DigiFlex® Performance™ Drives in High-Speed Applications

Introduction

ADVANCED Motion Controls® DigiFlex® Performance™ digital servo drives are an excellent solution for velocity control. However, there are a few details to be reviewed when considering them for high-speed applications. This document will provide the necessary information to determine if the required application speed can be attained.

The following three topics related to high-speed operation will be covered:

1. Maximum allowed speed for proper commutation of the motor
2. Acceptable velocity ripple when using Hall sensors for velocity control
3. Maximum encoder frequency when using an incremental encoder for velocity control

Information on the *ADVANCED* Motion Controls' servo drive in use as well as motor information will be needed.

Maximum Allowed Speed for Proper Commutation

Commutation is the act of maintaining the correct torque angle on a motor. When using a brushless motor, commutation is achieved by using feedback to determine the motor position, and commutation algorithms to output current to the motor phases.

As the motor rotates, the drive responds to changes on the commutation sensors by rotating the commanded phase angle. As the motor rotates faster, phase lag occurs. At a certain point, the commutation sensors change faster than the drive can respond to, resulting in loss of torque and ultimately loss of commutation.

To determine the maximum speed a DigiFlex Performance drive can accurately commutate, several pieces of information are required:

1. Maximum electrical cycles/second that the drive can sample and process
2. Switching frequency of the drive (found on the drive datasheet)
3. Pole count of the motor (found on the motor datasheet)

Empirical data shows that *ADVANCED* Motion Controls' digital drives can reliably sample and process an electrical cycle speed of up to 10 electrical degrees per sample. Sample rates depend on the switching frequency of the drive in use.

Based on this information it is possible to calculate the speed at which performance problems will begin to be evident.

Example - DPRANIE-015S400 with a six pole motor

DPRANIE-015S400 Switching Frequency = 20 kHz

$$\frac{20{,}000\left(\frac{samples}{sec}\right) * 10\left(\frac{deg}{sample}\right)}{360\left(\frac{deg}{elec\ cycle}\right)} = 556\left(\frac{elec\ cycles}{sec}\right)$$

This result will now be used to calculate the maximum possible speed before performance issues arise.

$$Electrical\ Cycles = \frac{Num\ of\ motor\ poles}{2} = 3$$

$$\frac{556\left(\frac{elec\ cycles}{sec}\right)}{3\left(\frac{elec\ cycles}{rev}\right)} = 185.33\left(\frac{rev}{sec}\right)$$

$$185.33\left(\frac{rev}{sec}\right) * 60\left(\frac{sec}{min}\right) = 11.12\ kRPM$$

If higher speeds are needed than what is achievable based on the above calculations, an analog drive could be considered. Since analog drives continuously monitor the commutation data, they do not have the sampling limitations that digital drives do. Another alternative is to use a motor with a lower pole count.

Note: ADVANCED Motion Controls' brushless analog servo drives can only commutate the motor trapezoidally using Hall sensors. Incremental encoders can be used for velocity control on certain analog drives, but they cannot be used for commutation. For this reason a digital drive must be used if sinusoidal commutation is required.

Acceptable Velocity Ripple with Hall Sensors

Velocity control using Hall sensors with a digital drive is partly dependent on how the drive samples the Hall sensors. When a drive is configured for Hall Velocity Mode, a velocity measurement is made based on Hall state sampling every velocity loop cycle. To see the effects of increased speed on the velocity ripple, it is required to determine how many samples there are between Hall state changes.

As the speed increases there are fewer samples between Hall state changes. Regardless of speed, there can still be up to 1 sample of error since the drive does not know where within the sample Hall state the motor is. As a result, the error becomes larger at high speeds.

