Development of the "Compact, Core-equipped SANMOTION Linear Servo Motor"

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1. Introduction

Linear servo motors for industrial applications have become remarkably popular in the past 10 years, with many being adopted on equipment requiring high accuracy such as exposure devices, as well as equipment requiring high-speed positioning such as surface mounters. Linear servo motors are mainly used due to having moving portions that use linear drive directly rather than passing through linear drive conversion mechanisms such as ball-screws, etc. This means they can significantly contribute to making equipment faster, more accurate and more energy efficient [1].

Regarding equipment for high-speed positioning applications, demands for weight reduction, higher acceleration/deceleration rates and low heat-emission are intensifying in a constant effort to improve productivity and high quality production [1] [2].

Moreover, due to the escalation of rare earth costs and supply instability in 2011, it has become desirable to develop productions which are not easily affected by fluctuation in raw material costs and resource availability by reducing the amount of magnets and highly scarce heavy rare earth elements (dysprosium, terbium, etc.) [3].

This paper introduces the features of the linear servo motors newly developed to respond to these kinds of demands. These motors include the core-equipped single magnet core type (hereinafter "single magnet core type") and core-equipped dual magnet core type (hereinafter "dual magnet core type").

First we show a comparison of the new models and conventional models' specifications. Next, we will discuss the features of these new models by highlighting the improvement in thrust density, maximum acceleration/deceleration rate, loss reduction and magnet usage compared with the conventional model.

2. New Model Specifications

Fig. 1 shows the new models of compact, core-equipped linear servo motors. Table 1 compares specifications of the new models with conventional models (products of equivalent thrust).

Both the single magnet core type and dual magnet core type models are surface magnet linear synchronization

Table 1: Specification comparison

Item	Symbol	[Units]	Model No./value			
			Single magnet core type		Dual magnet core type	
			Conventional model	New model	Conventional model	New model
Armature coil model No.	–	–	DS050C1N2	DS045CC1AN	DD050C2N2	DD045CB4AN
Magnet rail model No.	–	–	DS050M	DS045MC	DD050M	DD045MB
Rated thrust	F_c	[N]	260	260	900	800
Maximum thrust	F_p	[N]	580	500	2,100	2,200
Armature coil length	L_C	[mm]	200	130	402	349
Motor width	W_M	[mm]	85	65	140	118
Motor height	H_M	[mm]	58	48.5	90	80
Motor volume	V_M	[mm³]	9.86×10^5	4.10×10^5	5.07×10^6	3.29×10^6
Armature coil mass	M_c	[kg]	3.8	1.8	19.4	8.6
Magnet rail mass	M_{mr}	[kg/m]	7.6	2.9	23.4	21.7

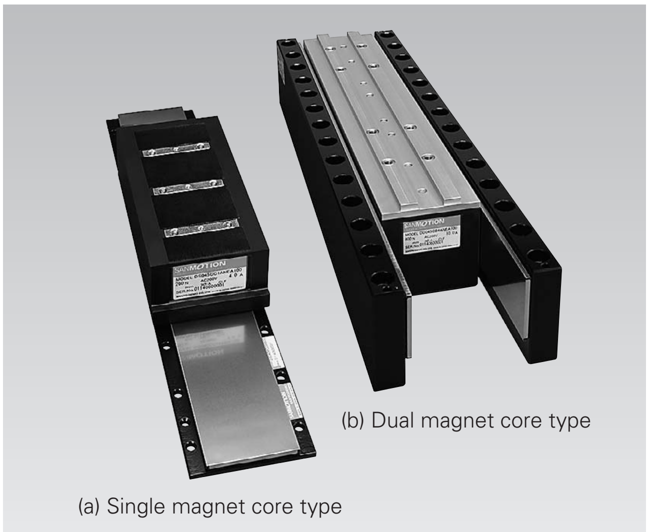


Fig. 1: External view of compact, core-equipped linear servo motors

motors. The single magnet core type is configured from a resin-molded armature sitting diagonally across from a permanent magnet, while the dual magnet core type is configured from the same resin-molded armature sandwiched between 2 magnet rails attached with permanent magnets. Due to its configuration, the dual magnet core type is able to minimize the magnetic attractive force generated between the armature core and permanent magnets, meaning only a small force is applied to linear motion support mechanisms such as the linear guide [(4)].

