Linear Motion Actuator for Direct Drive Applications

Masayuki SANADA*, Yoji TAKEDA**, Sadao ISHIKAWA**
and Takao HIRASA**

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Linear pulse motors are able to operate in an 'open-loop' control mode like rotary stepper motors, and therefore form convenient direct linear position actuators when used in conjunction with digital electronic circuit. Each pulse into their control circuit will produce an incremental linear motion on the motor. The principle of operation is the same as a rotary stepper motor, therefore several different arrangement are possible. The air gap between stator and mover must be keep as small as possible to perform high thrust force. In this paper, a new linear pulse motor with cylindrical structure is proposed. The cylindrical structure is very useful for compact actuator, easy handling and small gap maintenance. The 6 divided mover to reduce the eddy current is also examined.

1. Introduction

In recent years there is a growing interest in electromagnetic actuators such as switched reluctance motors and linear pulse motors etc.[1-6].

Especially, a linear pulse motor has many advantages for the precise position controller because the linear motion is directly performed without any mechanical link mechanism. The rugged construction, simple electric control circuit with minimum component, and high power density are the factors that are in favour of such actuators.

Linear pulse motors are able to operate in an 'open—loop' control mode like rotary stepper motors, therefore form convenient position actuators when used in conjunction with digital electronic circuit. Each pulse into their control circuit will produce an incremental linear motion on the motor. The principle of operation is the same as a rotary stepper motor, therefore several different types are possible. The linear pulse motor is classified into two types. The one is a variable reluctance linear pulse motor. The mover and stator have rectangular teeth of a fixed pitch. The construction of the mover is very simple and economical. The other is a hybrid type with the permanent magnet and the electrical magnet. The hybrid linear pulse motor is a machine capable of high thrust with very precise positioning.

* Graduate Student, Department of Electrical Engineering, College of Engineering.

** Department of Electrical Engineering, College of Engineering.

As the cylindrical linear pulse motor with the wrought iron core is used for the main flux pass of the mover and stator, the eddy current flows easily. This eddy current interferes the flux response, and decreases the frequency characteristics.

In this paper, the mover with divided magnetic core to improve the frequency response is examined. As the hybrid linear pulse motor has the large thrust and high accuracy positioning without the closed loop position control, the motor and its control system become very simple. This linear pulse motor, for example, is able to use for the pilot valve actuator, which controls the valve of the main oil cylinder.

2. Basic Construction

In the general linear pulse motor, the attraction force between stator and mover is over ten times larger than the required thrust force. The air gap between stator and mover must be kept as small as possible to perform the high thrust force. The air gap is maintained generally from 0.05mm to 0.1mm. The attraction force becomes very large as the air gap becomes narrow. The flat type linear pulse motor requires a strong and complex support system to keep a narrow gap. As the radial attraction force balances each other in a cylindrical structure the support system becomes simple, slim and light weight. Therefore, the cylindrical structure is very usuful to realize the compact actuator, easy handling and small gap maintenance.

Figure 1 shows the components of the cylindrical linear pulse motor. The tested motor is a cylindrical structure and hybrid linear pulse motor with permanent magnet. The specifications are shown in Table 1. The stator is constructed of four poles with small teeth, two ring exciting coils and a thin ring permanent magnet. Each stator pole is mounted 1 ／ 4 pitch apart from the mover tooth. The tooth width is 0.5mm, and the slot width is 0.6mm, therefore, one step displacement is 0.275mm

