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ELECTRIC AND PNEUMATIC HYBRID LINEAR ACTUATOR FOR POSITION AND THRUST CONTROL

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Abstract. One of actuators to be utilized on a power assist device is a pneumatic cylinder. It shows good performance of thrust force control. For requirement of both force and position control, we have developed electric and pneumatic hybrid linear actuator. In the hybrid actuator, a short-stroke pneumatic cylinder controls the thrust force and an electric linear motor controls the tip position of the actuator. This hybrid actuator can reduce the consumed energy in comparison with a conventional pneumatic cylinder. In addition, if the thin wall metal bellows air-spring which has no sliding friction at seal parts is utilized on the hybrid actuator instead of a conventional pneumatic cylinder, it is possible to control force without the hysteresis property. This study proposes the design strategy to apply a thin wall metal bellows air spring to this hybrid actuator system.

Keywords: Actuator, Position control, Force control, Hybrid, Pneumatic cylinder, Linear motor

INTRODUCTION

Recently, the study of a power assist device which aims to support human's muscular movement has been conducted. In previous work, we developed the power assist device with a conventional pneumatic cylinder. In fact, power assist devices introduced in the nursing care and hard labor field utilize pneumatic cylinder or electric motor. The advantages of a pneumatic cylinder are easy force controllability and high mechanical compliance. However, the disadvantages of a pneumatic cylinder are inferior precise position controllability, inferior energy efficiency, because it wastes of energy for compressing air and its air power source leads to increasing in size and weight in the actuator system. On contrary, the advantages of an electric linear motor are precise position controllability and compact battery power source. The disadvantages of an electric linear motor are difficulty of force control and sensitivity to loads.
In this study, we developed the electric and pneumatic hybrid linear actuator which consists of a short stroke pneumatic cylinder to control force and an electric linear motor to control position and we evaluated the power saving of the hybrid actuator.

