Calculating Stopping Accuracy of Brushless DC Motors

Stepper motors and servo motors with excellent stopping accuracy are commonly used when performing high-precision positioning operation. However, depending on usage conditions, brushless motors can stop with an overrun of several mm, with simple hall effect sensors used for speed control feedback. This paper explains this overrun, how to calculate stopping accuracy using overrun characteristics (typical value) of brushless motors, and two methods to improve stopping accuracy.

What is Stopping Accuracy?

Stop accuracy refers to "error of actual stop position with respect to target position". Most of this error is due to "overrun'" characteristics of the motor. In addition to "overrun", a slight "variation" can occur. In mathematical terms, "stop accuracy = overrun + variation". By comparison, "variation" is very small. An example is shown in Figure 2.

There are three main factors that affect stopping accuracy, and in the case of the highlighted cells in Figure 1 below, "overrun" can be minimized. Pay attention to the rotational speed, inertial load and friction load, and how they affect the overrun and stop accuracy of the brushless motor.

Factor		Overrun	Stop Accuracy
Rotational Speed	Fast	More	Low
	Slow	Less	High
Inertial Load	Large	More	Low
	Small	Less	High
Friction Load	High	Less	High
	Small	More	Low

Table 1 Factors Affecting Stopping Accuracy

Application Example

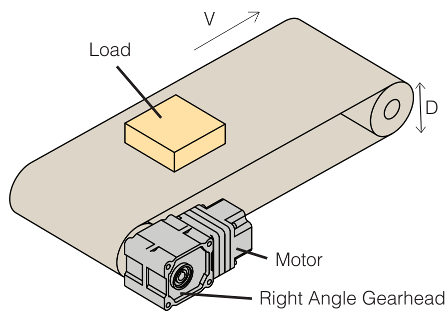

Figure 1 Application Example for Calculation Conditions

Application..Belt Conveyor
Belt Speed...V_L=0.005 to 1 [m/s]
Motor Power Supply..............................Single Phase 110VAC
Roller Diameter..**D**=0.1 [m]
Mass of Roller...M_2=1 [kg]
Total Mass of Belt and Workpiece............................M_1=7 [kg]
External Force..F_A=0 [N]
Friction Coefficient of Sliding Surface............................**M**=0.3
Efficiency of Belt Roller..**H**=0.9

For the requirements given for the conveyor application above, it was determined that a 120W brushless motor and a gearhead with reduction ratio of 15:1 would be able to move the inertial load of 200 x 10^{-4} kg•m^2 in the required speed range. A system consisting of a BLM5120HPK-5H15S brushless motor, a BLE2D120-A dedicated driver, and a CC005HBLF motor cable from our BLE2 Series was recommended.

1. How to Calculate Stopping Accuracy: Motor Speed (N_M) = 3000 r / min

Use the overrun characteristics of the 120W BLE2 Series under the below conditions:

General Specifications: 120 Watt/ BLE2 Series Motor and Driver

Condition

Voltage: Single-Phase 220 VAC
Frequency: 50/60 Hz
Speed: 1000/2000/3000/4000 r/min
Load Torque: 0
Temperature: Room Temperature

Note

Number of Tests: 50 Times (One motor is used)
Stop Mode: Instantaneous Stop
Shaft Type: Round Shaft Type

1) Conversion of Motor Shaft

Since the graph below is the value of the motor alone, convert the rotational speed and inertial load of the gear shaft obtained by the selection calculation to the motor shaft.

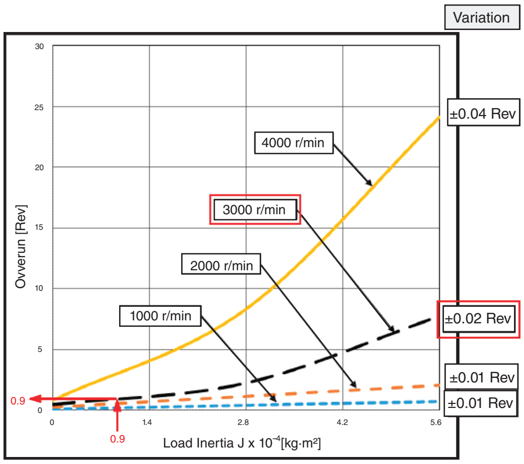

Figure 2 BLE2 Overrun Example at 3000 r/min

N_M	Motor Shaft RPM
N_G	Gear Shaft RPM
i	Gear Ratio
J_M	Inertial Load at Motor Shaft
J_G	Inertial Load at Gear Shaft
OR_G	Overrun at Gear Shaft
OR_M	Overrun at Motor Shaft
OR_C	Overrun at Conveyor
D	Diameter

①Motor shaft rotation speed
$N_M = N_G \times i = 191 \times 15 = 2865$ [r / min]
Use the curve of black dashed line of 3000 r / min to approximate.

②Motor shaft inertial load
$J_M = J_G \div i^2 = 200 \times 10^{-4} \div 15^2 \approx 0.9 \times 10^{-4}$ [kg · m²]

③When reading the overrun (vertical axis) value from the motor axis overrun ① (black dashed curve) and ② (horizontal axis), it is found that it is about 0.9 ± 0.2 [Rev].