3. Development Goals

The following 3 goals were established for the development of the new models in order to produce linear servo motors which satisfied the abovementioned market demands.

(1) Improved thrust property
(2) Size and weight reduction
(3) Reduction of magnet usage and non-use of heavy rare earth

In order to achieve these goals, the below items were investigated and linear servo motor properties were improved.

- Improvement of thrust property through optimization of loading distribution (electrical loading and magnetic loading percentage), and size/weight reduction.
- Size and weight reduction by shrinking and removing material from mechanisms and structures other than the motor magnet circuit.
- Optimization of magnet shape considering thrust property and demagnetization tolerance, as well as magnet grade selection.

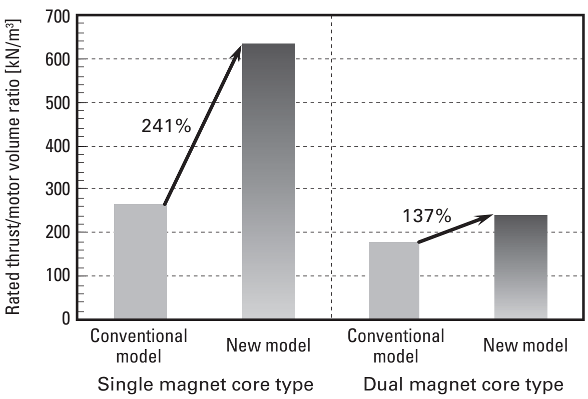
The next section discusses the results of these efforts compared with conventional models.

4. Comparison of Conventional Models and New Models

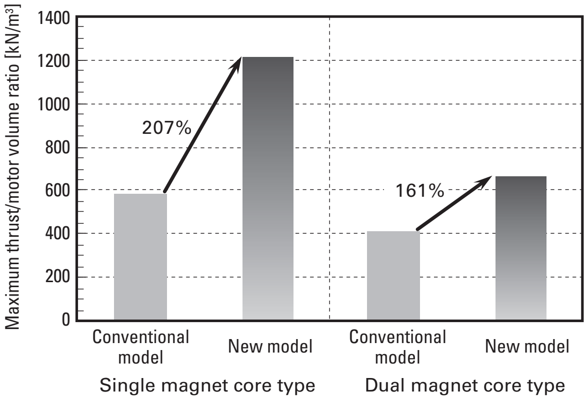
4.1 Improved thrust density

Fig. 2 compares the thrust densities of the new models and the conventional models. This is an index indicating the rated thrust and maximum thrust that the linear servo motor generates per unit of volume and the greater this value the smaller the size and higher the thrust of the linear servo motor is.

Thrust density was improved on the new models through revising the slot combination (armature core slot pitch and field magnet pole pitch percentage), increasing occupancy ratio of the slot inner windings for the armature core and improving the air gap magnetic flux density between the armature core and field magnet. As a result of these efforts, compared to conventional models, the rated thrust density

