Development of a Compact, Large Thrust, Low Magnetic Attractive Force Linear Servo Motor

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1. Introduction

Every year, the demand for linear servo motors grows, as they are an essential item to equipment which require high-speed drive and high-accuracy positioning, such as exposure machines and surface mounting machines. The advantage of a drive system using a linear servo motor is that equipment can be made high-speed, high-accuracy and energy-saving through the direct linear drive of load rather than using a linear motion conversion mechanism such as a ball screw(1).

In order to achieve even higher speed and accuracy, in addition to improving the linear servo motor thrust characteristic and reducing weight, it is necessary to reduce magnetic attractive force, which is an issue specific to core-equipped linear servo motors. Magnetic attractive force effects the apparatus which secure the motor and can cause such apparatus to distort or break. To prevent such issues, the mechanical strength of apparatus must be increased, however this in turn hinders weight reduction.

In order to solve these issues, Sanyo Denki has developed the compact, large thrust, low magnetic attractive force linear servo motor. The new model comes in two types; a core-equipped center magnet type (hereinafter "C-Mag Type") and a core-equipped twin type (hereinafter "Twin Type"). The C-Mag Type is a newly devised configuration (Pat.P).

This document first introduces the specifications and appearance of the new model. Next, explanations are provided regarding the respective configurations and characteristics of the C-Mag Type and Twin Type, and characteristics of this product are discussed using an example where it has been applied to use on an X-Y orthogonal robot.

2. Product Profile

Figure 1 shows the new model and Table 1 provides its specifications.

In regards to the newly devised C-Mag Type, a magnet rail has been arranged vertically in the center of the linear motor installation area and wedged between resin-molded armature coils on either side. In contrast to this, the Twin Type is the reverse of the C-Mag Type, with the resin-molded armature coils in the center of the linear motor installation area, wedged between two magnet rails on either side.

Table 1: Specifications of the new model

Item	Symbol	[Units]	C-Mag type	Twin type
Armature coil model No.	-	-	DT030CD1AN	DD035CC2AN
Magnet rail model No.	-	-	DT030M	DD035MB
Rated thrust	F_c	[N]	350	610
Maximum thrust	F_p	[N]	650	1400
Armature coil length*1	L_c	[mm]	145	253
Motor width	W_M	[mm]	86	105
Motor height	H_M	[mm]	55	70
Motor volume*2	V_M	[mm^3]	6.86×10^5	1.86×10^6
Armature coil mass	M_c	[kg]	2.4	5.0
Magnet rail mass	M_{mr}	[kg/m]	3.7	14.6

*1 Excluding the hall sensor portion
*2 Motor volume = Armature coil length x motor width x motor height

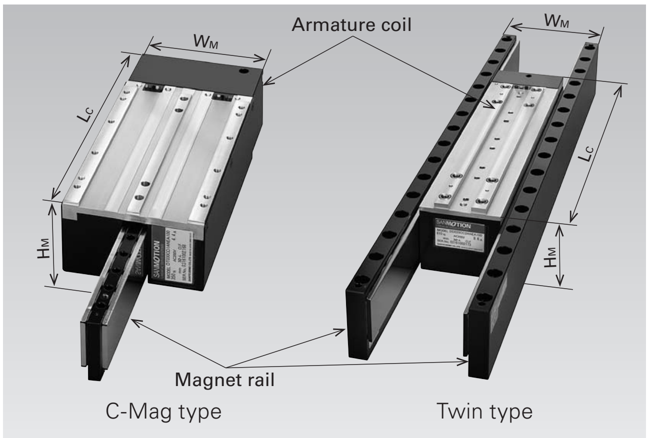

Fig. 1: New model

3. Specifications of the New Model

3.1 C-Mag type

3.1.1 Configuration and characteristics

Figure 2 shows the structural cross-section of a general core-equipped linear servo motor and indicates the direction of magnetic attractive force. In the case of core-equipped linear servo motors, magnetic attractive force works between the armature coil cores and magnets. This attractive force works in a vertical direction to thrust and is around five times stronger than maximum thrust. In order to support this attractive force, the apparatus which secure the linear servo motor (movable slider and fixed base) must have sufficient strength.

