C H A P T E R ⑤

ZXF Follower

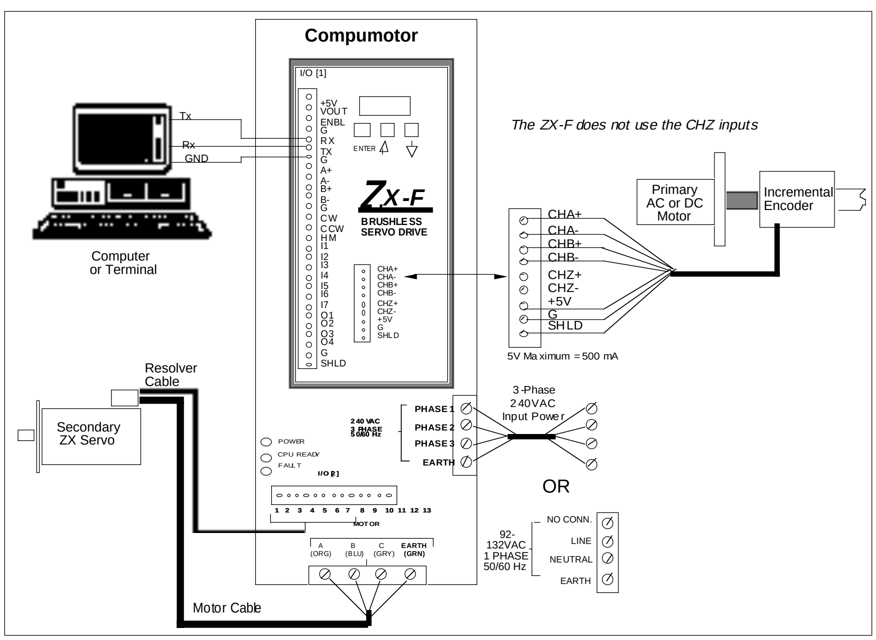
The information in this chapter will enable you to:

- ❏ Understand basic following concepts
- ❏ Understand the basic types of following and their common applications
- ❏ Become familiar with the ZXF commands associated with following

What is Following?

The ZXF can perform velocity following and distance following moves. The ZXF can follow from an incremental encoder input. Unless otherwise noted, all the features that will be presented or have been discussed are also valid in Following mode. The only difference is that you replace the velocity command with a speed ratio and the acceleration with a following acceleration for distance following. Instead of specifying the speed with the **`V`** command, you will specify the speed with respect to the primary axis using the **`FOL`** command.

☞ ***Helpful Hint:***
The primary axis is an AC or DC motor. The encoder is mounted on the shaft of the primary motor. The encoder provides the ZXF with the primary motor's position and velocity. The ZXF uses the position and velocity data to move the secondary axis (the secondary motor is following the motion of the primary motor). The ZXF moves the secondary motor based on the primary motor's moves. This concept of following can be used in different forms to satisfy different applications.



Typical Following System Configuration

Types of Following

There are four types of following application motion.

- ❑ Velocity following
- ❑ Velocity and position following
- ❑ Recede and advance while following (includes electronic cam)
- ❑ Phase error correction (synchronization)

The categories are presented roughly in order of increasing complexity. By identifying how the secondary axis motion relates to the primary axis, you will be able to determine your application's type and the applicable programming commands. Several features have been added to address more specific attributes of the various applications.

The ZXF has several features that enhance an application's functionality.

- ❑ Registration while following
- ❑ Jogging in the following mode
- ❑ Following a pulse train and a direction
- ❑ Following encoder pulses and the encoder direction
- ❑ Entering following percentage (**FOL**) via thumbwheels
- ❑ Entering following percentage (**FOL**) via front panel pushbuttons
- ❑ Capability of loading the primary encoder position into a variable

The ZXF can perform all of the ZX's programming functions. The only difference is that the motion profiles are now following moves and motion is based on a primary axis. The ZXF can also be used in Indexer mode. You can easily switch back and forth from follower and indexer functionality and create motion programs in which the ZXF serves as both a follower and an indexer.

