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General Theses

Driving Characteristics of Cylindrical Linear Synchronous Motor

Kazuhiro Makiuchi Satoshi Sugita Kenichi Fujisawa
Yoshitomo Murayama Nobuji Suzuki

1. Introduction

These days, industries are becoming increasingly active in adopting linear servo systems in industrial machine. Sanyo Denki began selling linear servo systems in 1997 and has since been receiving a number of inquiries. The company's linear servo systems come in three line-ups: linear guide cored, linear guide coreless, and cylindrical linear synchronous types. The first two are sold on an OEM basis with Kollmorgen Corporation. The Cylindrical Linear Synchronous Motor ("CLSM") was developed by Sanyo Denki and has a structure similar to that of an enclosed rotary motor, thus achieving superior features such as high reliability in water resistance, dust resistance and durability.

Firstly, this paper outlines CLSM configuration, then shows describes the characteristics of the CLSM compared with flat plate linear synchronous motors. Next, the authors experimentally examine the static and the dynamic driving characteristics [(1)] of the CLSM, and then demonstrate that the system has sufficient characteristics for high acceleration/deceleration driving and high-precision positioning.

2. Configuration of Cylindrical Linear Synchronous Motor

Fig.1 shows how the CLSM is typically applied as the Z-axis of a superfast drilling machine. The X, Y, and Z-axes are each constituted by a linear guide cored, linear guide coreless, and cylindrical cored linear servo system. The CLSM is in the middle.

The CLSM was developed to aim at high acceleration/deceleration driving and high-precision positioning, and designed mainly with ease of handling and reliability as high as conventional rotary motors.

Fig. 2 shows the structure of the developed CLSM (model ACC12-094), while Table 1 shows its main specifications. The stroke is 30mm, the maximum thrust is 1,000N, the velocity is 1.5m/s, and the repeatability is ± 5 µm .

Table 1 Main specifications of CLSM

	Item	Values (units)
Primary (stator)	Material of yoke	Silicon steel
	Wiring	3-phase star wiring
	Winding resistance (25 °C)	2.17[Ω / phase]
	Rated continuous thrust	420[N]
	Instantaneous maximum thrust	1000[N]
	Rated continuous effective current	4.6[A]
	Instantaneous maximum effective current	11.0[A]
	Maximum velocity	1.5[m/s]
	Sensor resolution	1[μm]
Secondary (mover)	Material of yoke	S45C
	Material of magnet	Nd-Fe-B
	OD of magnet	58[mm]
	Pole pitch	16[mm]
	Mover mass	2.63[kg]
Servo amplifier	Control style	PI
	Command system	Position control
	Position command mode	Pulse train input
	Bus voltage (DC)	280[V]
	Maximum response pulse frequency	500 (x 4)[kpps]

The CLSM is a synchronous motor based on a permanent magnet, whose thrust density is easily increased. The primary is made of a stator in order to prevent the cable from moving. The outside dimensions are 120mm sq. x 307mm, and a rotor with radially magnetized ring-shaped permanent magnets arranged on the yoke is supported with a ball spline bearing. A flat-plate linear motor entails a very high magnetic attraction between the stator and rotor, so that care must be exercised with regard to the rigidity and friction of the supporting mechanism. On the other hand, the CLSM is so designed that the magnetic attraction can be offset and the supporting mechanism can be simplified. This allows one to use a relatively small bearing, which then contributes to the size reduction of the motor.

The outside diameter of the permanent magnet is 58mm, the air gap with the stator teeth is 0.8mm, and the pole pitch is 16mm. The material of the mover core(secondary yoke) is S45C, and the stator core(primary yoke) is made of silicon steel. The stator has nine slots and is so designed that a ring-shaped core and a circularly wound coil are laid alternately for each slot.

The linear sensor uses an optical incremental encoder with a resolution of 1 micrometer, and the motor contains a linear scale on the mover and a sensor head on the stator.

The CLSM can be connected directly to a direct-acting unit by a direct drive, so that the unit mechanism can be simplified.