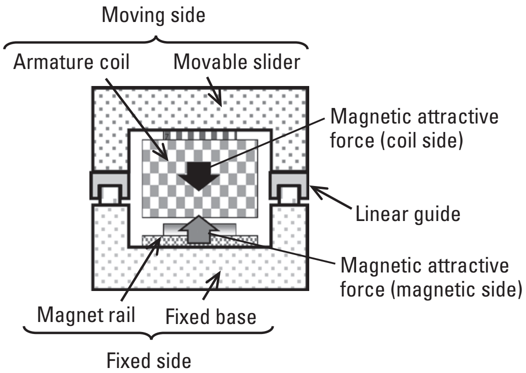

Fig. 2: Structural cross-section of a general core-equipped linear servo motor and direction of magnetic attractive force

Figure 3 shows the structural cross-section of the newly devised C-Mag Type and indicates the direction of magnetic attractive force. Magnetic attractive force works on the armature coils located on the outside of the motor in the direction of the magnet rail in the center, while another magnetic attractive force works on the magnet rail in the center in the direction of the armature coils located on the outside of the motor. The respective magnetic attractive forces are generated in opposing directions therefore negate themselves.

In this way, the C-Mag type's motor itself is of a configuration in which the overall magnetic attractive force is negated. As such, apparatus with this motor attached (movable slider and fixed base) are not effected by magnetic attractive force either on the moving side or fixed side, therefore the overall apparatus to which the motor is assembled can be simplified (made thinner) and easily made lighter.

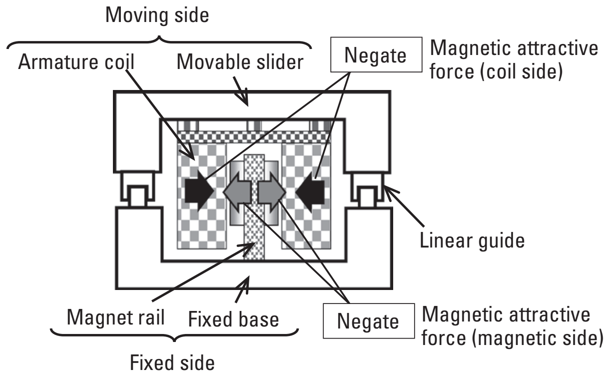

Fig. 3: Structural cross-section of the C-Mag Type and direction of magnetic attractive force

3.1.2 Thrust density and maximum acceleration

Figure 4 shows a comparison of C-Mag Type thrust density. Thrust density is the thrust generated per motor unit volume and the greater thrust density is, the more it indicates a linear servo motor is compact with large thrust(2).

The C-Mag Type was designed to optimize the magnetic circuit, minimize the coil end volume and optimize coil arrangement and wire termination method. This design has improved thrust density and, compared to a conventional twin type product with equivalent thrust, rated thrust density has been improved by 198%, while maximum thrust density has been improved by 142%.

Figure 5 shows the maximum acceleration of the C-Mag Type. Acceleration is derived from the following calculation; thrust ÷ movable portion mass (armature coil mass + load mass). The new model has improved thrust density, is more compact and lighter, which has consequently made it possible to achieve a high acceleration drive of over 25G at zero load mass and approximately 3G even under a load mass eight to ten times greater than the armature coil.

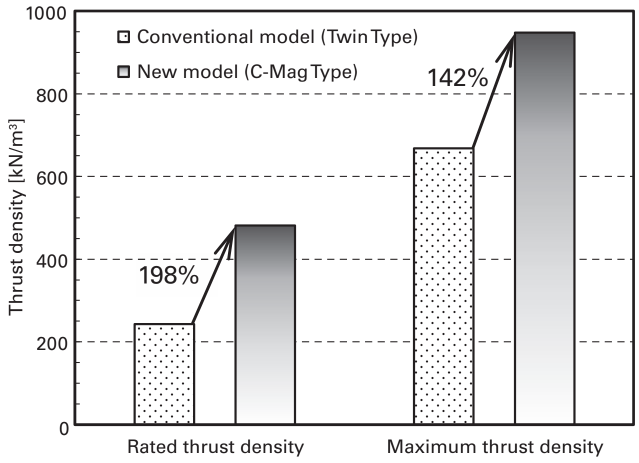

Fig. 4: Comparison of thrust density (C-Mag Type)