☞ ***Helpful Hint:*** The ZXF has the following programming capabilities:

- ❑ Variables, general-purpose & read-only (position [POS], primary encoder position [FEP], etc.)
- ❑ Math
- ❑ Complex branching—**IF ELSE**, **REPEAT UNTIL**, **WHILE**
- ❑ On-the-fly changes—MPP mode
- ❑ Flexible I/O
- ❑ Closed-Loop mode while following

For an explanation of the features that are common to both the ZX and the ZXF, refer to *Chapter ④ Application Design*. You should understand how to set the ZXF for following. You can use one command (**FSI**) to enter and exit the Indexer and Following modes.

Command	Description
FSI1	Enters the following mode
FSIØ	Exits the following mode(indexer mode)

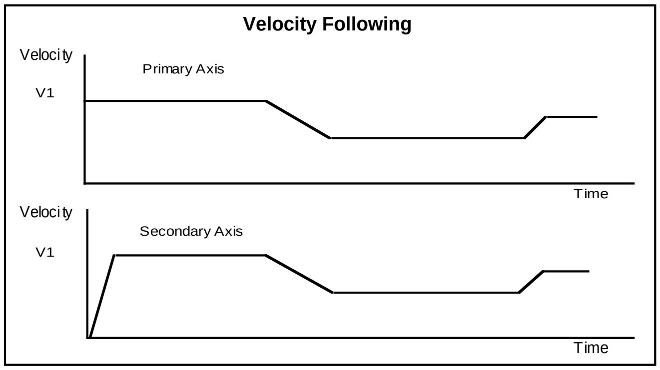
The rest of this chapter explains the four following types. Additional features of ZXF following will also be covered.

Velocity Following

In velocity following, the secondary axis uses the primary axis' speed. The relationship of the primary axis position with respect to the secondary axis is irrelevant. In these applications, the secondary axis accelerates at a specified acceleration up to a ratio of the primary axis' speed. Preset or continuous moves are performed in the same manner as in Indexer mode. Exact distances on the secondary axis can be moved in Preset mode, but instead of moving at a velocity specified by the **V** command, the secondary axis moves at a ratio of the primary axis' velocity specified by the **FOR** and **FOL** commands. The acceleration is independent of the primary axis encoder and is specified by **A** and **AD** (like an indexer).

Once the secondary axis accelerates to the specified following ratio, it tracks the primary axis' speed and position at the specified ratio. During the acceleration, the primary encoder speed and position are not followed. The acceleration ramp is independent of the primary axis. After the secondary axis accelerates to the specified following ratio, it will follow the primary axis (if the primary axis slows down, the secondary axis slows down).

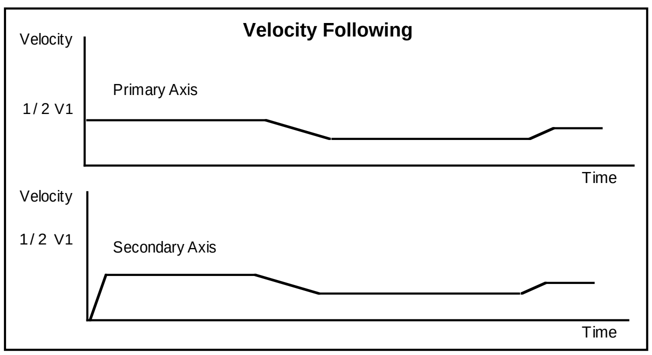
☞ ***Helpful Hint:*** Velocity following is used in dispensing and on-the-fly cutting applications.



Velocity Following

In each of the following categories described, the secondary axis only moves in the direction specified by either the **D** command, the **V** command, or the **H** command. If the primary axis changes direction, the secondary axis will still move in the same direction. Only the number of pulses and the rate of the pulses determines the secondary axis' motion. With position and direction tracking enabled, the secondary axis will follow the primary axis' direction. To illustrate velocity following, detach the encoder from the primary axis and manually move the encoder.

