Development of Compact Cylinder Linear Servo Motor "SANMOTION"

Yuqi Tang Masanori Tanaka

1. Introduction

The requirement for drive parts of industrial equipment to be high speed and high accuracy is growing stronger year after year. In particular, there is an increased demand for drive motors suitable for the manufacture of compact, high performance products due to the popularization of smartphones, tablet PCs and so on.

Linear servo motors can significantly contribute to improvement in the speed and accuracy of machinery due to direct linear drive not requiring a mechanism such as a ballscrew, etc. for rotational-linear motion conversion. Sanyo Denki's linear servo motors are adopted in many applications such as electronic part surface mounters and semiconductor manufacturing equipment(1).

Sanyo Denki has commercialized 3 types of linear servo motors; namely, the cylinder type, flat type and twin type. The cylinder type is the cylindrical linear servo motor developed primarily for the vertical axis (Z axis) of processing equipment. In the same way as general rotating motors, this servo motor has a magnet on the moving side and a fixed power cable. A cylindrical shape is adopted in order to balance magnetic induction force. As such, the support mechanism has been simplified and the mover has been lightened, making this servo motor suitable for short stroke/high hit rate applications(2).

This report gives a background to the development and introduces the performance, functions and features of the newly developed compact cylinder type linear servo motor (hereinafter "compact cylinder linear motor").

2. Background of the Development

For applications such as chip mounting heads on mounting equipment for electronic parts, there is a requirement for high-acceleration/deceleration drive and high duty continuous operation. One effective way of achieving these is to adopt a linear servo motor in the drive portion and perform direct drive.

Below is a list of the market requirements for Z axis linear motors used for chip mounting head applications.

(1) Greater thrust to achieve high-acceleration/deceleration.
(2) Downsizing of the motor to achieve downsizing and lightening of the chip mounting head.
(3) Motor width and structure making it possible to line multiple motors up in a set space.

In order to fulfill these market requirements, we have developed a 12 mm wide, Compact Cylinder Linear Motor which is both compact and offers greater thrust.

3. Outline of the New Model

3.1 External view and structure

Fig. 1 is an external view of the developed compact cylinder linear motor, while Fig. 2 gives its structural details and dimensions.

The new model achieves a reduced width of 12 mm at the same time as featuring an all-in-one structure with a built-in linear encoder and linear guide. The motor is configured from a mover with a built-in magnet inside a stainless steel pipe and a stator with a coil which has a back yoke