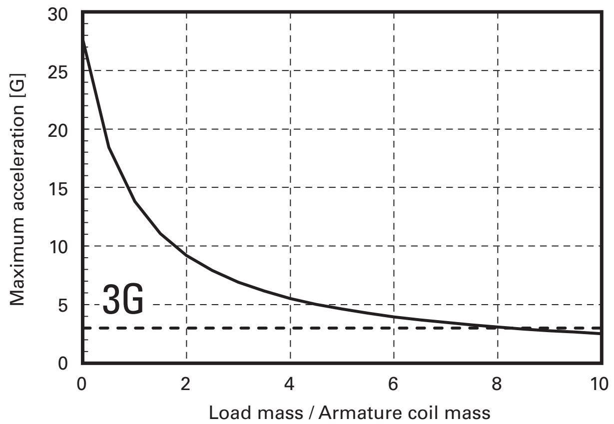

Fig. 5: Maximum acceleration (C-Mag Type)

3.2 Twin Type

3.2.1 Configuration and characteristics

Figure 6 shows the structural cross-section of the Twin Type and indicates the direction of magnetic attractive force. A magnetic attractive force works on the armature coils located in the center of the motor in the direction of the magnet rails on the outside, while a magnetic attractive force works on the magnet rails on the outside in the direction of the armature coil in the center. Magnetic attractive forces work on the armature coil in opposing directions, therefore negate themselves, making it possible to simplify the movable slider which secures the armature coils (make thinner) and easily reduce its weight. However, the magnetic attractive force which works on the magnet rails is unidirectional, therefore cannot be negated. There is a need to increase the mechanical strength of the fixed base and magnet rails that are being effected by the magnetic attractive force, therefore this point must be taken into consideration when using the Twin Type.

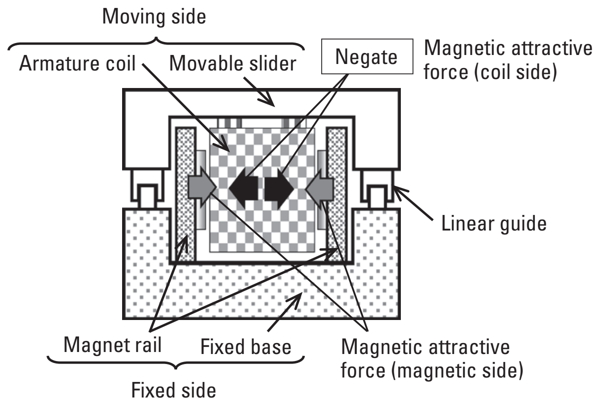

Fig. 6: Structural cross-section of the Twin Type and direction of magnetic attractive force

3.2.2 Thrust density and maximum acceleration

Figure 7 shows a comparison of Twin Type thrust density. On the new Twin Type model, the shape of the armature coil core has been improved and the magnetic circuit optimized to reduce loss. Furthermore, by lightening the structural members which do not contribute to thrust, the Twin Type has achieved a rated thrust density 137% that of the conventional model, and a maximum thrust density 113% higher.

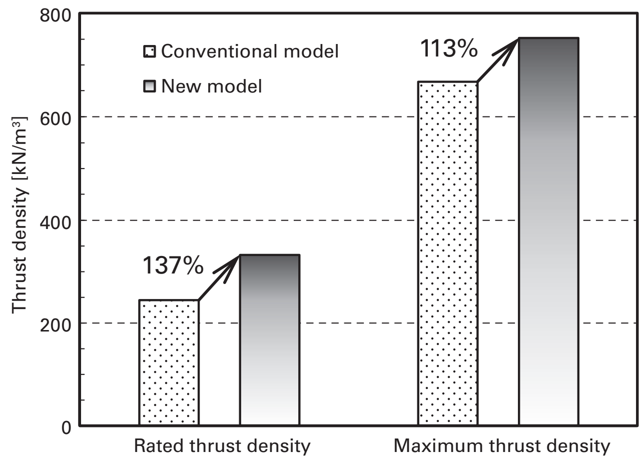

Fig. 7: Comparison of thrust density (Twin Type)

