss decreased and flow rate increased, because the tube length in the system has been extremely reduced.

As the effects of improvement by reducing the tube length changed, the gain of the output flow rate vs. the input-pressure of the 4 stage cascades of LPA from 162.6 to 216.1 is progressed about 32.9%.

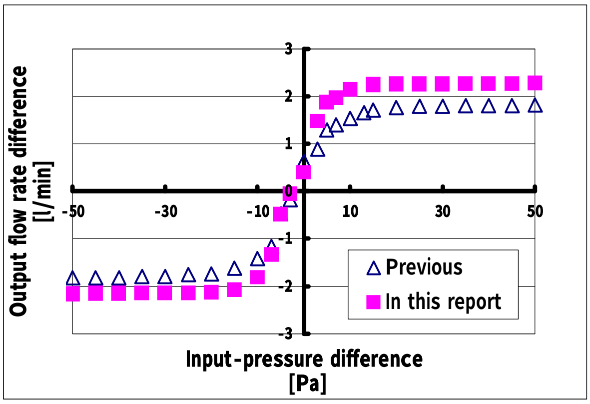

Fig.10 The flow characteristic to the input-pressure difference of the 4 stage cascades of LPA

CONCLUSION

This research treats the improvement of the opto-fluid servo system.

The high-speed response will be achieved by having the compact design of system. The details of the supply, the input, and the output are able to be known in this study.

This result will be useful when the accuracy and practicality of this system will be required in the future.

Research of the future needs the stability and the stationary of the system.

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