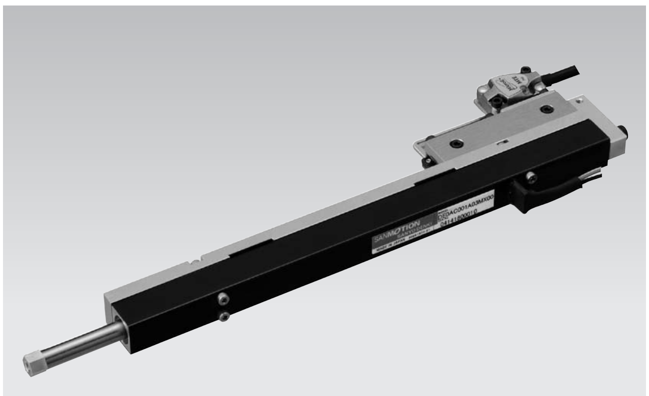

Fig. 1: External view of the Compact Cylinder Linear Servo Motor

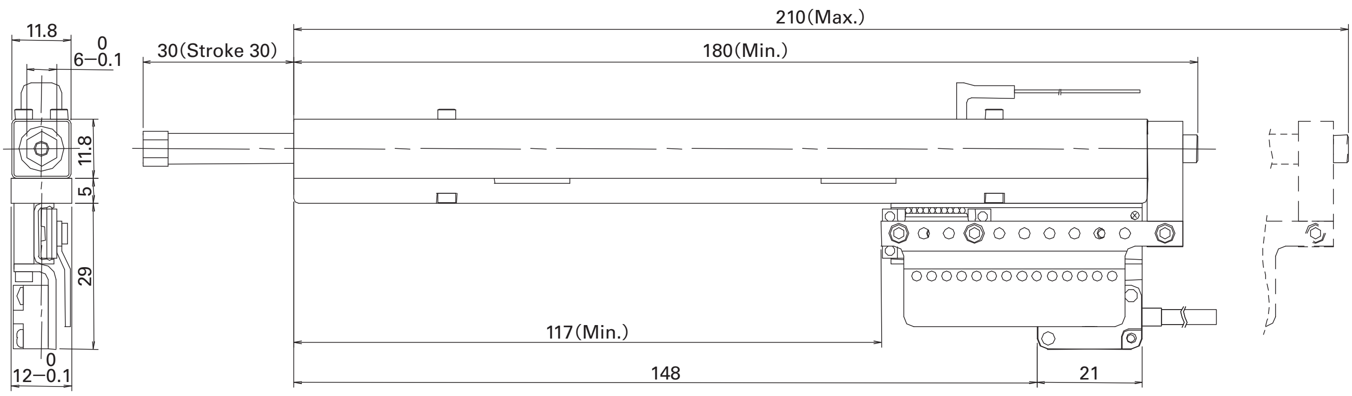

Fig. 2: Structure and dimension of the Compact Cylinder Linear Servo Motor

on an aluminum frame equipped with a forced air cooling mechanism.

The mover runs off linear drive while being supported by the linear bushes located on both ends of the stator. The linear encoder detection scale is guided by a linear guide to prevent rotation and is connected to the mover, therefore forming a structure whereby the linear encoder signal cable also does not move.

In regards to the stator (armature), by installing a back yoke on the outside of the cylindrical coil, the magnetic flux of the magnet can be used more effectively and in the case of multiple motors being lined up and used together, it is possible to avoid inter-shaft magnetic interference.

3.2 Performance and functions

Table 1 shows the specifications of the compact cylinder linear motor.

The maximum thrust of the motor is 16.5 N, the rated thrust is 5.1 N under natural air cooling, and the motor has been made more compact at the same time as achieving greater thrust. Moreover, because the no-load maximum acceleration reached 37.4 G, high-acceleration/deceleration was achieved. Also, with a maximum speed of 2 m/s, the developed motor is well-suited to high-speed operation.

Table 1: Specifications of the Compact Cylinder Linear Servo Motor

Item	Units	Specifications
Model No.	-	DE0AC001A03MX00
Drive mode	-	Sine wave
Excitation	-	Permanent magnet
Rated	-	Continuous
Rated thrust F_R	[N]	5.1
Continuous stall thrust F_S	[N]	5.1
Maximum thrust F_P	[N]	16.5
No-load maximum acceleration a_{max}	[G]	37.4
Rated speed V_R	[m/s]	1.0
Maximum speed V_{max}	[m/s]	2.0
Stroke S	[mm]	30
Rotor mass M_C	[g]	45
Motor mass W	[g]	185
Linear encoder	-	Incremental
Linear encoder resolution (after being multiplied by 4)	[μm]	1

4. Product Features

4.1 Greater thrust

4.1.1 Improved magnetic flux density

The thrust F of compact cylinder linear motors generally uses the proportional constant K_F and can be expressed in the following equation[3].

$$F = NBLI = K_F I \text{ [N]} \quad (1)$$

where,
F : Thrust [N]
N : Coil turns
B : Average density of the magnetic flux [T] which interlinks with the coil
L : Average length of coil for each turn [m]

I : Current [A]
K_F : Thrust constant [N/A]

As shown in equation (1), motor thrust is directly proportional to the density of the magnetic flux interlinking with the coil. In other words, the most important element in increasing motor thrust is interlinking as much magnetic flux with the coil as possible. We successfully improved motor thrust by investigating the below items in order to increase density of the magnetic flux interlinking with the coil.

- Optimize magnetic pole pitch and coil dimensions by arranging the magnetic poles of permanent magnets so that the same poles face and repel each other.
- Increase the density of the magnetic flux interlinking with the coil at the same time as reduce permanent magnet usage by inserting a magnet spacer between the magnets with the same poles facing each other.
- Clarify the ratio of magnet length and magnet spacer length where the density of the magnetic flux interlinking with the coil becomes the greatest.

Fig. 3 shows the motor thrust characteristic to accompany change in the magnet ratio (magnet length/ magnet pole pitch) performed through FEM analysis.

