1. Foreword

Linear modules have been incorporated into various manufacturing machines for automobiles, photovoltaic generation systems, lumber processing, aircraft, packaging, and medical treatment systems since the 1980s. They are used as basic component parts for portal Cartesian coordinate robots including tip units and pick-and-place units of robots and are an indispensable technology for automation and transfer mechanisms. Depending on their applications, they are required to have high positioning accuracy or endurance under load. They are used in a variety of working environments ranging from outdoor locations to clean rooms. This article introduces AXDL linear modules developed by NTN-SNR to respond to diversifying market needs.

2. AXDL Series

2.1 Features of the AXDL series linear module

In an AXDL series linear module, a driving unit, a guide mechanism and a moving stage are joined to an aluminum frame with a unique structure. The most outstanding feature is its high general versatility that allows the optimum driving unit and guide mechanism to be combined to the frame freely.

The features of the AXDL series linear module are as follows:

1) Selection of a drive unit allowed

(1) Toothed-belt drive unit

Fig. 1 shows the appearance of an AXDL linear module equipped with a toothed-belt drive unit. The stage is fastened to the toothed belt, and is moved by the toothed belt motor-driven from the drive head. The toothed-belt drive unit is capable of being advanced at a high speed of 10 m/s as a result of combining it with the track roller parallel guide described later.

The AXDL series toothed belt drive module is characterized by the method of fixing the toothed belt that facilitates the replacement of belts. In common toothed belt drive units, toothed belts are often arranged at locations at which it is difficult to handle the inside of the unit, requiring many man-hours for belt replacement. For AXDL series products, a new fixing method has been developed, as shown in Figs. 2 and 3, in which the part on the cross-section of the stage through which the toothed belt is passed is formed as a space with a wedge-shaped cross-section, into which a wedge member is squeezed as if the toothed belt were to be inserted there. This fixing method allows the toothed belt to be fixed securely and replaced without removing component parts.

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(2) Ball screw drive unit

Fig. 4 shows the AXDL ball screw drive module. In the AXDL module equipped with a ball screw drive unit, the type of feed screw and the accuracy class of ball screws can be selected depending on the performance required.

In the standard specification, rolled ball screws with the accuracy class of T7* are used, while ball screws of up to accuracy class T3** can be selected for high-accuracy positioning applications. In addition, trapezoidal screws can be selected for adjustment action application not requiring positioning accuracy.

When a ball screw drive unit is used for high-speed transfer applications, it is necessary to be careful not to exceed the allowable rotational speed of the ball screw. The allowable rotational speed is determined by the shaft diameter of the ball screw and the distance between the supports and must not be exceeded.

NTN-SNR developed a wire-driven ball screw floating support mechanism shown in Fig. 5, making it possible to handle a high-load condition through an improvement of the shape of the support unit. This mechanism is structured to allow a pair of support units with a coupling element to move axially as the ball screw nut moves. Fig. 6 shows an example of action of a floating support equipped with a pair of support units. Applying support units makes it possible to reduce the support-to-support distance in comparison with a structure having a fixed support bearing only. Increasing the number of support units has made it possible to increase the allowable rotational speed as shown in Fig. 7.

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*Class C7 in the JIS notation
** Class C3 in the JIS notation
2) Selection of a guide mechanism
(1) Linear guide
Linear guide using a ball with a holder is applied. This guide mechanism has a high load capacity, having a higher rigidity, a higher accuracy, and a longer life than the track roller described later. Fig. 8 shows a cross-sectional view combined with a linear guide perspective view.

(2) Track roller guide unit
Generally, the rated operating speed of a linear module using a linear guide is up to 5 m/s. With the AXDL series, however, combining the track roller guide mechanism with the toothed belt drive as shown in Fig. 9 allows the system to reach a speed of 10 m/s.

3) The latitude in selecting a drive motor is large.
Motor flanges, couplings, and reduction gears allowing the combination with a motor with the best drive characteristics.

2.2 Improvement of the design of the AXDL series products
The AXDL series products are born out of the incorporation of a variety of improved technologies into the existing AXC series. The points of improvement are shown below:

1) Optimization of the frame shape
Since the cross-sectional shape of the frame affects the rigidity of the unit, it is necessary to increase the moment of inertia of area in two directions shown in Fig. 10, Ix and Iy.

