

## Method for Calculating Moment Loads on Linear Actuators

*An electric linear actuator is a combination product consisting of a linear mechanism and an electric motor, and when pre-assembled offers an easier design, shorter installation time, and high quality.*

*While the actuator is operating, moment loads occur due to not only gravity, but also because of acceleration and deceleration of the load. Because moment loads can damage actuators, confirming that they are within specification is critical. However, calculating moment loads on linear actuators can be complicated and time consuming.*

*This paper describes a method for calculating moment loads in a simple way and makes actuator selection easier.*

### 1. Introduction

By combining a motor with linear mechanical components, electric linear actuators benefit design engineers by shortening the time to design, install and adjust the equipment (Refer to Figure 1).

When electric linear actuators are in operation, moment loads occur due to gravity applied to the load and the acceleration of the load. Because moment loads have great influence on the service life of actuators, it is essential to make sure that they are within the actuator specifications. However, calculating moment loads of electric linear actuators can be complicated and time consuming, because installation directions and motions are typically considered for linear actuators.



Figure 1 Electric Linear Actuators and Cylinders

### 2. Selection of Linear Actuators (The Concept of Moment Leads)

Figure 2 shows the flow of linear actuator selection. First, check the size and transportable mass of a linear actuator. Next, check the positioning time in order to determine operating conditions that meet the required positioning time. Lastly, check to see if the moment applied to the actuator is within the permissible range.

#### ① Check the size and transportable mass of a linear actuator

Select the right size electric linear actuator that meets the desired conditions. (Check the frame size, table height, transportable mass, and thrust force.)

#### ② Check the positioning time

Refer to the "Positioning Distance – Positioning Time" graph in the catalog to see if the desired positioning time meets the requirement.

#### ③ Check operating conditions

From the graphs of "Positioning Distance - Operating Speed" and "Positioning Distance – Acceleration", check the operating speed and acceleration that meet the ② conditions.

#### ④ Check the moment

Consider the acceleration and check to see if the dynamic permissible moment used for the electric linear actuator is not exceeding its specification range.

Selection completed.

Figure 2 Flow Chart of Linear Actuator Selection

### 3. Structure of Electric Linear Actuators

Using the EAS Series as an example, the structure of electric linear actuator is shown in Figure 3. Also, Figure 4 shows its cross-section structure.

The load applied to a table and moment loads are all supported by a linear guide consisting of a guide rail and guide block.

These loads have an influence on the life of the linear guide and thus, are important to consider during the selection process.

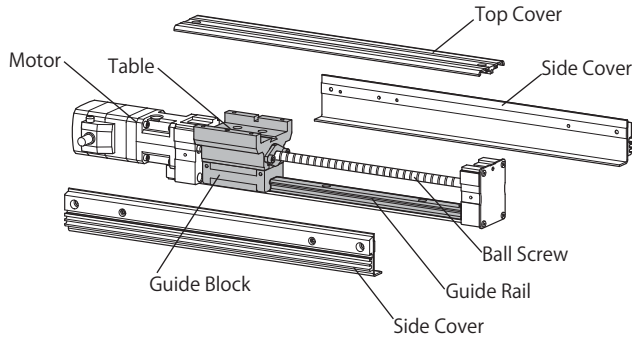


Figure 3 Structure of Electric Linear Actuator (EAS Series)

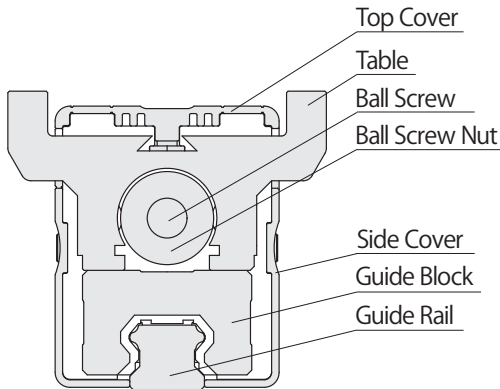


Figure 4 Cross-Section Structure of Electric Linear Actuator (EAS Series)

**4. Moment Applied to Actuator**

The moment applied to an electric linear actuator is explained in the next section.

**4.1. Moment Applied to Electric Linear Actuator**

As shown in Figure 5, when the center of gravity of the carried load is overhung from the center of the table of the electric linear actuator, the moment is applied from the center of the table as the support point. The moment applied to an electric linear actuator can be obtained from the following formula.

$$M = m \cdot g \cdot L \dots\dots\dots(1)$$

- M : Moment applied to an electric linear actuator
- L : Overhung distance
- m : Load mass
- g : Gravitational acceleration

From this point forward, the gravitational acceleration is deemed 9.807m/s<sup>2</sup> in this article.