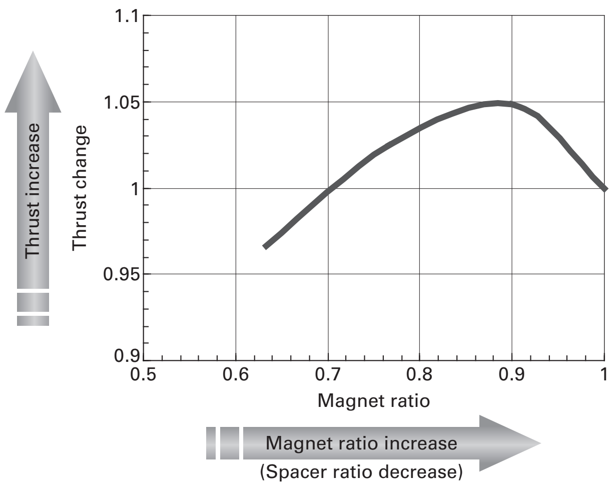

Fig. 3: Magnet ratio – thrust characteristic (calculation result)

If it is assumed the motor thrust when all magnets are used (magnet ratio = 1) is "1" then,

- if the magnet ratio is 0.7 or above, the motor thrust will be greater compared to when all magnets are used, making it possible to both reduce permanent magnet usage and achieve greater thrust.
- When magnet ratio was around 0.9, the motor thrust was its greatest at approximately 1.05 times greater than when all magnets were used.

4.1.2 Thrust characteristics

Fig. 4 shows the current (I) - thrust (F) characteristic of the new model, while Fig. 5 shows the speed (V) - thrust (F) characteristic.

The current – thrust characteristic increases in a straight-line, and it is clear that current is being used effectively. Moreover, it is clear from the speed – thrust characteristic that the new model possesses high-speed drive and wide-range output characteristics.

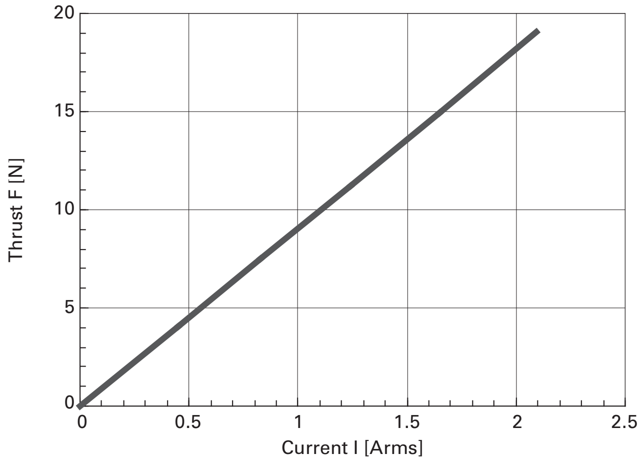

Fig. 4: Current I- thrust F characteristic

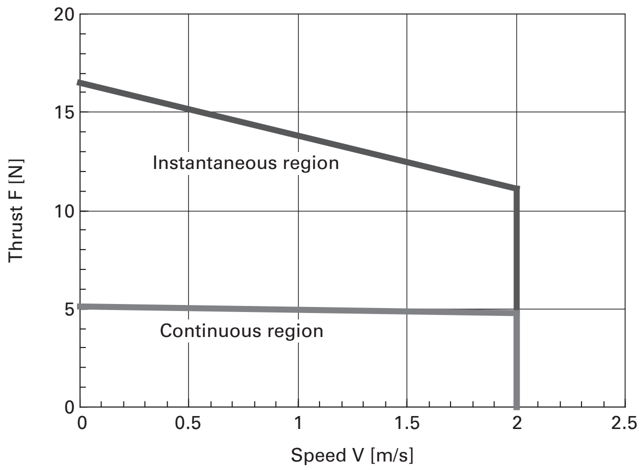

Fig. 5: Speed V – Thrust F characteristic

4.2 Reduced loss

Using the motor constant K_m, we evaluated the correlation between motor thrust and loss. The motor constant K_m for the compact cylinder linear motor is shown below.

$$K_m = \frac{F}{\sqrt{P_C}} = \frac{K_F}{\sqrt{3R_\Phi}}$$
$$= \frac{B}{\sqrt{3\rho}}\sqrt{\zeta A_C L}$$
$$= \frac{B}{\sqrt{3\rho}}\sqrt{\zeta V_C} \quad [N/\sqrt{W}] \qquad (2)$$

Where, K_m : Motor constant $[N/\sqrt{W}]$
P_C : Motor copper loss [W]
R_Φ : Motor phase resistance [Ω]
ρ : Copper resistivity
(= 1.673×10^{-8} [Ω·m])
ζ : Coil lamination factor
A_C : Coil cross-sectional area [m^2]
V_C : Coil volume [m^3]

Motor constant K_m is the product of the magnetic flux density B as magnetic loading and the coil effective volume ζV_C as electrical loading and a higher motor constant means greater thrust and lower loss.