3. Characteristics and uses of the CLSM

Among traditional direct-acting mechanisms are air cylinder, oil cylinder and ball screw mechanisms. The air cylinder is widely used in simple reciprocating motion with a relatively small thrust. Although it is advantageous in that it is inexpensive, it requires air-pressure equipment of about 490kPa. The hydraulic cylinder is usually suited for large-thrust applications and is capable of positioning precision of about 0.1mm and a certain degree of velocity control. However, the hydraulic pump motor requires the control of oil temperature, prevention of oil leaks and other ingenuities. In that sense, motor driving is advantageous in that connections to a power cable alone are enough to achieve high-precision positioning and variable-velocity running easily. The ball screw mechanism is relatively inexpensive and enables a rise in thrust, but there are now apparent limitations on their possibilities to meet recent requirements for higher velocity and acceleration. Linear servo systems have been spotlighted as a new direct-acting mechanism that meets the requirements for higher velocity and acceleration, as well as higher precision, and are used for conveyors and laser processors.

The most common type of linear motor is a flat plate linear motor consisting of a linear guide. The CLSM, however, is different from these flat plate linear motors. Table 2 compares the CLSM with flat plate linear synchronous motors. The following is a summary of the CLSM characteristics.

(1)The motor is integrally structured in a similar fashion to the rotary type. It is also equipped with a flange, so that it can easily be incorporated into a machine.

(2)With the exception of the output shaft, the system is of a fully-enclosed type structure. It therefore has high resistance to water and dust (IP55) and can be incorporated into a machine tool exposed to cutting oil.

(3)The use of a model based on movable permanent magnets allows the winding and cable to be fixed to the frame. This achieves high heat radiation and reliability.

(4)The permanent magnets are arranged on the mover in a ring-shaped manner at 360 degrees. This offsets magnetic attraction. As a result, the service life of the ball spline shaft can be increased.

(5)The offset of the magnetic attraction obviates the need to increase the rigidity of the mover, so that the mass of the mover can be reduced. The result is high acceleration performance.

(6)The system is structured so as to make it hard to design a long-stroke model.
The CLSM is small and fast and has a short stroke and a high hit rate. Among its conceivable uses include drilling machines, mounters, and stitchers.

Table 2 Comparison of the CLSM with a flat plate linear synchronous motor

	CLSM	Flat plate linear motor
Installation Waterproofing mover Magnetic attraction Stroke Main uses	Ikale IP55 Movable permanent magnets It is offset Small stroke Drilling machine Mounter	Equipped with a linear guide Open Based on a configuration About 5 times the rated thrust Unlimited Travel shaft of a robot Conveyor

4. Driving characteristics of the CLSM

4.1 Static characteristics of the CLSM

Fig. 3 shows configuration of the control circuit and of the measuring unit of the CLSM. Since the linear motor has a stroke end, unlike the rotary type, it is based on position control. The CLSM performs the positioning control of a full-closed loop in response to feedback signals from an incremental linear encoder. Position commands correspond to pulse train commands. Thrust was measured with a load cell, and velocity and positions were measured with a laser interferometer.

Fig. 4 shows the static thrust-excitation current characteristics of the CLSM. Fig. 5 shows the static thrust-displacement characteristics of the CLSM based on excitation current as a parameter. The thrust was measured in the stroke range of 30mm. The detent force was ± 15N, no more than 8% of the continuous thrust of 420N.

4.2 Dynamic characteristics of the CLSM

Fig. 6 shows the 1 μ m feed step response characteristics of the CLSM. Fig. 6 shows the positioning characteristics of the system when the commands are varied in steps.

The CLSM uses a linear encoder with a resolution of 1 μ m, where 1 μ m corresponds to 1 pulse of position command. There is an error of about 0.5 μ m in the stop position, but a positioning resolution of 1 μ m is implemented.

Fig. 7 shows the reciprocating driving characteristics at no load of the CLSM. The velocity, imposition output, and position command pulse train output were measured when the system was reciprocated over a stroke of 10mm. At that time, the velocity was 1.3m/s maximum, and the repetition frequency 17Hz. Since the acceleration time is 5ms up to a velocity of 1.3m/s, it is known that an acceleration of 25G was achieved. The imposition signal is produced when positioning is complete. In this test, the authors assumed that positioning was complete when the value was set to ± 10 μ m with regard to the target position. The time required for positioning over a 10mm stroke is 25ms, and it is shown that the system achieves precise and fast positioning.

5. Conclusion

This paper describe configuration of the Cylindrical Linear Synchronous Motor and summarizes its characteristics. The CLSM was developed in an attempt to achieve high acceleration/deceleration driving and precise positioning. The authors then demonstrated in a series of experiments that the system can run with a micro-feed of 1 micrometer and at an acceleration of 25G at no load. When the positioning setting width was ± 10 μ m , the 10mm positioning time was 25ms. These values are presumably sufficient for a high-acceleration, high-precision, and high-hit-rate machinery.