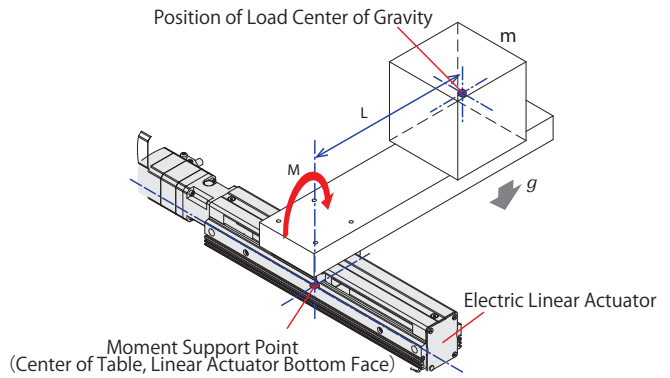


Figure 5 Example of Moment Applied to Electric Linear Actuator

**4.2. Moment Direction**

There are three different directions of moments applied to electric linear actuator: pitching direction, yawing direction and rolling direction (Refer to Figure 6). The moment support points are on the bottom face (installation surface) of the linear actuator and the center of the table.

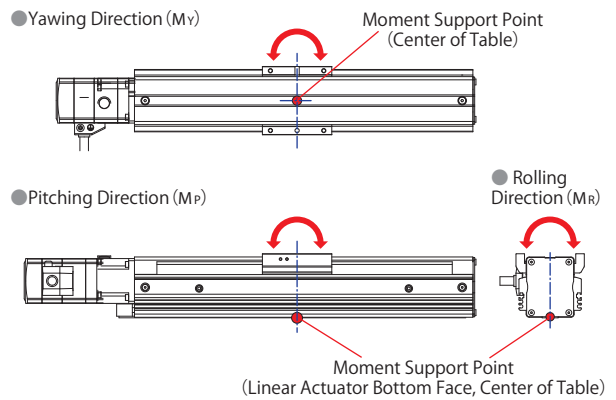


Figure 6 Moment Directions Applied to Electric Linear Actuators

**4.3. Moment Direction Determined by Installation Direction**

Directions of moments applied to electric linear actuators can change depending on the installation condition of the load and the installation direction of the actuator itself. Figure 7 shows how the direction of a moment changes when the installation direction of an actuator is changed under the same installation condition of the load.

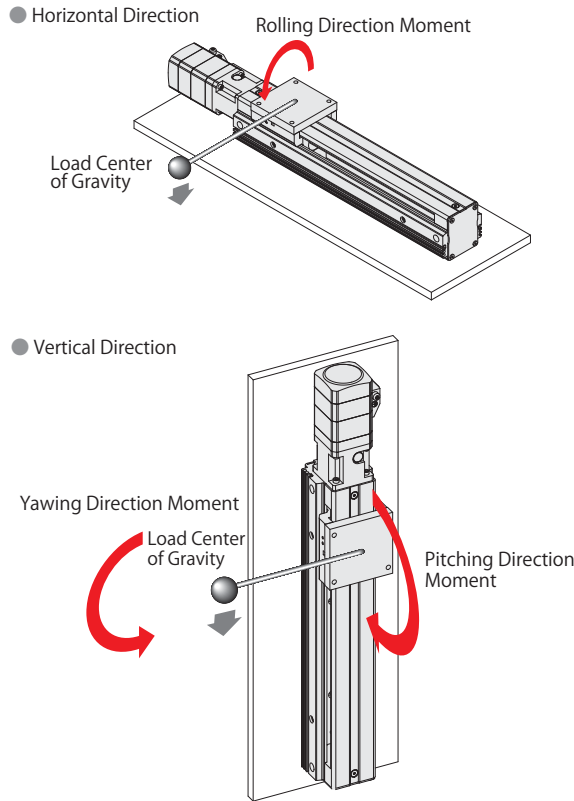


Figure 7 Difference of Moments Caused by Installation Directions

#### 4.4. Static Permissible Moment and Dynamic Permissible Moment

##### 4.4.1. Static Permissible Moment

The moment applied to the stopped linear actuator is called the static moment. The permissible value of the static moment of a linear actuator is called the static permissible moment and it is determined by the mechanical strength factors of a linear guide and table. When an external force is applied while the linear actuator is stopped, it is necessary to check that the static moment is within the permissible range at each direction.

##### 4.4.2. Dynamic Permissible Moment

The moment applied to the linear actuator while transporting a load is called the dynamic moment. Because acceleration is applied during operation, the moment is applied depending on the overhung distance from the table.

The calculation methods of the moment at each direction, when transporting a load with a linear actuator as shown in Figure 8, are shown in the proceeding formulas.

Each denotation in Figure 8 indicates the meaning as follows:

- $M_P$  : Pitching direction moment
- $M_Y$  : Yawing direction moment
- $M_R$  : Rolling direction moment
- $L$  : Overhung distance in the direction of the Y-axis load center of gravity
- $H$  : Overhung distance in the direction of the Z-axis load center of gravity
- $m$  : Load mass
- $\alpha$  : Operating acceleration
- $g$  : Gravitational acceleration

The mass of the arm and the position of the center of gravity are omitted in this figure.