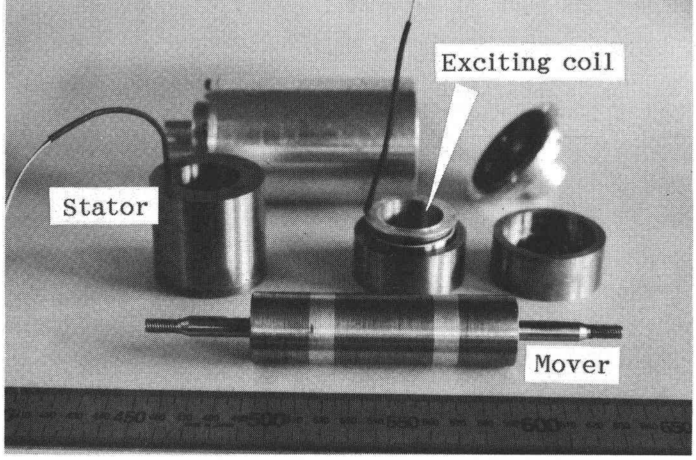

Fig. 1 Components of the cylindrical linear pulse motor.

Table 1 Specification of tested motor.

ITEM	SPECIFICATION
Pitch (mm)	1.1
Tooth Width (mm)	0.5
Slot Width (mm)	0.6
Slot Depth (mm)	1.0
Gap Length (mm)	0.1
Number of Turns of Coil (Turns)	480
Permanent Magnet	CORMAX2000
Size (mm)	ϕ 61 × 186
Total Weight (kg)	1.7

with 2 phase excitation, and 0.1375mm with 1−2 phase excitation. The slot depth of the mover and stator is 1.0mm. The air gap between the mover and stator is 0.1mm. Number of turns of exciting coils is 480 turns per phase. Total weight is 1.7kg.

Teeth of the stator and the mover are constructed by a ring laminated process[7]. Every slot and tooth are made of laminated 0.6mm brass ring and 0.5mm silicon steel ring. The steel ring and brass ring are inserted alternately into the wrought iron body. This laminated process performs the easy manufacturing.

3. Static and Dynamic Characteristics

Figure 2 shows the experimental system of the tested motor. The motor is set on the base stand and 80N weight is preloaded to the motor. The pressure sensor is set on a head of the push screw, thrust is displayed in digit on the instrumentation amplifier. Displacement is measured by the digimatic indicator, which has 0.001mm resolution. As the mover end is pushed by the screw, the displacement of the mover

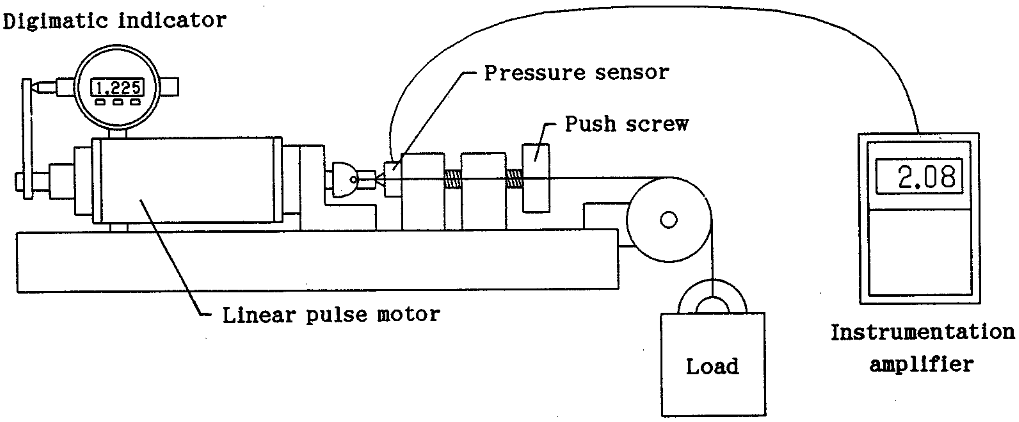

Fig. 2 Experimental system.

is displayed on the digimatic indicator. The thrust of the mover is measured after subtracting the preloaded weight from the indicated value of the instrumentation amplifier. For dynamic characteristics measurement, an appropriate drive circuit is connect to the motor.