In the figure, if the primary velocity changed after the following ratio was achieved, position and velocity were tracked exactly. If the primary axis' velocity were half as fast as the example in the figure below, a different phase or positional relationship would result during acceleration from rest. This is why it is velocity following. Again, once the secondary axis accelerates to the specified following percentage, it will follow velocity and position exactly.



Primary Axis as Half Speed with Velocity Following

Setting Up Velocity Following

To perform velocity following, you must use two commands.

Command	Description
FOR	Relates the number of secondary motor steps per unit of travel to the corresponding primary encoder steps per unit of travel.
FOL	Relates the speed of the secondary axis to the speed of the primary axis as long as FOR is set correctly. The value is entered as a percentage of the primary axis speed.

The ZXF uses the equation to determine the number of motor steps.

$$\text{Motor Steps} = \text{FOR} \bullet \frac{\text{FOL}}{100} \bullet \text{Encoder Steps}$$

These two commands, (**FOR** and **FOL**) remove the complication of having a different resolution for measurement of distance on the primary and secondary axes. Once you relate the number of primary encoder pulses per unit of travel to the number of secondary motor pulses per that same unit of travel, you can relate their speeds. You can specify the secondary axis to move at 50% of the speed of the primary axis (1:2 ratio) or 100% of the speed (1:1 ratio). The encoder is usually mounted on the primary axis or through gearing and will measure a certain number of pulses per inch. The secondary axis would also have some certain number of pulses per inch. The ratio of the secondary axis steps to the primary axis' steps is entered in the **FOR** command. If the primary axis moves at 10 ips (inches per second) and the secondary axis is also set to move at 10 ips, a speed percentage of 100 is all that needs to be programmed (**FOL1ØØ**). The remaining commands are standard ZX commands. **Use the following steps to implement the *Velocity Following* feature**.

Step ① Enter the number of secondary motor steps per unit of travel per number of primary encoder steps per the same unit of travel. In this example, motor step resolution is 25,000 steps/rev and encoder resolution is 4,000 steps/rev. The unit of travel is 1 revolution. The ratio is 25,000/4,000 or 6.25.

Command	Description
> FOR6.25	Sets the motor step to encoder step ratio of 6.25
> OFF	Turns the ZXF off
> CMR25ØØØ	Sets motor resolution to 25000 steps/rev
> ON	Turns the ZXF on

Step ② Enter the following mode with the **FSI** command.

Command	Description
> FSI1	Enters the following mode

Step ③ Set the speed ratio. If the secondary axis is to move at the same speed as the primary axis (100% of the primary axis' speed), enter **FOL1ØØ**.

Command	Description
> FOL1ØØ	Secondary axis will move at 100% of the primary axis' speed

Step ④ Set the ZXF to Continuous mode and begin motion with the **G** command.

Command	Description
> MC	Enters Continuous mode
> A5ØØ	Sets acceleration
> AD5ØØ	Sets deceleration
> G	Initiates motion

Turn the encoder. The ZXF should move at the same speed that you are turning the encoder. Change the direction that you turn the encoder (note the secondary axis' motion). Follow the steps below.

Step ① Execute the following commands.

Command	Description
> S	Stops the continuous motion command issued above
> 1FSP1	Enables Direction Tacking mode
> G	Initiates motion

Step ② Turn the encoder or move the primary axis so that the encoder moves. The ZXF will begin moving. Change the direction that the encoder is moving. The ZXF will change direction. To change the relative direction between the ZXF and the encoder, use the change direction command (**H**±). Now turn the encoder and note that the ZXF's relative direction has changed. Direction tracking and pulses can only be used in Continuous mode. Preset moves can also be performed in Velocity Following mode.

Preset Moves In Velocity Following

A preset move is performed as in the standard Indexer mode. Issue the mode normal command (**MN**) and specify a distance in terms of secondary motor steps. In a preset move:

① The secondary axis accelerates (A) to the desired speed percentage.

② It decelerates at the rate set with the AD command.

③ It moves the specified distance (D) and stop.