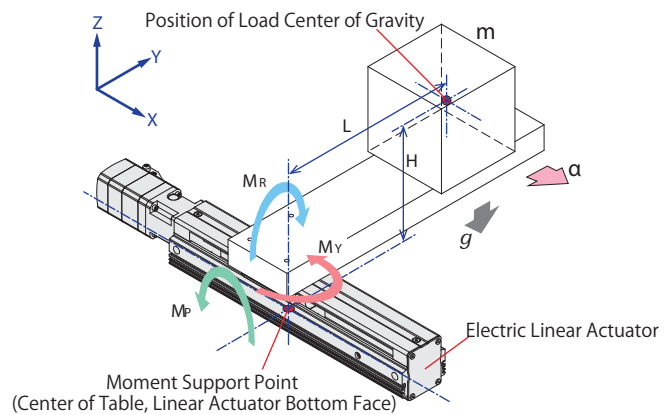


Figure 8 Example of Dynamic Moment Applied to Linear Actuator

Formula 2 calculates the pitching direction moment; formula 3 calculates the yawing direction moment; and formula 4 calculates the rolling direction moment.

$$M_P = m \cdot \alpha \cdot H \dots\dots\dots (2)$$

$$M_Y = m \cdot \alpha \cdot L \dots\dots\dots (3)$$

$$M_R = m \cdot g \cdot L \dots\dots\dots (4)$$

Calculate the ratio by dividing the moment values calculated by these formulas (2), (3), and (4) with the dynamic permissible moments at each direction, which are the product specifications. Next, add all of the calculated moment ratios at each direction. If the total sum is less than 1, as shown in the moment formula (5), then it can be used.

$$\frac{|MP|}{MP_{max}} + \frac{|MY|}{MY_{max}} + \frac{|MR|}{MR_{max}} \leq 1 \dots\dots\dots(5)$$

**MP<sub>max</sub>** : Dynamic permissible moment in the pitching direction  
**MY<sub>max</sub>** : Dynamic permissible moment in the yawing direction  
**MR<sub>max</sub>** : Dynamic permissible moment in the rolling direction

**5. Moment Loads Calculation Example of Single Shaft Linear Actuator**

In this section, moment loads calculation examples are explained per installation direction. A single shaft linear actuator is used as an example. The following shows a calculation example of moment loads when selecting the **EASM4XD020ARAC** electric linear actuator with a slide width of 45mm (1.771 in.) and table height of 60mm (2.362 in.):

**5.1. When Installing in Horizontal Direction**

Figure 9 shows an electric linear actuator installed horizontally with the load overhung in the direction of the Y-axis. The dynamic permissible moment of the electric linear actuator is shown below:

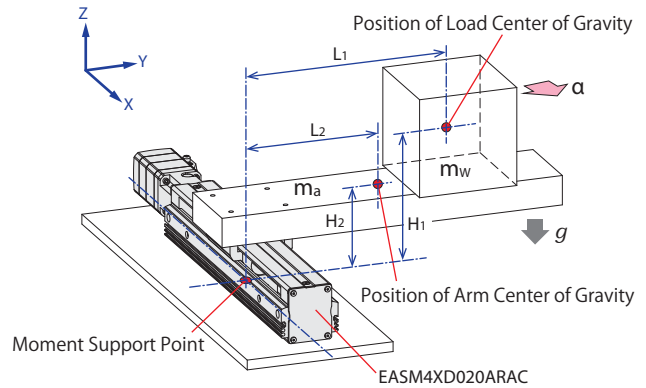
**MP<sub>max</sub>** : Pitching direction 16.3 [N•m]  
**MY<sub>max</sub>** : Yawing direction 4.8 [N•m]  
**MR<sub>max</sub>** : Rolling direction 15.0 [N•m]

The load center of gravity from the actuator and the overhung distance of the arm's center of gravity are shown below:

**L1** : Load center of gravity overhung distance in Y-axis direction 150 [mm]  
**L2** : Arm center of gravity overhung distance in Y-axis direction 100 [mm]  
**H1** : Load center of gravity overhung distance in Z-axis direction 90 [mm]  
**H2** : Arm center of gravity overhung distance in Z-axis direction 65 [mm]

The load mass, arm mass, and acceleration are shown below:

**m<sub>w</sub>** : Load mass 1.5 [kg]  
**m<sub>a</sub>** : Arm mass 0.5 [kg]  
**α** : Acceleration 3.0 [m/s<sup>2</sup>]