Figure 8 shows the maximum acceleration of the new Twin Type model. The thrust density has also been improved on the Twin Type model, and by making it more compact and lighter, we have achieved a high acceleration drive of over 25G at zero load mass and approximately 3G even under a load mass eight to ten times greater than the armature coil.

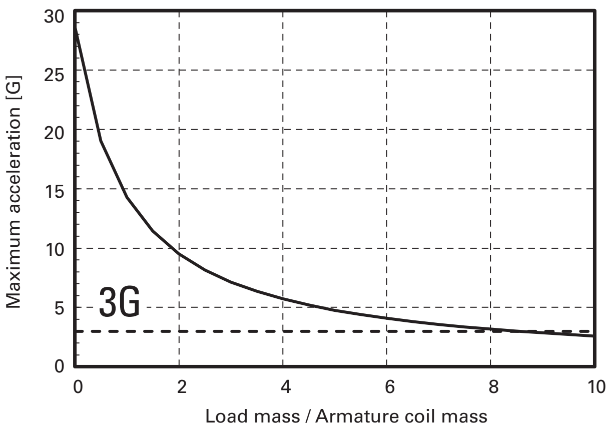

Fig. 8: Maximum acceleration (Twin Type)

4. Examples of Use

Figure 9 shows an X-Y orthogonal robot to which a C-Mag Type and a Twin-Type have been applied to the upper axis and lower axis respectively.

As Table 2 shows, the C-Mag Type on the upper axis does not create a magnetic attractive force which effects the movable slider or fixed base, therefore these components can be simplified and lightened. The entire upper axis can be made lighter, therefore alleviating the load which is applied to not only the upper axis motor, but also the lower axis motor, therefore increasing motor acceleration. As such, the C-Mag Type is ideal for use in locations where the entire apparatus moves.

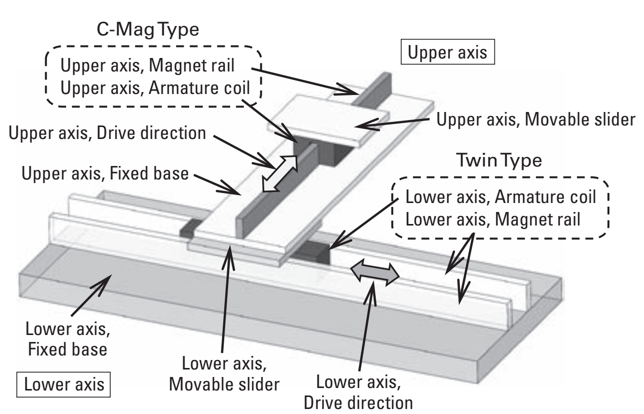

Fig. 9: Conceptual image of an X-Y orthogonal robot (excluding the linear guide)

Table 2: Comparison of magnetic attractive force working on equipment

	Movable slider	Fixed base
C-Mag Type	No magnetic attractive force	No magnetic attractive force
Twin Type	No magnetic attractive force	Magnetic attractive force has an effect

In the case of the Twin Type on the lower axis, there is no magnetic attractive force on the movable slider, therefore the movable slider can be simplified and made lighter, and the acceleration of the lower axis motor can be increased. Meanwhile, magnetic attractive force does work on the fixed base, therefore its mechanical strength must be raised and it cannot be made lighter. However, the fixed base is fixed to the equipment and does not move, therefore does not affect the drive characteristic even if it is heavy. In fact, if the fixed side of the lower axis is made lighter, the problem of vibration, etc. may occur. As such, the Twin Type is ideal for use in places where the fixed side is not moved.