The frame is composed of extruded aluminum members. In manufacturing extruded parts, aluminum bars (billets) are extruded through a trimming die to form extruded parts with a desired cross-section. By induction-heating billets to about 500°C in advance, adequate material liquidity associated with forming is obtained. The forming conditions are optimized so that stable drift velocity may be obtained even when the thickness varies locally in the same cross-section. The straightness of the AXDL 240Z product is optimized within the physical limits of the extrusion process by means of the finite element analysis so that it may be less than 0.5 mm/m (in conformity with DIN EN 12020-2).

The cross-sectional structure of the frame manufactured by the extrusion shown in Fig. 11 exerts a significant effect on the rigidity of the linear module and that of the unit as a whole. Rigidity shows the amount of deformation of the unit due to load. This is an important element determining the function and durability of the unit.
Rigidity was measured on AXDL 240 double-row linear guide products (with a height of 25 mm), double-row track roller guide products (with a track diameter of 47 mm) and conventional AXC 120 single-row linear guide products according to the coordinate system shown in Fig. 10. The rigidity is denoted with the inclination angle produced by the moment load, converted into the displacement at 1 m ahead. The experimental results are shown from the moment load $M_a$ (Fig. 12), $M_b$ (Fig. 13), and $M_c$ (Fig. 14).

2) Optimization of rigidity of component members

Fig. 15 shows an example of the calculation of the effect on the device rigidity of different module component parts by means of finite element analysis, which was carried out in addition to the optimization of the frame cross-sectional shape in order to increase the rigidity of the unit as a whole. An analysis carried out on an imagined condition of combined component parts (the track roller guide and the stage in the case represented by Fig. 15) allows mutual effects of members on one another to be evaluated and the effect on the entire unit to be estimated.

3) Improvement of the method of joining the linear guide unit with the ball screw drive unit

When the linear guide unit is joined with the ball screw drive unit, it is important to prevent stress that will affect the durability of the entire unit from occurring. As shown in Fig. 16, NTN-SNR has improved the method of joining the nut holder of the ball screw with the linear guide unit. The structure is such that the joint with the linear guide unit is formed
via the beam that projects only in the direction of the radius from the ball screw nut holder. This reduces the generation of stress due to the error in relative positions between the ball screw and the linear guide unit. This improvement also eliminates the adjustment during the assembly process and thereby preventing the occurrence of defects in assembling.

4) Improvement of dust-tightness by means of optimization of the seal structure

The dust-tightness of the unit is important from the viewpoint of improving the durability and reducing maintenance work. As shown in Fig. 17, a seal strip and a side strip, both made of polyamide (PA), are provided to improve the dust-tightness.

5) Increased ease of assembling to the unit

Fig. 18 shows the structure of the drive head of the toothed belt drive unit. For AXDL series products, the ease of assembling is improved by assembling the motor drive shaft into the drive head. This makes it possible to secure the compactness of the unit even with a large diameter pulley incorporated into the assembly, providing the following advantages:

⇒ Restraining the installation height of the system
⇒ Securing a large effective stroke length as compared with the total length of the system

3. Example of application of the AXDL series product

Fig. 19 shows an example of application of the AXDL series product to a two-shaft screw driving robot for automobile production systems.

Using the AXDL series product with a parallel-arranged two-row guide mechanism in this application has made it possible to accommodate a large angular moment (M_C). In a quest to prevent vibration associated with the movement of the shaft, the rigidity of each module has been increased.

Y axis: Servo-motor-driven AXDL 160 toothed belt module equipped with a planetary reduction gear
Z axis: AXDL 110 ball screw drive module equipped with a motor-mounting flange and a coupling to connect with a servo motor
The Z-axis is equipped with an electric driver to screw the valve cover to the cylinder head of an automobile engine.
4. Conclusion

The high-rigidity AXDL series linear module has been developed to meet strict requirements for accuracy, freedom from maintenance, and motion responsiveness. The unification of design concepts has made it possible to combine a drive unit and a guide mechanism, both suitable to a particular application, to flexibly meet diversified customer needs varying in terms of the size and function. Added to this have been technologies of ball screw support schemes, methods of fixing toothed belts, and perfect sealing of internal component parts to achieve a long service life and high stability of operation.

Furthermore, the connection and fixing brackets for the AXDL series products are standardized to allow the AXDL series products to be used in combination with all conventional AXC and AXL series products.

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