**Figure 9 Calculation Example of Dynamic Moment Applied to Actuator (Horizontal Direction)**

- Pitching Direction Moment MP  
 $MP = (m_w \cdot \alpha \cdot H1) + (m_a \cdot \alpha \cdot H2)$   
 $= (1.5 \times 3.0 \times 0.09) + (0.5 \times 3.0 \times 0.065)$   
 $= 0.50 \text{ [N}\cdot\text{m]}$
- Yawing Direction Moment MY  
 $MY = (m_w \cdot \alpha \cdot L1) + (m_a \cdot \alpha \cdot L2)$   
 $= (1.5 \times 3.0 \times 0.15) + (0.5 \times 3.0 \times 0.1)$   
 $= 0.83 \text{ [N}\cdot\text{m]}$
- Rolling Direction Moment MR  
 $MR = (m_w \cdot g \cdot L1) + (m_a \cdot g \cdot L2)$   
 $= (1.5 \times 9.807 \times 0.15) + (0.5 \times 9.807 \times 0.1)$   
 $= 2.70 \text{ [N}\cdot\text{m]}$

From the Permissible Moment Formula (5):

$$\frac{|MP|}{MP_{max}} + \frac{|MY|}{MY_{max}} + \frac{|MR|}{MR_{max}}$$

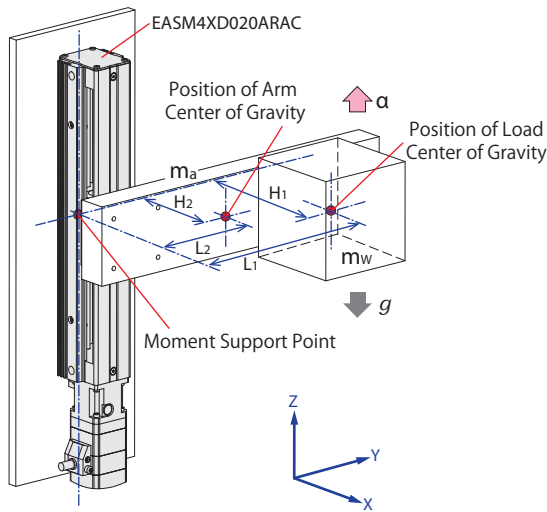
$$= \frac{|0.50|}{16.3} + \frac{|0.83|}{4.8} + \frac{|2.70|}{15.0}$$

$$= 0.38 \leq 1$$

Based on the results, the moment is within the dynamic permissible moment and thus, it can be used.

**5.2. When Installing in Vertical Direction**

Figure 10 shows a calculation example of the dynamic moment when a linear actuator is installed in the vertical direction. Installation dimensions, loads, and operating conditions are exactly the same as 5.1.



**Figure 10 Calculation Example of Dynamic Moment Applied to Actuators (Vertical Direction)**

• Pitching Direction Moment MP

$$\begin{aligned}
 MP &= (m_w \cdot \alpha \cdot H_1) + (m_a \cdot \alpha \cdot H_2) + \\
 &\quad (m_w \cdot g \cdot H_1) + (m_a \cdot g \cdot H_2) \\
 &= (1.5 \times 3.0 \times 0.09) + (0.5 \times 3.0 \times 0.065) + \\
 &\quad (1.5 \times 9.807 \times 0.09) + (0.5 \times 9.807 \times 0.065) \\
 &= 2.15 \text{ [N}\cdot\text{m]}
 \end{aligned}$$

• Yawing Direction Moment MY

$$\begin{aligned}
 MY &= (m_w \cdot \alpha \cdot L_1) + (m_a \cdot \alpha \cdot L_2) + \\
 &\quad (m_w \cdot g \cdot L_1) + (m_a \cdot g \cdot L_2) \\
 &= (1.5 \times 3.0 \times 0.15) + (0.5 \times 3.0 \times 0.1) + \\
 &\quad (1.5 \times 9.807 \times 0.15) + (0.5 \times 9.807 \times 0.1) \\
 &= 3.52 \text{ [N}\cdot\text{m]}
 \end{aligned}$$

The rolling direction moment MR is not applied, thus it is 0 [N·m]. From the Permissible Moment Formula (5):

$$\begin{aligned}
 &\frac{|MP|}{MP_{\max}} + \frac{|MY|}{MY_{\max}} + \frac{|MR|}{MR_{\max}} \\
 &= \frac{|2.15|}{16.3} + \frac{|3.52|}{4.8} + \frac{|0|}{15.0} \\
 &= 0.87 \leq 1
 \end{aligned}$$

Based on the results, the moment is within the dynamic permissible moment and thus, it can be used.