Figure 3 shows the experimental results of the thrust distribution. The maximum

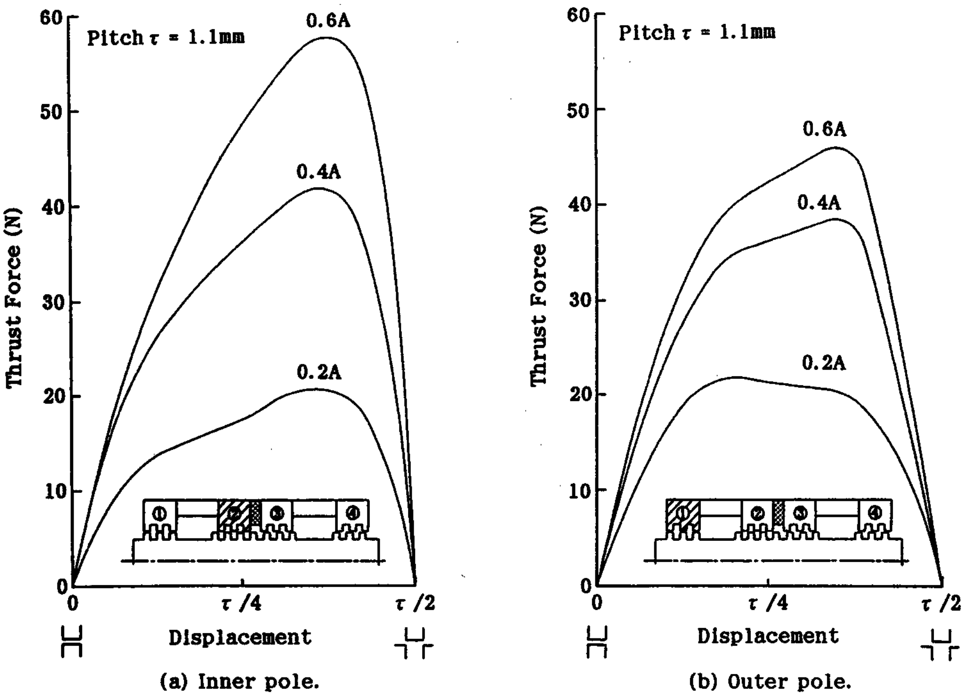

Fig. 3 Thrust distribution.

static thrust is more than 55N at the inner pole excitation, and 45N at the outer pole excitation. Figure 4 shows the pulse−displacement characteristics. The tested motor has very small hysteresis and no accumulation of step error.

Figure 5 shows the pull-in thrust characteristics. Tested motor has 42N maximum starting thrust with 2 phase excitation mode. Figure 6 shows the step response of the tested motor. There are no transient vibration and instability phenomenon such as an over shoot or an under shoot by the resonance of the mover. Since the wrought iron core is used for the main flux pass of the mover and stator, the eddy current flows easily. This eddy current interferes the quick flux response and decreases the frequency characteristics.

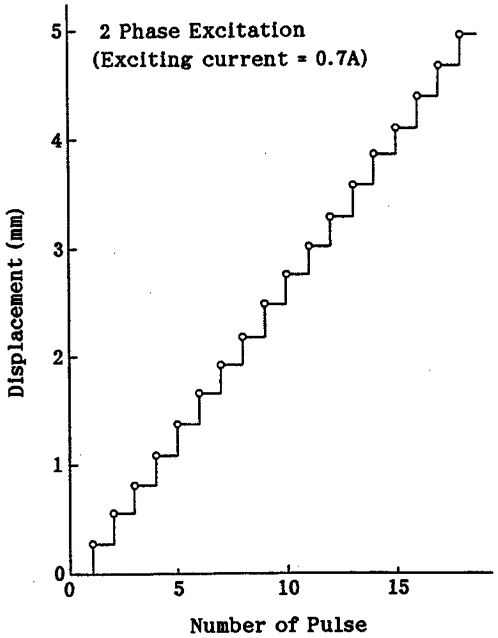

Fig. 4 Pulse−displacement characteristics.