2) Conversion of Gear Shaft

Convert the overrun obtained in 1) to the gear axis.
$OR_G = OR_M \div i = (0.9 \pm 0.2) \div 15 \approx 0.06 \pm 0.013$ [Rev]

3) Conversion of Conveyor Belt

Convert the overrun obtained in 2) to the belt conveyor axis.
$OR_C = D \times \pi \times OR_G = 100 \times 3.14 \times (0.06 \pm 0.013) \approx 19 \pm 4$ [mm]

From the equations, it can be inferred that the overrun of the belt conveyor is 19 mm and the variation is ± 4 mm.

2-1. Improvement of Stopping Accuracy: Deceleration & Stop Motor Speed (N_M = 3000 r / min to 1000 r / min to stop)

As you can see from the overrun characteristics in table 1, the overrun becomes smaller as the rotation speed decreases.
Here, we calculate the overrun when stopping after decelerating.

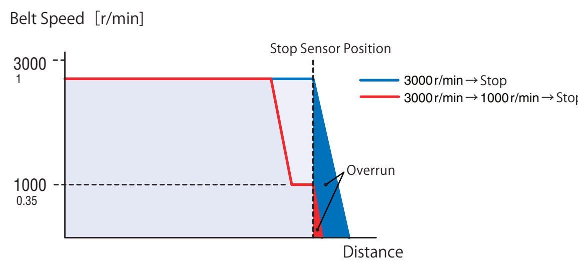

Figure 3 Overrun Characteristics

Calculate by the same procedure as **1. How to Calculate Stopping Accuracy**.
Reading overrun (vertical axis) from 1000 r / min (curve with blue broken line) and 0.9×10^{-4} [kg · m²] (horizontal axis) shows that it is about 0.2 ± 0.1 [Rev]

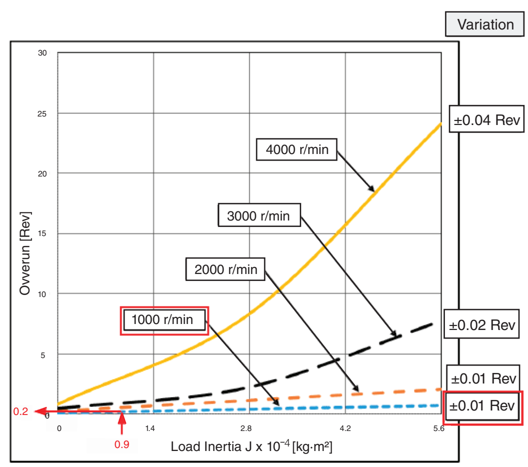

Figure 4 BLE2 Overrun Example at 1000 r/min

Convert this value to the gear axis.
$OR_G = OR_M \div i = (0.2 \pm 0.1) \div 15 \approx 0.013 \pm 0.007$ [Rev]

Finally convert to belt conveyor axis.
$OR_C = D \times \pi \times OR_G = 100 \times 3.14 \times (0.013 \pm 0.007) \approx 4 \pm 2$ [mm]

From the above, it can be inferred that the overrun is 4 mm and the variation is about ± 2 mm.

2-2. Improvement of Stopping Accuracy: Increase Gear Reduction Ratio (i = 15→30)

As mentioned, the overrun of the gear shaft is the value of the motor shaft divided by the gear reduction ratio. Therefore, overrun can be suppressed by increasing the reduction ratio.

Here, we calculate the overrun when increasing the reduction gear ratio. (In this case, the speed of the belt will also halve to Max 0.5 m / s.)

1) Conversion of Motor Shaft

①To comply with the same conditions of the motor shaft rotation speed in **1. Calculate Stopping Accuracy**, use the stopping accuracy calculation: N_M = 3000 r / min", use the black dashed curve of 3000 r / min.

②Motor shaft inertial load
$J_M = J_G \div i^2 = 200 \times 10^{-4} \div 30^2 \approx 0.2 \times 10^{-4}$ [kg · m²]

③When reading the value of overrun (vertical axis) from the motor axis overrun ① (black dashed curve) and ② (horizontal axis), it is about 0.6 ± 0.2 [Rev].

2) Conversion of Gear Shaft

Convert the overrun obtained in 1) to the gear axis.
$OR_G = OR_M \div i = (0.6 \pm 0.2) \div 30 \approx 0.02 \pm 0.007$ [Rev]

3) Conversion of Conveyor Belt

Convert the overrun obtained in 2) to the belt conveyor axis.
$OR_C = D \times \pi \times OR_G = 100 \times 3.14 \times (0.02 \pm 0.007) \approx 6 \pm 2$ [mm]

From the above, it can be inferred that the overrun is 6 mm and the variation is about ± 2 mm when the gear reduction ratio is increased from 15:1 to 30:1.

3. Conclusion

This document shows how to determine stop accuracy according to speed and inertial load as well other methods to effectively improve stopping accuracy of brushless motors. Our knowledgeable technical support engineers are available to help if any calculation assistance is needed.

Motor Shaft Rotation Speed [r/min]	Gear Reduction Ratio	Belt Speed [m/s]	Stop Precision	
			Overrun [mm]	Variation [mm]
3000	15	1	19	±4
3000 —> 1000	15	1 —> 0.35	4	±2
3000	30	0.5	6	±2