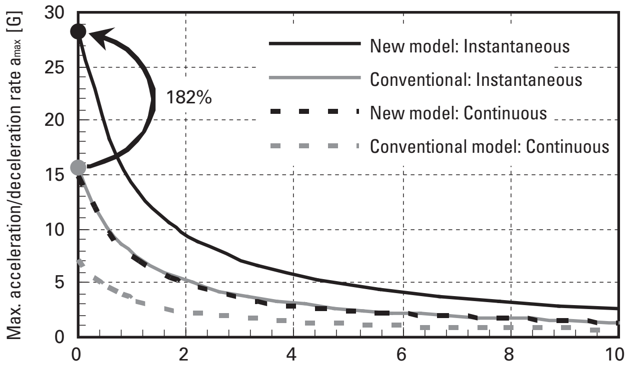


(a) Rated thrust density comparison

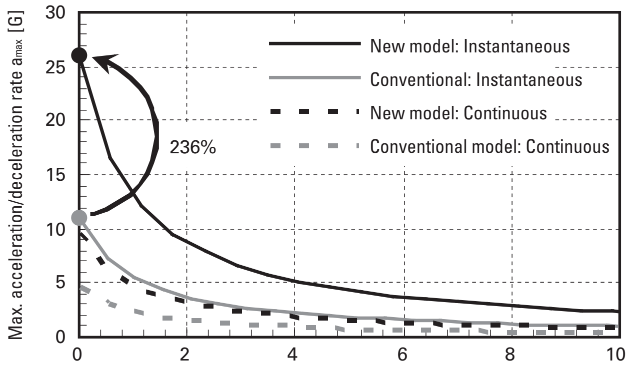


(b) Maximum thrust density comparison

Fig. 2: Thrust density comparison



(a) Single magnet core type



(b) Dual magnet core type

Fig. 3: Comparison of max. acceleration/deceleration rate

(Instantaneous max. acceleration/deceleration rate: (Max. thrust F_p) / (Load mass M_L + armature coil mass M_c),
Continuous max. acceleration/deceleration rate: (Rated thrust F_c) / (Load mass M_L + armature coil mass M_c))

of the new models has improved by 241% for the single magnet core type and 137% for the dual magnet core type, while the maximum thrust density has improved by 207% for single magnet core type and 161% for dual magnet core type.

Improvements in thrust density contribute to reducing the size of the new models.

4.2 Improved maximum acceleration/ deceleration rate

Fig. 3 shows a comparison of maximum acceleration/deceleration rate. This figure is a comparison of potential maximum acceleration/deceleration rate if the load mass as opposed to the armature coil mass of the linear servo motor is varied and this maximum acceleration/deceleration rate a_{max} [m/s^2] can be expressed with the following formula.

$$a_{max} = F / (M_L + M_c)$$

where, F : Thrust [N]

M_L : Load mass [kg]

M_c : Armature coil mass [kg]

The maximum acceleration/deceleration rates of the new models were improved by increasing the maximum/rated thrust through improving thrust density, reducing size and weight through structural revisions and reducing weight by removing material from portions other than the motor magnetic circuit. As a result, the maximum acceleration/deceleration rates of these new models were improved by 182% and 236% on the single magnet core type and dual magnet core type respectively in a no-load state compared to the conventional models. Moreover, even when driving a realistic load whereby (M_L) / (M_c) ratio is roughly 5-times greater, it is possible to achieve an instantaneous and continuous maximum acceleration/deceleration rate of 4 to 5 [G] and 2 to 3 [G].

Improvement of the maximum acceleration/deceleration rates has resulted in reduced drive tact time, thus meaning that these new models help to improve productivity.

4.3 Loss reduction

Fig. 4 compares loss reduction ratios.

Loss has been reduced on the new models through increasing winding occupancy ratio and optimizing winding specifications. Loss reduction of 11% for single magnet core type and 15% for dual magnet core type has been achieved on the new models.

By reducing loss, the new models can suppress the thermal expansion of equipment caused by motor heat generation and contribute to higher accuracy of equipment.

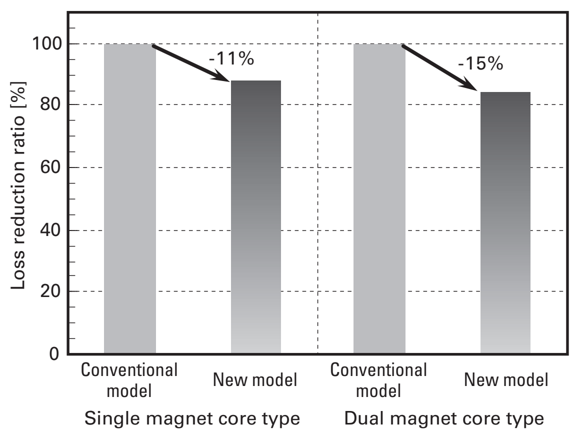


Fig. 4: Loss reduction rate

4.4 Magnet usage reduction and non-use of heavy rare earth

Fig. 5 compares the amount of magnet used in the new models and the conventional models. This is a comparison of the magnet mass necessary to generate unit thrust of the linear servo motors.