One can safely say that the CLSM excels in acceleration, precision, thrust, and ease of handling, unlike traditional direct-acting mechanisms: such as air and hydraulic cylinders and ball screw mechanisms. The CLSM can be proposed as a new direct-acting mechanism designed to increase the level (which was the limit of traditional direct-acting mechanisms) by one or even two steps.

References

(1)Sugita, Fujisawa, Murayama, Suzuki: "Driving Characteristics of Cylindrical Linear Synchronous Motors," Documents of the Linear Drive Study Group, The Institute of Electrical Engineers of Japan, L.D.-99-35 (February 1998)

Kazuhiro Makiuchi
Joined company in 1998
Servo Systems Division, 1st Design Dept.
Worked on design and development of linear motors

Satoshi Sugita
Joined company in 1995
Control Systems Division, Component Technology Dept.
Worked on design and development of linear motors

Kenichi Fujisawa
Joined company in 1992
Control Systems Division, Component Technology Dept.
Worked on design and development of servo amplifiers

Yoshitomo Murayama
Joined company in 1980
Control Systems Division, Component Technology Dept.
Worked on design and development of serve amplifiers

Nobuji Suzuki
Joined company in 1966
Servo Systems Division
Worked on design and development of
rotary machines and linear motors

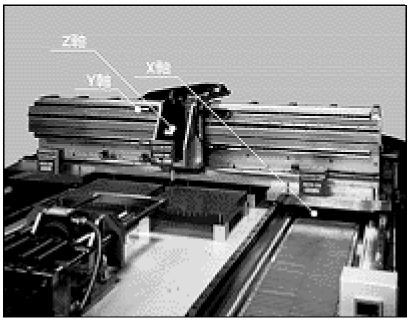

fig.1 External view of a typical superfast drilling machine based on a CLSM

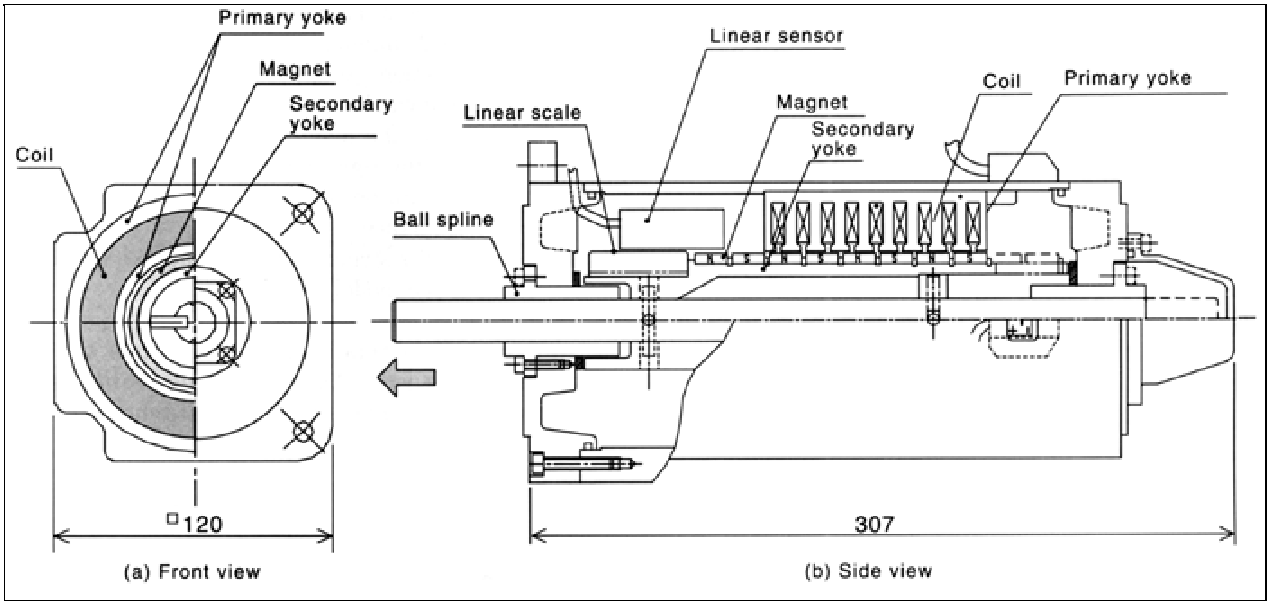

fig.2 Structure of a typical CLSM (figures in mm)