Figure 10 shows a trial calculation of the weight reduction affect when the C-Mag Type is used on the upper axis as per Figure 9, while Table 3 shows the specifications of the upper axis movable slider and fixed base assumed for the trial calculation. This example compares the equipment mass + motor mass of the C-Mag Type and Twin Type, respectively. There is a difference in the magnetic attractive force working on the fixed base for the C-Mag Type and Twin Type, therefore the thickness of the fixed base differs

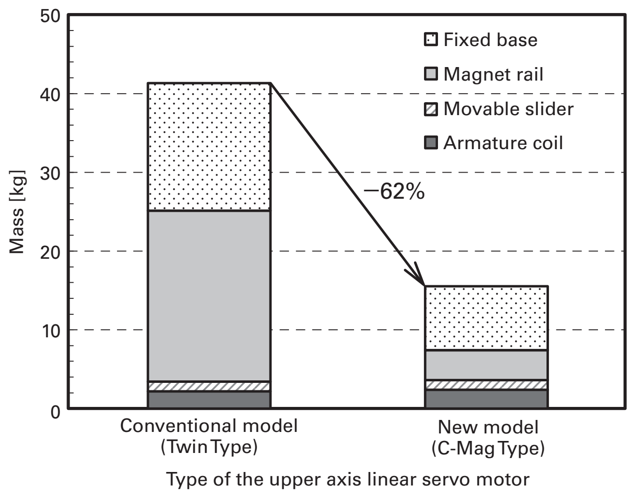

Fig. 10: Example of weight reduction due to using a C-Mag Type (Upper axis mass when applied to the upper axis in Figure 9)

Table 3: Specifications of the upper axis movable slider and fixed base

	Conventional model (Twin Type)	New model (C-Mag Type)
Upper axis movable slider	150 × 200 × 15 t (1.2 kg) Aluminum	
Upper axis fixed base	1000 × 200 × **30 t** (16.2 kg) Aluminum	1000 × 200 × **15 t** (8.1 kg) Aluminum

depending on which type is used. Furthermore, if the Twin Type is used, the magnet rails must be made thicker than if the C-Mag Type was used in order to minimize distortion and collapse. The difference in thickness of the fixed base and magnet rails largely impacts the difference in their masses. In this example, a 62% weight reduction is achieved by using C-Mag Type instead of Twin Type.

5. Conclusion

This document has introduced the configurations of the newly developed linear servo motor, which includes the C-Mag Type and Twin Type, as well as the characteristics and examples of use thereof.

The characteristics of the new model are as follows.

(1) Large thrust density (small and lightweight with a large thrust)
Compared with the conventional model, the rated thrust density of the C-Mag Type is approx. 2 times greater, and the maximum thrust density is approximately 1.5 times greater. For the Twin Type, rated thrust density is approx. 1.4 times greater and the maximum thrust density is approximately 1.1 times greater.

(2) High acceleration (high responsivity) is possible
Maximum acceleration is high because the new model is compact and lightweight, but at the same time, large thrust is achieved. For both types, a high acceleration drive of around 3G is possible under a load mass approx. eight to ten times greater than the armature coil.

(3) Small magnetic attractive force
The structure is one whereby the motor itself can negate the magnetic attractive force working in a vertical direction to thrust, therefore apparatus can be simplified and lightened. Particularly in the case of the newly devised C-Mag Type, the magnetic attractive force that works on the apparatus can be reduced to zero.

In this way, the new model is a linear servo motor which offers both high acceleration and user-friendliness, therefore we believe it will make a significant contribution towards the downsizing, cost reduction and improved productivity of our customers' equipment.

Reference
(1) Sugita, Misawa, Tang, Takahashi: An Introduction of Linear Servo Motors for Industrial Application, 2014 National Symposium by the Institute of Electrical Engineers of Japan, 5-S24-2 (2014)
(2) Misawa, Takahashi, Sato: Development of the "Compact, Core-equipped. SANMOTION Linear Servo Motor", SANYO DENKI Technical Report, No.37 (2014)

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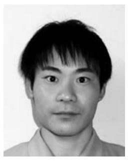

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