If the primary axis' speed varies, the acceleration ramp will be the same, but the distance that the secondary axis travels to reach its following ratio will be different. The positional relationship or phase relationship is not maintained during acceleration. Once the secondary axis achieves the following percentage speed, it will track both velocity and position exactly.

Step ① Attach the encoder to the primary axis. Start the primary axis moving

Step ② Enter the following set of commands.

☞ ***Helpful Hint:*** The secondary axis moves 125,000 motor steps at the same speed as the primary axis. Repeat the example, but vary the primary axis' speed. The secondary axis still moves 125,000 steps, and its speed varies with the primary axis.

Command	Description
> MN	Enters Normal mode
> FSPØ	Exits the direction tracking mode
> A5ØØ	Sets acceleration
> AD5ØØ	Sets deceleration
> FOL1ØØ	Sets the following speed percentage to 100
> D125ØØØ	Sets the distance to 125000 steps
> G	Initiates motion

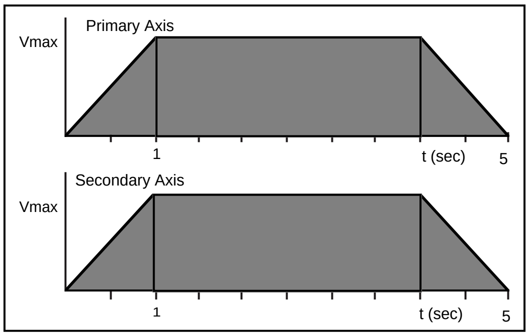
Velocity following is the simplest form of following. All motion in the ZXF is programmed like the ZX. The only exception is that the velocity command is replaced by a following percentage. Direction tracking must be disabled (**FSPØ**) while following in Preset mode (**MN**).

Position and Velocity Following

Position and velocity following is the most common form of following. In this case, the secondary axis must maintain a specific positional relationship with the primary axis. The primary axis moves a specific number of primary encoder pulses while the secondary axis moves a specified number of secondary motor steps. The secondary axis moves at the same speed as the primary axis (a 1:1 speed ratio) in most of these applications. Coil winding applications, however, are an exception. In these applications, the primary (i.e., the spindle axis) and secondary axes (i.e., the traverse axis) relationship is based on a desired pitch. This pitch defines a position and velocity that will arbitrarily set the speed based on the application. The positional relationship is usually defined by a single traverse that corresponds to a specific number of spindle axis turns, thus defining a specific number of primary encoder pulses during which a specific number of secondary pulses must be traveled.

Primary Axis at Rest

There are two variations of position and velocity following. The difference is in the primary axis' motion. The less common form starts the primary axis motion from rest. The secondary axis must follow the primary axis pulse for pulse. In this type of application, the secondary axis is in a continuous move and tracks the primary axis' motion exactly. A web positioning system where two axes are guiding the web (one edge is the primary axis and the other edge is the secondary axis), is an example of such an application. The web can be positioned based on the primary and secondary axes relationship.



Pulse-for-Pulse Following

If the primary axis starts from rest, the secondary axis must track it pulse for pulse (**FSA** command). If position tracking is disabled, the ZXF will only follow the pulse count and will not change direction if the primary axis changes direction. This is acceptable in many applications. In some applications, however, the primary axis may overshoot when it comes to a rest and the encoder will change directions. The secondary axis may mimic the overshoot if position tracking is enabled.

Since the ZXF is following the primary axis' pulse count only, it actually moves the secondary axis too many pulses. By enabling Position Tracking (**FSP1**), you can track the primary encoder's direction and pulse count and not accumulate excess pulses caused by overshoot.

Command	Description
FSA1	Enables Pulse Tracking—secondary axis instantly accelerates between commanded velocities
FSP1	Secondary axis tracks both the direction & pulse count from the primary encoder

Disable Following Synchronized Acceleration (**FSFØ**) and enable Continuous Move mode to use Pulse Tracking (**FSA1**).