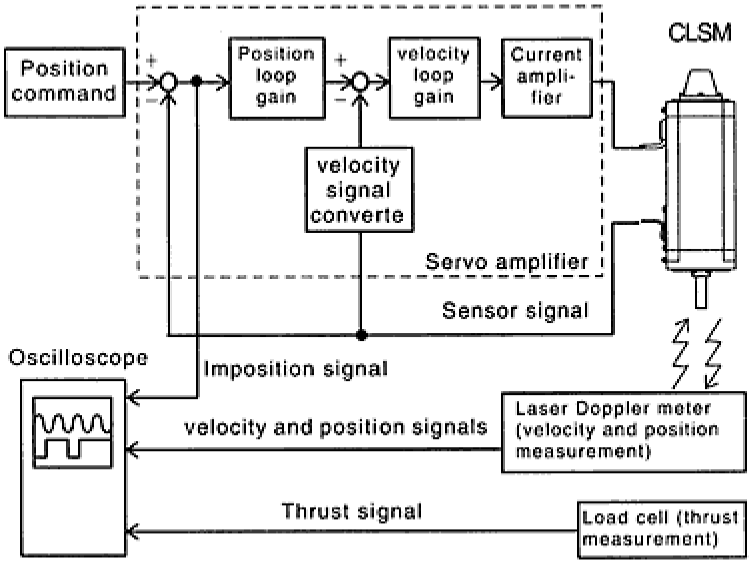

fig.3 Configuration of the control circuit and the measuring unit of the CLSM

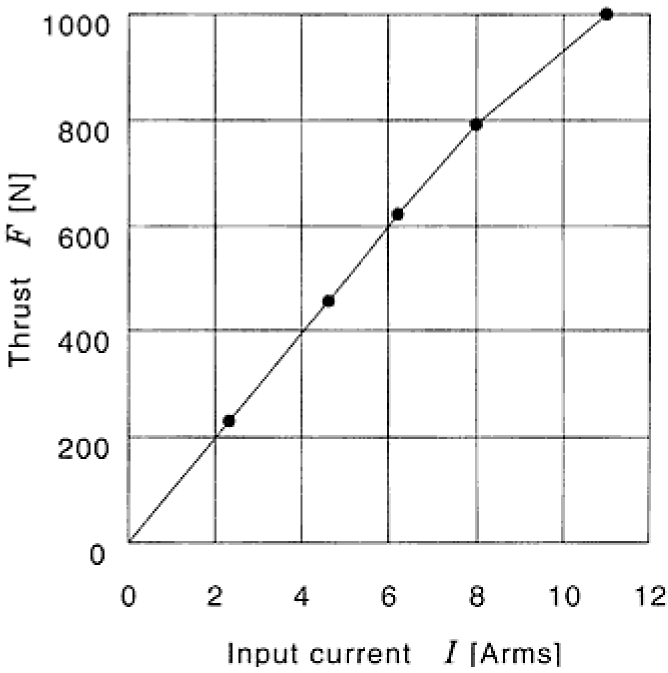

fig.4 Static thrust-excitation current characteristics of the CLSM

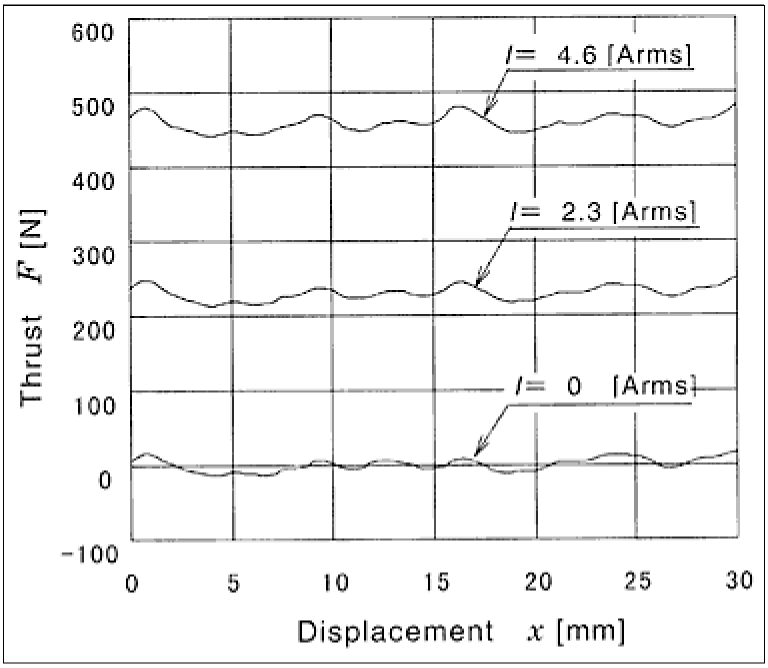