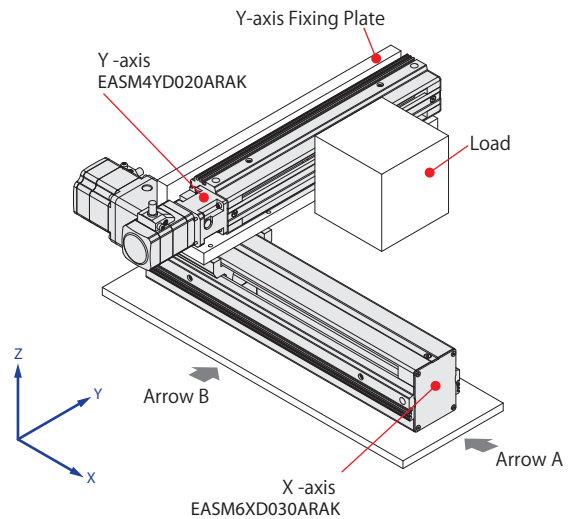
**6.2 Method of Moment Loads Calculation When Combining 2 Axes**

Next, as an example of combining 2 axes, the moment loads calculation of the X-Y combination of electric linear actuators is explained.

With the X-Y combination, the single Y-axis, which transfers the load, is calculated first, in order to determine whether the Y-axis is usable. Then, for the calculation of moment loads of the X-axis, the moment load of the total mass of the Y-axis and the moment load generated when the Y-axis accelerates to transfer the load are added to the calculation.

Figure 11 shows an example of the X-Y combination of electric linear actuators.

**EASM6XD030ARAK** is fixed on the X-axis slide and **EASM4YD020ARAK** is combined on the Y-axis. The Y-axis is fixed on the Y-axis fixing plate, and then fixed on the X-axis table.



**Figure 11 Example of X-Y Combination**

**1) Calculation of Moment Loads for Y-axis**

First, the moment load applied to the Y-axis is calculated (Refer to Figure 12). The dynamic permissible moments of the Y-axis actuator **EASM4YD020ARAK** are indicated below.

- MPmax** : Pitching direction 16.3 [N·m]
- MYmax** : Yawing direction 4.8 [N·m]
- MRmax** : Rolling direction 15.0 [N·m]

The overhung distance of the load center of gravity from the Y-axis, load mass, and acceleration of the Y-axis are indicated as follows.

- X1** : Overhung distance of load center of gravity from X-axis 150 [mm]
- mw** : Load mass 2.0 [kg]
- α** : Y-axis operating acceleration 3.0 [m/s<sup>2</sup>]

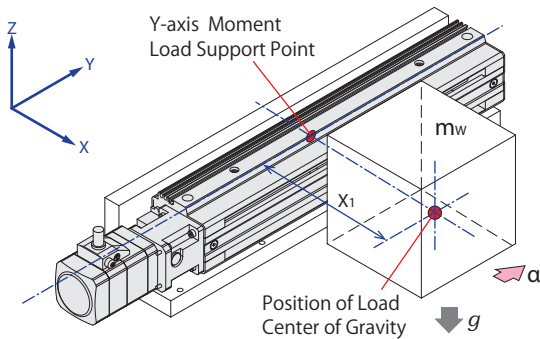


Figure 12 Calculation of Moment Loads of Y-axis

- Pitching Direct Moment **MP**  

$$MP = (mw \cdot \alpha \cdot X1)$$

$$= (2.0 \times 3.0 \times 0.15)$$

$$= 0.90 \text{ [N}\cdot\text{m]}$$

Because the moment **MY** is not applied to the yawing direction, it is 0 [N·m].

- Moment **MR** Applied to Rolling Direction  

$$MR = (mw \cdot g \cdot X1)$$

$$= (2.0 \times 9.807 \times 0.15)$$

$$= 2.94 \text{ [N}\cdot\text{m]}$$

From the Permissible Moment Formula

(5):

$$\frac{|MP|}{MP1max} + \frac{|MY|}{MY1max} + \frac{|MR|}{MR1max}$$

$$= \frac{|0.90|}{16.3} + \frac{|0|}{4.8} + \frac{|2.94|}{15.0}$$

$$= 0.25 \leq 1$$

The moment of the Y-axis slide is within the specification range and thus, it can be used.

## 2) Calculation of Moment Loads for X-axis

Next, the moment load applied to the X-axis slide is calculated. The dynamic permissible moments of the X-axis slide **EASM6XD030ARAK** are indicated below.

- MP2max** : Pitching direction 31.8 [N·m]
- MY2max** : Yawing direction 10.3 [N·m]
- MR2max** : Rolling direction 40.6 [N·m]

The load from the X-axis, load center of gravity of the Y-axis, and overhung distance of the load center of gravity of the Y-axis slide fixed plate are indicated as follows.