The motor constant can be increased by either increasing the magnetic flux density as magnetic loading or increasing coil effective volume as electrical loading.

The method of increasing B as magnetic loading is as per discussed in 4.1.1. Moreover, the coil volume becomes limited due to the requirement for motor downsizing, therefore the coil lamination factor must be improved in order to raise electrical loading.

On the new model, the coil lamination factor has been raised through aligned wire winding and the coil tap wires, lead wires and so on have been arranged creatively to secure maximum coil winding space, thus achieving greater motor thrust and reduced loss.

4.3 Forced air cooling

Depending on usage conditions, the new model performs forced air cooling by passing compressed air through the motor frame, thus improving continuous thrust.

Fig. 6 gives a comparison of motor continuous thrust for natural air cooling and forced air cooling at a flow rate of 6 L/min (each motor).

- When a single motor axis (1 unit) was used, the motor continuous thrust went from 5.1 N of natural air cooling to 6.1 N of forced air cooling, improving by 120%.
- When multiple motor axes (3 units) were used, the motor continuous thrust went from 4.8 N of natural air cooling to 5.6 N of forced air cooling, improving by 118%.

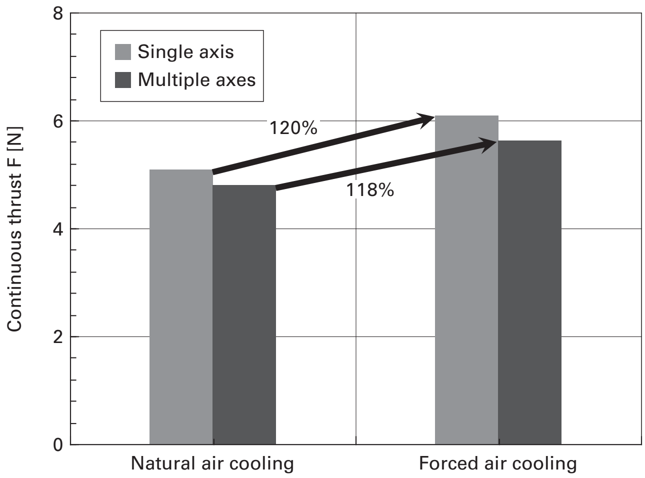

Fig. 6: Comparison of motor continuous thrust depending on usage conditions
(forced air cooling compressed air flow rate: 6 L/min)

4.4 Higher performance of multiaxial positioning

As Fig. 2 showed, the armature coil of the compact cylinder linear motor is □11.8 mm, which is smaller than the frame width of 12 mm. When multiple motors are lined up and used together, this structure has the following advantages.

- Motors can easily and accurately be lined up along the frame width.
- When performing forced air cooling, a gap forms between the armature coils, thus securing a path for the cooled air and improving cooling efficiency.

5. Conclusion

This report has introduced the features of a compact cylinder linear motor suitable for short stroke/high hit rate applications.

With a motor width of 12 mm, the new model is small at the same time as achieving a greater rated thrust of 5.1 N and possessing an all-in-one structure with a built-in linear encoder and linear guide. Moreover, due to being of a structure which enables not only single axis use, but also multiple axes to be used in parallel, the new model is able to respond flexibly to the specifications of customers' equipment.

Sanyo Denki believes that these features make a significant contribution to increasing productivity of our customers' equipment such as mounting equipment for electronic parts.

Reference

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Yuqi Tang
Joined Sanyo Denki in 1999.
Servo Systems Division, 1st Design Dept.
Worked on the development and design of linear servo motors. Doctor of Engineering

Masanori Tanaka
Joined Sanyo Denki in 2006.
Servo Systems Division, 1st Design Dept.
Worked on the development and design of linear servo motors.