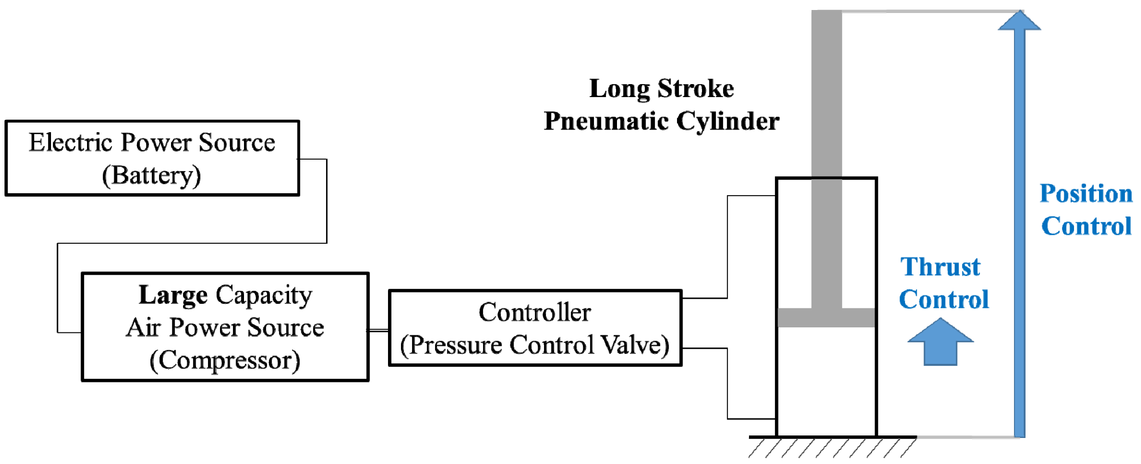

Fig.1 Conventional pneumatic cylinder system

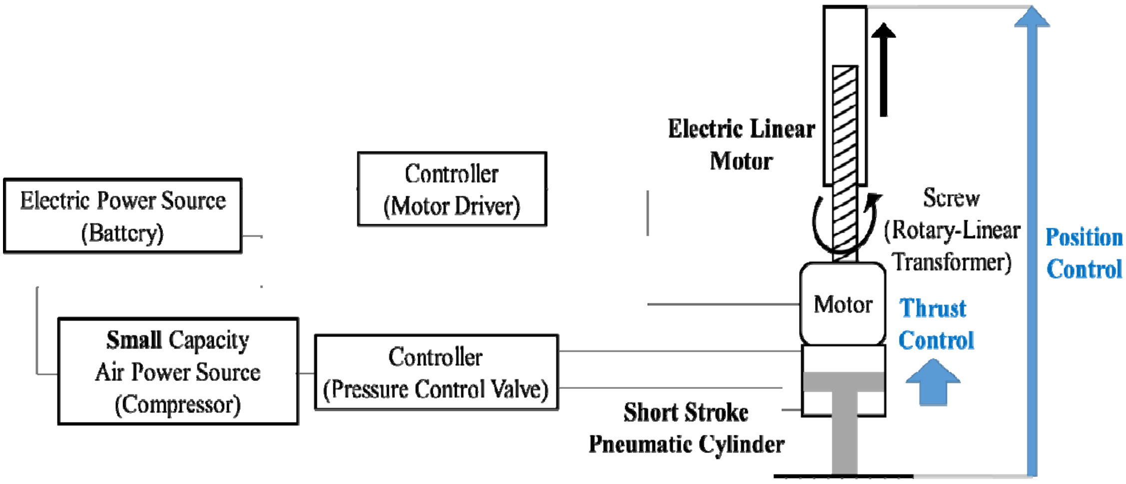

Fig.2 Electric and pneumatic hybrid linear actuator

ELECTRIC AND PNEUMATIC HYBRID LINEAR ACTUATOR

A conventional pneumatic cylinder system is shown in Fig.1. The conventional pneumatic cylinder for power assist and position control use is required for long stroke.
Its air power source is large in the system and consumes the energy for air compression. The system of electric and pneumatic hybrid linear actuator is shown in Fig.2. The hybrid actuator consists of a short stroke pneumatic cylinder and an electric linear motor. The short stroke pneumatic cylinder works as a thrust generator. The electric linear motor controls the position of the output shaft, compensating the position fluctuation of the pneumatic cylinder. The most advantages of the hybrid actuator are that the hybrid actuator makes its pneumatic power system smaller and its power transmission more efficient because the power loss to generate the compressed air is reduced. The advantages of the hybrid actuator are thrust control is easy, position control is precise, air power source of the hybrid actuator gets smaller than that of a conventional pneumatic cylinder and mechanical compliance is high but the disadvantages of the hybrid actuator are the system is more complex and force in position control declines because force of an electric linear motor is less than that of a pneumatic cylinder generally. The drawback that the whole length becomes long has been solved by combination of a serially connected pneumatic cylinder and an electric linear motor, as shown in Fig.3. Table.1 shows the specification of the hybrid actuator which has been developed in this study.

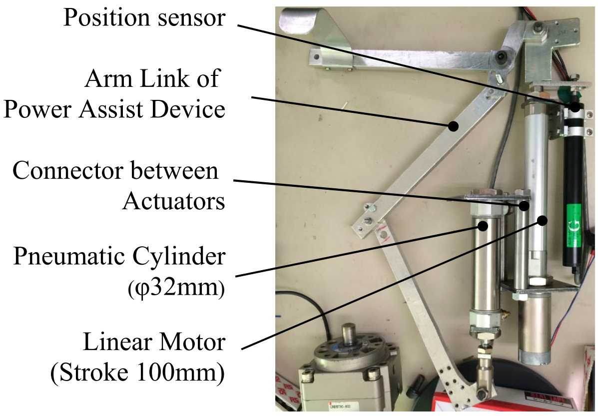

Fig.3 Prototype hybrid actuator for power assist device

Table.1 Specification of the hybrid actuator

Hybrid actuator		
Body length		340mm
Body width		130mm
Stroke		100mm(175mm)
Mass	Electric	0.48kg
	Pneumatic	0.71kg
	Hybrid	1.43kg
Force in force control		～600N
Force in position control		～80N

POWER-SAVING PERFORMANCE OF ELECTRIC AND PNEUMATIC HYBRID LINEAR ACTUATOR

The result of position control is shown in Fig.4 and that of force control is shown in Fig.5. Fig.4 and Fig.5 show that it is possible to control position and force of the hybrid actuator. Fig.4 and Fig.5. show the measured energy consumption.Table.4 shows the energy consumption and comparison with the conventional pneumatic cylinder's energy consumption in the same condition. When the target position was sinusoidal wave of which amplitude is 30mm and frequency was 0.2Hz, hybrid actuator's rod followed the target and consumed the energy of 30.4J at 2-cycle. A pneumatic actuator consumed the energy of 59.8J in the same condition. The power consumption of the hybrid actuator was reduced to 50.8% compared to the consumption of the conventional pneumatic actuator. When the target force was sinusoidal wave of which amplitude 30N and frequency was 0.1Hz, hybrid actuator's force followed the target and consumed the energy of 30.8J at 2-cycle. A pneumatic actuator consumed the energy of 42.8J in the same condition. The energy consumption of the hybrid actuator was reduced to 28.3%. This will contribute to reduce the battery electric power consumption for mobile and wearable power assist device.

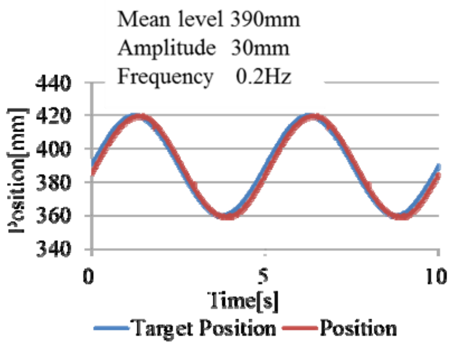

Fig.4 Position control

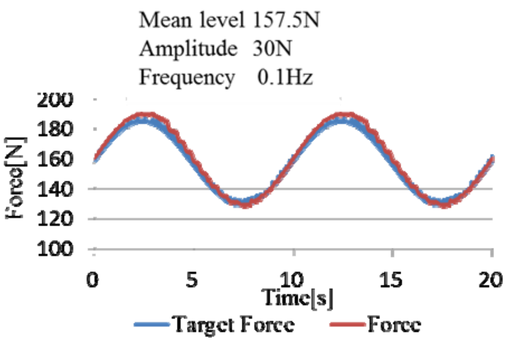

Fig.5 Force control

Table.2 Reduction rate of the hybrid actuator's energy consumption in position control and force control