Primary Axis in Motion

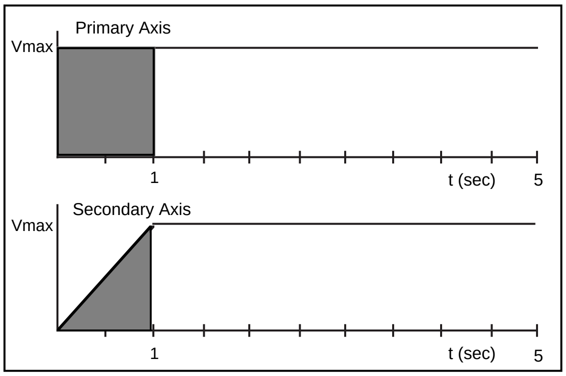
The most common form of position and velocity following begins with the primary axis already in motion. The secondary axis must accelerate to the primary axis' specified speed ratio. In this type of application, the secondary axis must accelerate to a known positional or phase relationship with the primary axis. The primary axis is usually a conveyer or web and the secondary axis performs an operation on the web or parts on the conveyer. The primary axis is always moving, so the secondary axis must move at the same speed and with the correct orientation to perform some operation on the moving primary axis. To maintain positional and velocity relationships, the secondary axis must accelerate over a known distance with respect to the primary axis (i.e., following acceleration is needed). The Set Following Synchronization Rate (**FAC**) and Set Following Synchronization Count (**FEN**) commands are used in conjunction with the velocity following commands.

☞ ***Helpful Hint:***
It does not matter if the speed of the primary axis varies, the secondary axis' acceleration is based on primary encoder steps (not time).

The **A** and **AD** commands used in velocity following are replaced by a following acceleration. A following acceleration is attained by stepping through subsequent ratios from the present following ratio to the final following ratio (**FOL**). The increment between ratios is set by the **FAC** command. Incrementing from one ratio to the next is based on the primary encoder changing by a set number of primary encoder pulses. This number of pulses is set by the **FEN** command. For example, if the value for **FAC** is 1, the value for **FEN** is 10, and the final following speed percentage is 100 (**FOL**), the secondary axis must accelerate from zero speed to 100% of the primary speed. From rest, every 10 primary encoder steps (**FEN**) the following percentage will change by an increment of 1% (**FAC**) until it is equal to the final following percentage of 100% (**FOL**). Therefore, the secondary axis will accelerate over 1000 primary encoder steps.

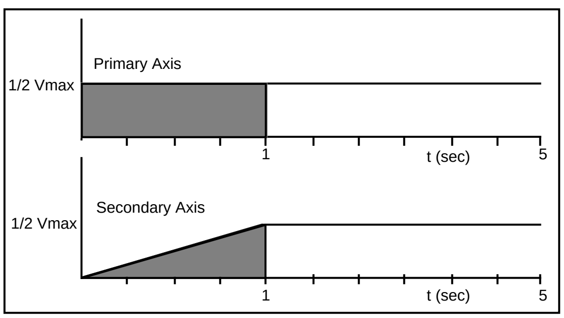
The shaded area indicates the distance moved by both the primary and secondary axes while the secondary axis is accelerating. The secondary axis moves 1/2 the distance that the primary axis moves. This will always be the case when the secondary axis accelerates from rest to the same speed as the primary axis, when the primary axis is already moving.

☞ ***Helpful Hint:***
If the primary axis' speed is 1/2 the maximum velocity, the acceleration ramp will be twice as long. The shaded portions in the top figure are equivalent to the shaded portions in the bottom figure. The primary axis' velocity can change at any time, even during the secondary axis' acceleration ramp, without changing the positional relationship.