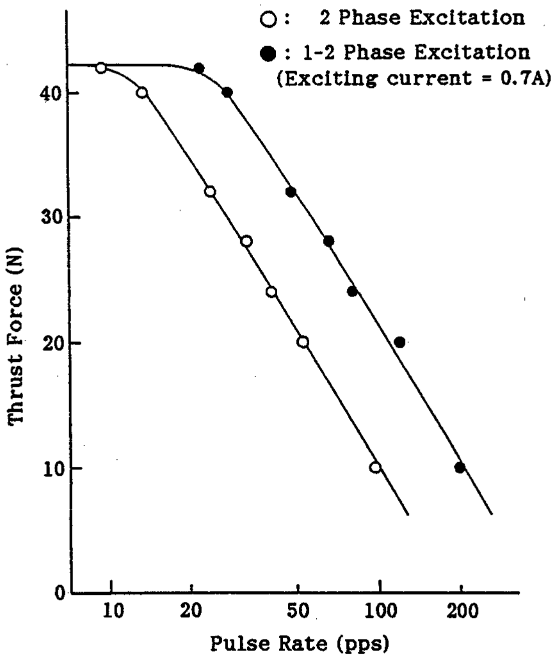

Fig. 5 Dynamic pull-in thrust characteristics.

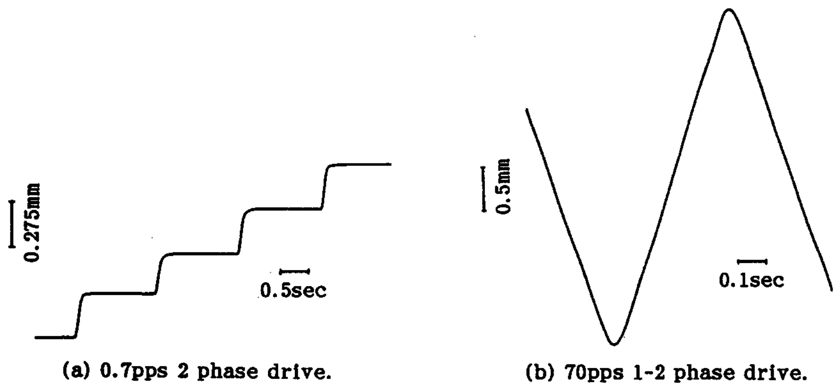

Fig. 6 Step response.

4. Improvement of Dynamic Characteristics

The frequency response is improved by the high resistivity magnetic material or laminated silicon steel. The high resistivity magnetic material, however, has small maximum saturated flux density. Therefore, a large cross sectional area is required to pass the same flux and the size and weight become large. The laminated technique in the cylindrical structure is also troublesome and impractical, because the cylindrical structure requires the radial laminated core.

Figure 7 shows the scheme of the 6 divided mover. This mover has 6 radial narrow slots, and the laminated ring teeth and slots. The eddy current induced in the mover hardly flows because of 6 radial slots.

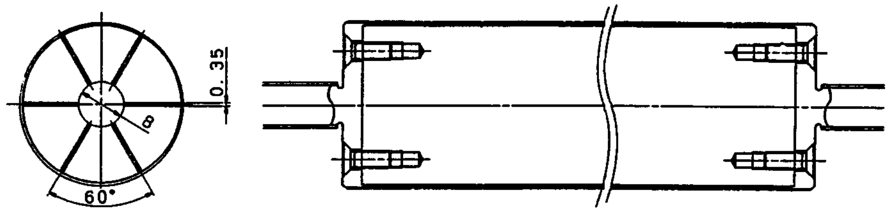

Fig. 7 Scheme of the 6 divided mover.