- X1**: Load center of gravity overhung distance in X-axis direction by 150 [mm] (5.91 in.)
- X2**: Y-axis fixed plate center of gravity overhung distance in X-axis direction by 50 [mm] (1.97 in.) in a negative direction
- X3**: Y-axis center of gravity overhung distance in X-axis direction by 10 [mm] (0.39 in.)
- Y1**: Load center of gravity max. overhung distance in Y-axis direction by 230 [mm] (9.06 in.)
- Y2**: Y-axis fixed plate center of gravity overhung distance in Y-axis direction by 80 [mm] (3.15 in.)
- Y3**: Y-axis center of gravity overhung distance in Y-axis direction by 60 [mm] (2.36 in.)
- Z1**: Load center of gravity overhung distance in Z-axis direction by 120 [mm] (4.72 in.)
- Z2**: Y-axis fixed plate center of gravity overhung distance in Z-axis direction by 90 [mm] (3.54 in.)
- Z3**: Y-axis center of gravity overhung distance in Z-axis direction by 130 [mm] (5.12 in.)

The mass of the Y-axis fixed plate, mass of the Y-axis slide, and X-axis operating acceleration are indicated as follows.

- MP** : Y-axis fixed plate mass 0.5 [kg]
- Ms** : Y-axis slide mass 2.1 [kg]
- β** : X-axis operating acceleration 0.5 [m/s<sup>2</sup>]

Figure 13 shows the arrow A in Figure 11, and Figure 14 shows the arrow B in Figure 11.

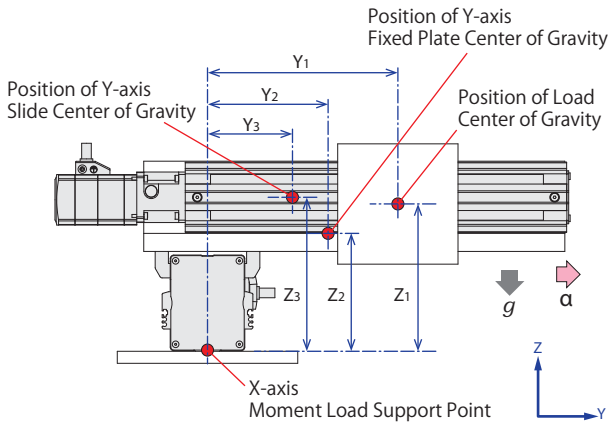


Figure 13 Arrow A

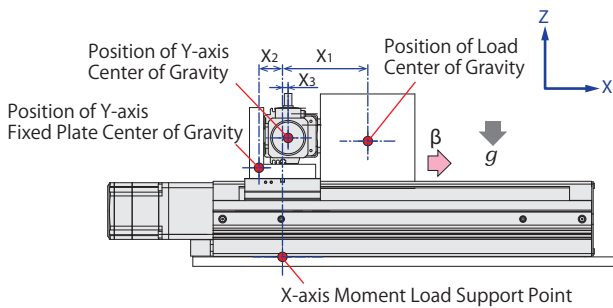


Figure 14 Arrow B

When calculating moment loads, simulate the condition of the moment load applied to the X-axis at its maximum, and calculate under the condition when the Y1 is at its peak.

• Pitching Direction Moment MP

$$\begin{aligned}
 MP &= (m_w \cdot \beta \cdot Z_1) + (m_p \cdot \beta \cdot Z_2) + \\
 &\quad (m_s \cdot \beta \cdot Z_3) + (m_w \cdot g \cdot X_1) + \\
 &\quad (m_p \cdot g \cdot X_2) + (m_s \cdot g \cdot X_3) \\
 &= (2.0 \times 0.5 \times 0.12) + (0.5 \times 0.5 \times 0.09) + \\
 &\quad (2.1 \times 0.5 \times 0.13) + (2.0 \times 9.807 \times 0.15) \\
 &\quad + \{0.5 \times 9.807 \times (-0.05)\} + \\
 &\quad (2.1 \times 9.807 \times 0.01) \\
 &= 3.18 \text{ [N}\cdot\text{m]}
 \end{aligned}$$

• Moment MY Applied to Yawing Direction

$$\begin{aligned}
 MY &= (m_w \cdot \beta \cdot Y_1) + (m_p \cdot \beta \cdot Y_2) + \\
 &\quad (m_s \cdot \beta \cdot Y_3) + (m_w \cdot \alpha \cdot X_1) \\
 &= (2.0 \times 0.5 \times 0.23) + (0.5 \times 0.5 \times 0.08) \\
 &\quad + (2.1 \times 0.5 \times 0.06) + (2.0 \times 3.0 \times 0.15) \\
 &= 1.21 \text{ [N}\cdot\text{m]}
 \end{aligned}$$

• Moment MR Applied to Rolling Direction

$$\begin{aligned}
 MR &= (m_w \cdot g \cdot Y_1) + (m_p \cdot g \cdot Y_2) + \\
 &\quad (m_s \cdot g \cdot Y_3) + (m_w \cdot \alpha \cdot Z_1) \\
 &= (2.0 \times 9.807 \times 0.23) + (0.5 \times 9.807 \times 0.08) \\
 &\quad + (2.1 \times 9.807 \times 0.06) + (2.0 \times 3.0 \times 0.12) \\
 &= 6.86 \text{ [N}\cdot\text{m]}
 \end{aligned}$$