To be able to determine how much velocity error should be expected for the speed the motor is rotating/traveling, several pieces of information are required:

1. Switching frequency of the drive (found on the drive datasheet)
2. Pole count of the motor (found on the motor datasheet)

Example

For a six pole motor being used with a drive with a switching frequency of 20 kHz, the expected velocity ripple will be calculated at 3000 RPM and 12000 RPM. First, determine how many samples between each Hall state change for each speed:

3000 RPM:

$$\frac{elec\ cycles}{rev} = \frac{Num\ of\ motor\ poles}{2} = \frac{6}{2} = 3$$

$$3\left(\frac{elec\ cycles}{rev}\right) * 6\left(\frac{Hall\ changes}{elec\ cycles}\right) = 18\left(\frac{Hall\ changes}{rev}\right)$$

$$3000\left(\frac{rev}{min}\right) * 18\left(\frac{Hall\ changes}{rev}\right) * \frac{1\ min}{60\ sec} * \frac{1\ sec}{20000\ samples} = 0.045\left(\frac{Hall\ changes}{sample}\right)$$

Take the inverse to get *(samples/Hall state changes)*:

$$\frac{1}{0.045} = 22.22\left(\frac{samples}{Hall\ changes}\right)$$

Based on a possibility of up to 1 sample of error, for 3000 RPM one sample is 1/22.22, or 4.5%, so the best possible regulation is:

3000 RPM ± 135 RPM.

12000 RPM:

$$\frac{elec\ cycles}{rev} = \frac{Num\ of\ motor\ poles}{2} = \frac{6}{2} = 3$$

$$3\left(\frac{elec\ cycles}{rev}\right) * 6\left(\frac{Hall\ changes}{elec\ cycles}\right) = 18\left(\frac{Hall\ changes}{rev}\right)$$

$$12000\left(\frac{rev}{min}\right) * 18\left(\frac{Hall\ changes}{rev}\right) * \frac{1\ min}{60\ sec} * \frac{1\ sec}{20000\ samples} = 0.18\left(\frac{Hall\ changes}{sample}\right)$$

Take the inverse to get *(samples/Hall state changes)*:

$$\frac{1}{0.18} = 5.56\left(\frac{samples}{Hall\ changes}\right)$$

Based on a possibility of up to 1 sample of error, for 12000 RPM one sample is 1/5.56, or 18%, so the best possible regulation is:

12000 RPM ± 2160 RPM.

The example above looks at the theoretical best case based on sampling of the Hall sensors. In reality, other factors affect performance at high speeds. Use of empirical and theoretical data resulted in the following set of equations that provide a worst case scenario for performance at high speeds. Most applications will be well under these ripple values.

Specifications	Value	Details
Max Frequency (kHz) in Electrical Cycles	Fs/12	Fs = drive switching frequency in kHz
Calculated Frequency in Electrical Cycles (kHz)	Fe, Calculated	Calculated using motor pole count and required speed
Maximum Velocity Ripple Error	0-100%	For Fs = 20 10% for Fe ≤ 0.17 20% for 0.17 < Fe ≤ 0.33 33% for 0.33 < Fe ≤ 0.55 50% for 0.55 < Fe ≤ 0.83 100% for 0.58 < Fe ≤ 1.67 For Fs = 10 10% for Fe ≤ 0.17 33% for 0.17 < Fe ≤ 0.28 50% for 0.28 < Fe ≤ 0.42 100% for 0.42 < Fe ≤ 0.83

For additional information on using Hall sensors with a high speed application, please contact *ADVANCED* Motion Controls.

Maximum Encoder Frequency for Velocity Control

The maximum encoder frequency allowed when using *ADVANCED* Motion Controls' digital drives is 20 MHz (5 pre-quadrature). This value is also provided on the drive datasheet. Use this value along with the motor encoder resolution to determine the maximum speed attainable:

Example – 1000 line encoder

The maximum speed with an *ADVANCED* Motion Controls' digital drive and a 1000 line encoder is:

$$20000000\left(\frac{counts}{\text{sec}}\right) * 60\left(\frac{sec}{min}\right) * \frac{1}{4 * 1000}\left(\frac{rev}{counts}\right)$$

$$= \mathbf{300}\ \boldsymbol{kRPM}$$