Figure 8 shows one example of the electromagnetic effects of the 6 divided mover. If the eddy current does not flow, the induced voltage is indicated by the linear dotted line. The induced voltage of the 6 divided mover is larger than that of the conventional mover. Therefore, it is clear that the influence of eddy current is improved by the 6 divided mover.

Figure 9 shows the pull-in thrust characteristics. Thrust force is normalized by the maximum pull-in thrust force. The improved tested motor has broad region of maximum pull-in thrust in comparison with the conventional tested motor. In the region of high frequency pulse rate, the improved and the conventional tested motor have nearly equal characteristics. This reason is that the inertia of the mover limits the pull-in thrust characteristics at high frequency.

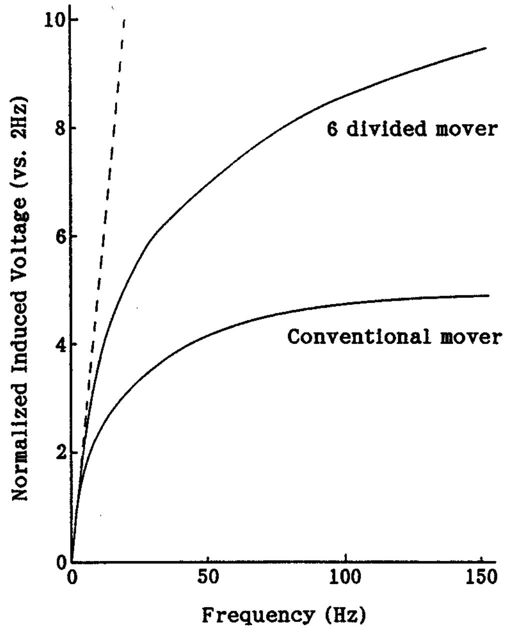

Fig. 8 Electromagnetic effect of the 6 divided mover.

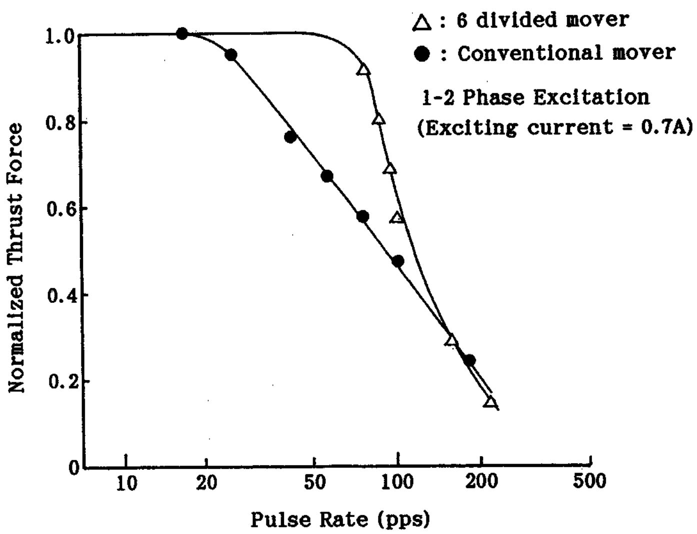

Fig. 9 Dynamic pull-in thrust characteristics.

5. Conclusion

In this paper, a new linear motion actuator with cylindrical structure for direct drive applications is proposed. The characteristics of the cylindrical hybrid linear pulse motor and the mover with the 6 divided core to improve the frequency response are examined. From the experimental results, the following conclusions are obtained.

(1)The cylindrical structure is very useful for the compact actuator, easy handling and small gap maintenance.

(2)The eddy current interferes the quick flux response and decreases the frequency response.

(3)The influence of eddy current is improved by the 6 dividing.

(4)The motor with the 6 divided mover has broad region of maximum pull-in thrust in comparison with the motor with the wrought iron mover.

As this linear pulse motor have very small positioning hysteresis, large thrust forces and no accumulation of step error, this actuator is sufficiently able to use for the position controller in the direct drive applications.

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