From the Permissible Moment Formula

(5):

$$\begin{aligned}
 &\frac{|MP|}{MP_{2\max}} + \frac{|MY|}{MY_{2\max}} + \frac{|MR|}{MR_{2\max}} \\
 &= \frac{|3.18|}{31.8} + \frac{|1.21|}{10.3} + \frac{|6.86|}{40.6} \\
 &= 0.39 \leq 1
 \end{aligned}$$

The moment applied to the X-axis is below the specification value and thus, it can be used. Based on the findings, both the X and Y axes meet respective dynamic permissible moments and therefore, it is determined that they are usable. The same steps of calculations are taken for the X–Y–Z combination with the addition of a Z-axis; start calculating the moment from the endmost axis, which is the Z-axis, then move on to the Y-axis and the X-axis.

7. Deflection of When Moment is Applied to a Table

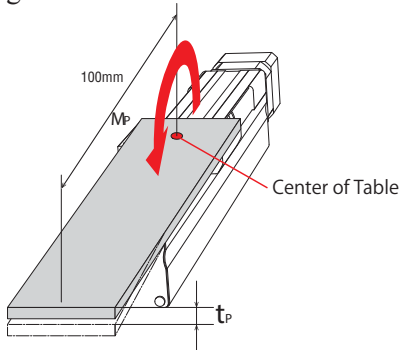
When the moment is applied to the slide, the table inclines in the moment direction. This inclination causes displacement to the overhung position. Table 1 shows the deflection amount when applying the dynamic permissible moments in each direction to the EAS Series slide table, as shown in Figure 15. The measurements are taken at the overhung position of 100mm (3.94 in.) from the center of the table, and the values are for reference only.

Table 1 Deflection Amount of Actuator Table When Dynamic Permissible Moment is Applied

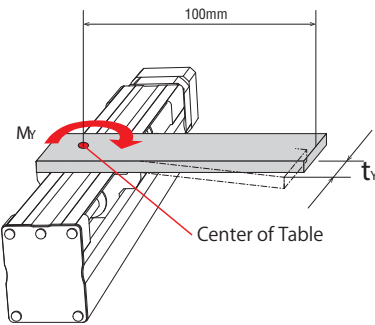
Series	Size	tp	ty	tr
EAS	4	0.11 mm	0.03 mm	0.38 mm
	6	0.11 mm	0.03 mm	0.41 mm

\*The value excluding the plate deflection.

• Pitching Direction



• Yawing Direction



• Rolling Direction

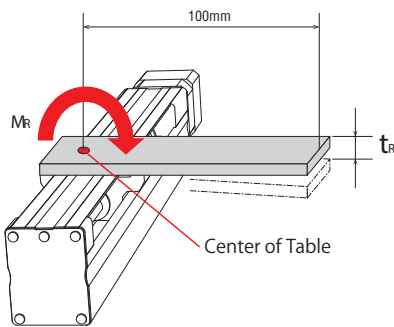


Figure 15 Deflection Amount of When Dynamic Permissible Moment is Applied

8. Calculation of Moment Loads for Electric Cylinders

When using an electric cylinder, it is necessary to externally install a guide to support the rod so that it can support the moment loads. The series of an electric cylinder with a guide (shaft guide) that can be used while applying loads to the rod is also available (Refer to Figure 16). In this section, calculation examples of moment loads for an electric cylinder with a guide are explained.

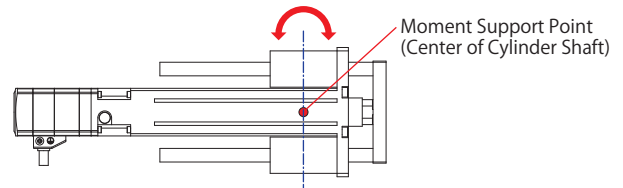


Figure 16 Electric Cylinder with Guide (EAC Series)

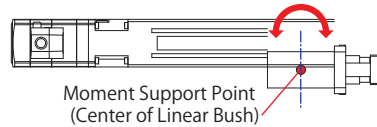
8.1. When Moment is Applied to Electric Cylinder with Guide

For an electric cylinder with a guide, there are directions for which moments are applied, just like an electric linear actuator. Figure 17 shows the moment directions which are applied to the cylinder with a guide.

● Yawing Direction ( $M_y$ )



● Pitching Direction ( $M_p$ )



● Rolling Direction ( $M_r$ )

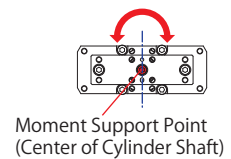


Figure 17 Moment Directions Applied to Cylinder with Guide

8.2. Moment Loads Calculation of Electric Cylinder with Guide

8.2.1. Transferring Loads in Vertical Direction

A calculation example of moment loads applied to a linear bush, when a cylinder with a guide transfers loads in the vertical direction, is shown below. The following are shown in Figure 18.