Improvement of thrust property and reduction of magnet usage oppose each other, however the new models are able to maintain an equivalent thrust property to the conventional models at the same time as reducing magnet thickness by 5% through appropriation of the demagnetization tolerance margin. Furthermore, adding to the advantages gained through improved thrust density, the magnet mass required to generate unit thrust has been reduced. As a result, the new models have 36% and 26% less magnet usage for the single magnet core type and dual magnet core type respectively compared with the conventional model.

The new models are equipped with magnets which do not contain heavy rare earth. Heavy rare earth is added to secure magnet properties at high temperatures however due to its scarcity and high cost it is preferable to minimize its usage. Magnets adopted on the conventional models contained a certain percentage of heavy rare earth however on the new models, magnets with high coercivity free of heavy rare earth have been used. New materials were chosen after sufficiently evaluating their reliability regarding basic motor properties, demagnetization tolerance, material strength, anti-corrosiveness and so on.

Thanks to successfully reducing magnet usage and freeing the motors of magnets containing heavy rare earth, Sanyo Denki has created a product not easily effected by fluctuation in raw material costs and resource availability.

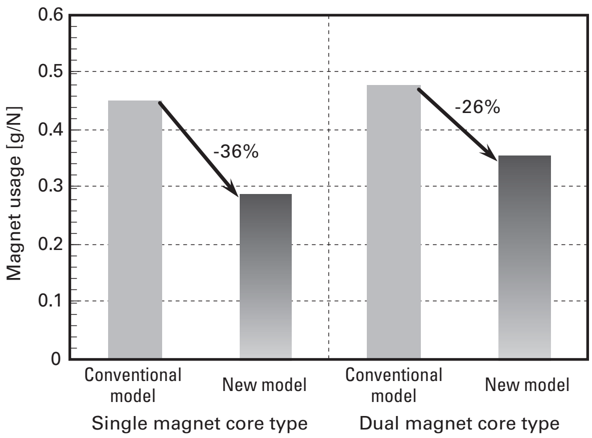


Fig. 5: Magnet usage comparison

5. Conclusion

This paper has introduced the features of single magnet core type and dual magnet core type compact, core-equipped linear servo motors with reduced magnet usage in order to satisfy demands of size and weight reduction in regards to equipment for high-speed positioning applications.

These new models have approximately 50% less motor volume and armature coil mass compared to conventional models with equivalent rated thrust at the same time as having approximately 2-times and 1.5 times better thrust density for the single magnet core type and dual magnet core type respectively. Moreover, maximum acceleration/deceleration rate able to be driven has been improved by approximately double, loss has been reduced by approximately 10%, magnet usage has been reduced by approximately 30% and rare metal has been eliminated entirely.

These features are believed to significantly contribute to improvement in productivity of customer equipment and high-quality production.

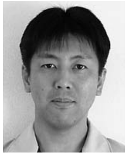
Documentation

(1) Onodera: "Features of Latest Motor Technologies and Advantageous Utilization" Machine Design, Vol.55, No.8, p.116-120 (2011)

(2) Sugita, Misawa, Tang, Takahashi: "Introduction of Linear Servo Motors for Industrial Applications", 2014 IEEJ National Convention Symposium, 5-S24-2 (2014)

(3) Hioki, Miyashita, Horiuchi, Onda: "Development of Small Capacity, High Precision AC Servo Motor" SANYODENKI Technical Report, No.35 (2013)

(4) Misawa, Sugita, Onodera: " Linear Servo Motor "Core Installed Double Side Type" " SANYODENKI Technical Report, No.15 (2003)



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