	Position Control		Force Control
	Sinusoidal wave		Sinusoidal wave
	UP	UP &DOWN	
Pneumatic	59.8J	59.8J	42.8J
Hybrid	21.6J	30.4J	30.8J
Reduction Rate	39.0%	56.6%	72.0%

1. The energy consumption's value is per 2-cycle.
2. Reduction Rate = (Hybrid) / (Pneumatic) × 100

In this study, an electric linear motor with a screw which is a rotary-linear transformer is used. When the hybrid actuator contracts, it wastes the energy because the electric power with negative voltage is required for contracting the length of the actuator. That is the cause of the difference between up and down motion in energy consumption in position control. The pneumatic cylinder consumes a slight energy because it only keeps its thrust force and does not need large flow rate of compressed air. As the result of total energy consumption of the hybrid actuator, the energy consumption of the hybrid actuator is about a half of that of the conventional pneumatic cylinder in position control. The conventional pneumatic cylinder wastes much energy for compressing air of working fluid. In force control, the energy consumption of the hybrid actuator decreased because the total amount of compressed air become decreased.

IMPROVEMENT OF THRUST CONTROL PERFORMANCE

The prototype hybrid actuator consisted of short stroke pneumatic cylinder and electric liner motor. The pneumatic cylinder has a seal mechanism which prevents from air leak but this part generates a friction and a hysteresis of friction when the direction of movement of cylinder rod changes. The hysteresis will be removed by application of a special thin wall metal bellows(1)(2), as shown in Fig.6, instead of a conventional pneumatic cylinder. This special thin wall metal bellows was developed by our laboratory and a viscoelastic ring is inserted

in the groove of general thin wall metal bellows. A conventional thin wall metal bellows can not only expand and contract but also endures about 0.1MPa but this idea with viscoelastic ring insertion makes it possible to expand and contract and endure up to 0.7MPa. Therefore, we can apply a special thin wall metal bellows instead of a pneumatic cylinder to control force. In force control, we need the length of a thin wall metal bellows because it act as a spring. Force control of a special thin wall metal bellows is more complex than that of a conventional pneumatic cylinder. The proposed hybrid actuator will be able to control force without the hysteresis. A combination of an electric linear motor and thin wall metal bellows shown in Fig.7 is in progress.
Since the thrust force of thin wall metal bellows is larger than that of an electric linear motor, the size of the hybrid actuator will become small. The proposed hybrid actuator can remove the hysteresis and its size is smaller.

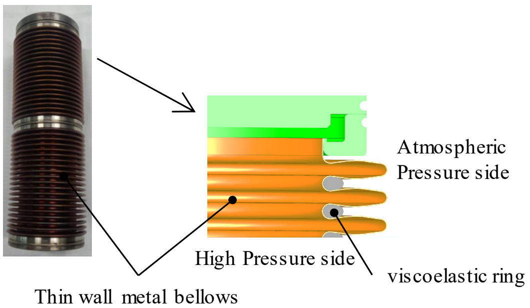

Fig.6 Pressure-resistant thin wall metal bellows

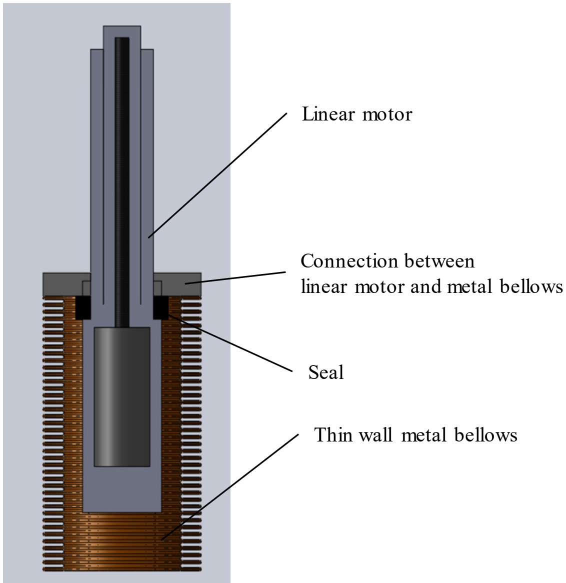

Fig.7 Connection between linear motor and metal bellows

CONCLUSION

The hybrid actuator can perform both precise position control and easy force. In position control, the energy consumption of this hybrid actuator was reduced to 50.8% compared to the consumption of the pneumatic actuator. In force control, this hybrid actuator was reduced to 28.3%, as well. This contributes to reduce electric power consumption for mobile and compact pneumatic power system makes it easy to put whole pneumatic system on power assist devices.
In addition, we showed the possibility to remove a friction hysteresis by exchanging a pneumatic cylinder into a thin wall metal bellows and suggested its design.

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