- $M_R$  : Pitching direction moment applied to linear bush
- $L$  : Overhung distance
- $m$  : Load mass
- $\alpha$  : Operating acceleration



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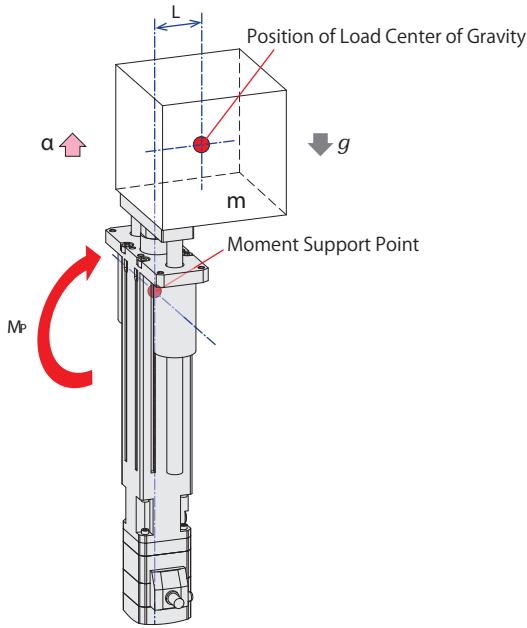


Figure 18 Example of Moments Applied When Installed Vertically

As shown in Figure 18, when indicating the pitching direction moment as  $M_p$ , which is applied to the vertically installed linear bush, it can be calculated with the following formula (6).

$$M_p = (m \cdot g \cdot L) + (m \cdot \alpha \cdot L) \dots\dots\dots (6)$$

This is to confirm that the calculated value of the pitching direction moment is within the range of the dynamic permissible moment.

## 8.2.2. Transferring Loads in Horizontal Direction

Next, with the cylinder with a shaft guide as shown in Figure 18, the home position is set when the rod is inserted all the way. Figure 19 shows the relationship between the positioning distance and the transportable mass when transferring the load in the horizontal direction.

The load in the horizontal direction has the load itself and also the self-weight of the cylinder rod and shaft guide. This is applied to the linear bush as the moment. These aspects are considered and included in the figure.

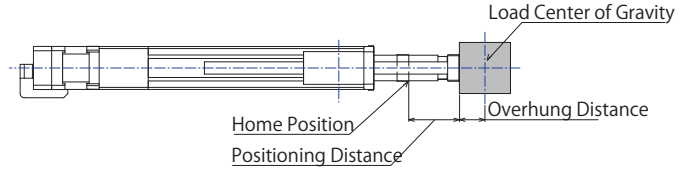
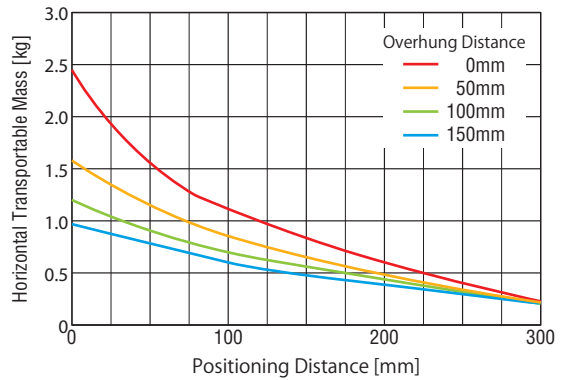
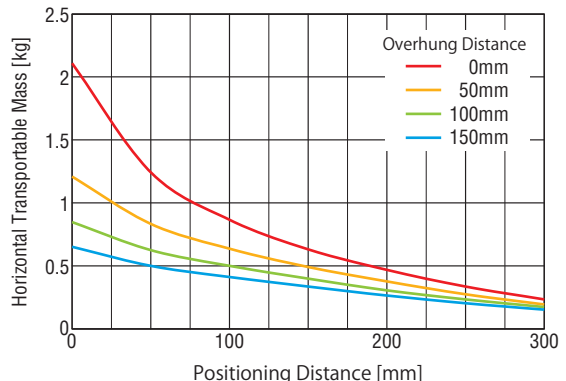


Figure 19 Diagram When Transferring Loads in Horizontal Direction



EAC4



EAC6

Figure 20 Relationship Between Positioning Distance and Transportable Mass When Installed Horizontally

## 9. Summary

The concept and procedures of moment load calculation methods for electric linear actuators and cylinders were explained in this article. With the actual equipment, there are various kinds of equipment conditions and driving conditions for electric actuators and cylinders and thus, it is very difficult to explain all the operating conditions. Oriental Motor offers selection calculations based on the operating conditions. For further details, please contact the nearest Oriental Motor sales office.