fig.5 Static thrust-displacement characteristics of the CLSM

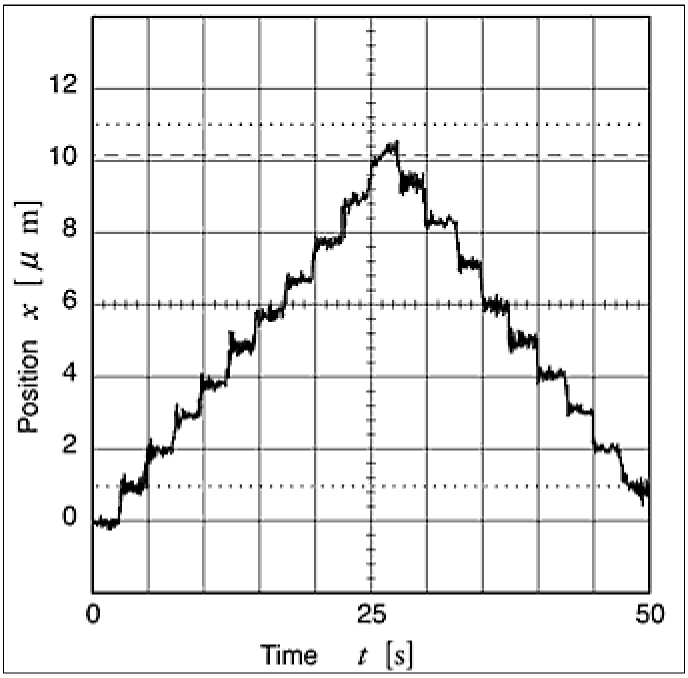

fig.6 1-micrometer feed step response characteristics of the CLSM

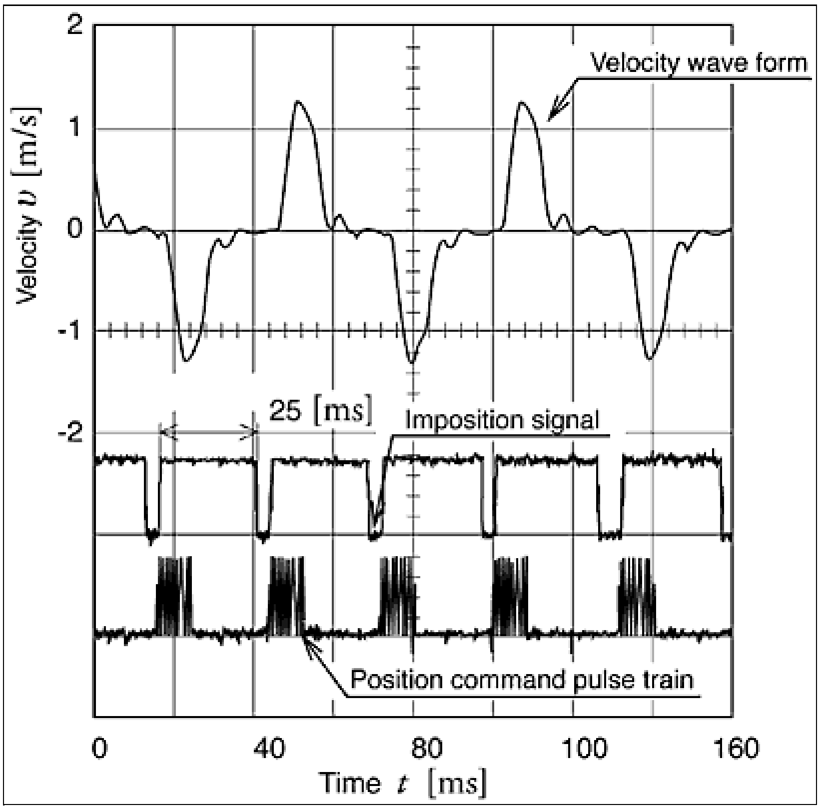

fig.7 Reciprocating driving characteristics at no load of the CLSM (imposition width: ±10mm)