Design of an Integrated Pneumatic-Electromagnetic Hybrid Linear Actuator

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***Abstract*— We propose a compact direct-drive hybrid actuator with pneumatic-electromagnetic integrated structure. In this hybrid actuator, pneumatic and electromagnetic actuator components are perfectly integrated into a compact body. The actuator can realize both high bandwidth frequency control and high power weight ratio. Concept and design of this actuator are described.**

I. INTRODUCTION

Development of mechanisms for humanoid and exoskeleton robots to realize safe human-robot interaction is an important issue of robotics. High bandwidth variable impedance and high power/weight ratio actuator is crucial for such kind of applications. However, every actuator with single actuation principle has some drawbacks and advantages, and hybrid actuators are getting a lot more attention lately [1], [2].

Noda et al. proposed a pneumatic-electric (P-E) hybrid actuator [3] considering an optimal torque distribution method for their exoskeleton robot named "XoR" [4]. Output force of the actuator is generated by an antagonistic pair of pneumatic artificial muscles and a DC servomotor. However, previous hybrid actuators were made just connecting two types of actuators via mechanical parts e.g. link, timing belt and gear. Because of this, they tend to become large and fragile due to their complicated structures.

To solve this problem, we proposed an integrated pneumatic-electromagnetic hybrid linear actuator (IPEHLA). This actuator has an efficiently shared architecture in terms of volume space and force transmission. The pneumatic and the electromagnetic actuator components share the stator (cylinder) and the mover (piston), and there is no connection mechanism between them. Force of this actuator can be 10 times as large as one of single electromagnetic linear actuator with same volume.

II. PROPOSED HYBRID LINEAR ACTUATOR

The cross-sectional view of proposed hybrid linear actuator is shown in Fig. 1 (iii). Pneumatic and electromagnetic actuators are perfectly integrated into a compact body. The stator and the mover of the electromagnetic actuator component work as cylinder and piston of the pneumatic actuator component, respectively, and potentially provide the capability to exploit both advantages of these components.

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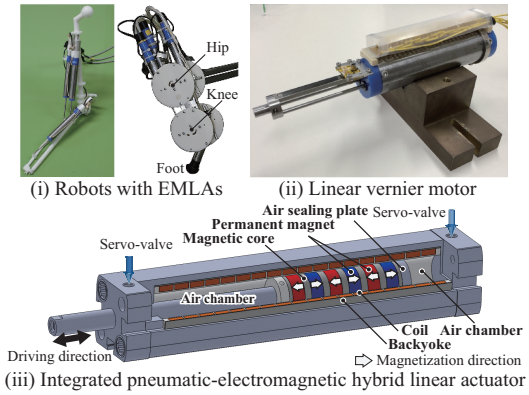

Fig. 1. Robotic arm with EMLAs, LVM and CAD model of IPEHLA

Thus, no connection mechanism between two actuators is necessary. Nakata et al. have been studying a direct-drive electromagnetic linear actuator (EMLA) which can control the output force by quick changes of exiting coil current and enables robots' joint to have active visco-elastic characteristics [5] (See Fig. 1 (i)). Furthermore, a linear vernier motor (LVM) with high force density employing magnetic gearing effect has been proposed [6] (See Fig. 1 (ii)). These electromagnetic structure can be applied to the hybrid actuator and improve the output force and response characteristics. The stator is composed of a back yoke, sets of 3-phase coils and 2 air vents at each end connecting to servo-valves. The back yoke works as magnetic shielding and a leakage of magnetic flux to outside the actuator is negligibly small. The mover is composed of sets of ring-shaped permanent magnets (NdFeB) between magnetic cores and an air sealing plate at one end. Axially opposite magnetized magnets are alternatively arranged. Thanks to this structure, high magnetic flux can be generated, especially the effective radial component of flux with an inward and outward direction from the magnetic cores. Output force is broadly controlled by compressed air and difference between target and actual force is compensated by high bandwidth control of electromagnetic force. A prototype is in the process of production. Demonstration video will be shown on the day of the workshop.

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