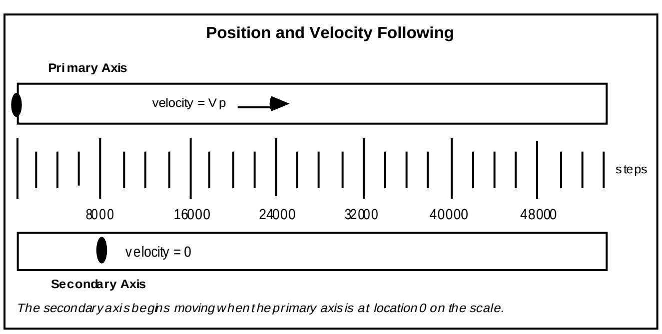
Following Acceleration

☞ ***Helpful Hint:***
This figure shows how the acceleration rate varies if the primary axis' speed varies



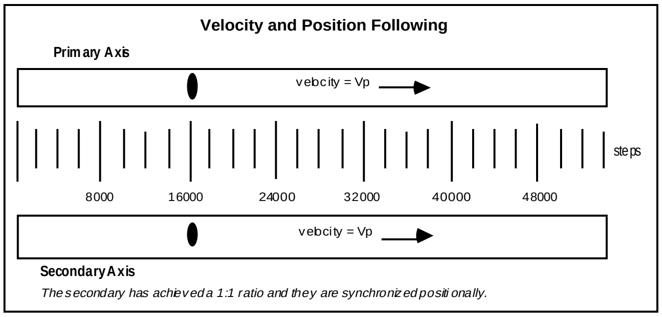
Following Acceleration With Primary Axis Velocity Change

The shaded area for the secondary axis is 1/2 of the shaded area under the primary axis curve. When the primary axis is moving and the secondary axis must start from rest and accelerate to the primary axis' velocity, the secondary axis will always move 1/2 the distance. Using following acceleration, the secondary axis adjusts its acceleration according to the primary axis' velocity (it will always accelerate over the same distance while the primary axis moves a specified distance). To synchronize secondary and primary axes' positions, the secondary axis must start ahead of the primary axis to compensate for the fact that the primary axis is already moving (velocity = Vp).



Starting a Velocity & Position Following Move—1:1 Ratio

The key to position and velocity following is that the Vp value does not matter. Assuming the application in the figure above is programmed with following acceleration (the spots) while accelerating over 8000 primary encoder steps, will always be at a 1:1 speed ratio after the primary axis moves the 16000 steps (see figure below).



Velocity & Position Following After Acceleration Is Done

Following Acceleration

Accelerating over a known distance with respect to a known primary axis distance allows you to synchronize the exact phase relationship you want between the primary and secondary axes. Following acceleration enables this synchronization.

Command	Description
FAC	The increment of following ratio by which the following ratio changes during acceleration
FEN	The number of encoder pulses that cause the following ratio to increment to the next value
FSF1	Enables Acceleration mode

Calculating FAC & FEN with Axis #1 Data

To determine what **FAC** and **FEN** values, you must know the following:

- ❑ The maximum velocity that the primary axis can travel (the velocity must be in units of primary encoder steps per second)
- ❑ The distance in primary encoder steps that the primary axis will move during which time the secondary axis will accelerate or the maximum acceleration that the secondary axis can accelerate

These parameters will be denoted as follows:

Vp_{max} = Maximum primary velocity in encoder steps per second

Dp_{acc} = Distance primary axis travels while secondary axis accelerates in primary encoder steps

OR

As_{max} = Maximum acceleration of the secondary axis

Based on these equations, the values for **FAC** and **FEN** can be determined:

FEN Equation

$$\textbf{FEN} = Vp_{max} \bullet \frac{TF}{1000} \qquad Vp_{max} = \frac{\text{Primary Encoder Counts}}{\text{Second}}$$

TF = Primary Encoder Sample Period in ms

FAC Equation

$$\textbf{FAC} = \frac{\textbf{FOL} \bullet Vp_{max}}{Dp_{acc}} \bullet \frac{TF}{1000} \qquad Vp_{max} = \frac{\text{Primary Encoder Counts}}{\text{Second}}$$

TF = Primary Encoder Sample Period in ms

FOL = Following percentage in units of percent

Dp_{acc} = Distance primary axis moves during secondary axis accel in units of primary axis encoder counts

Typically, the application will have the secondary axis start from rest and accelerate up to an **FOL** value of 100 (1:1 ratio). However, the FOL value can be any value that is within the limits of the motor/drive system. D_{acc} is in units of primary encoder steps. Determining the **FAC** and **FEN** values sets the number of primary axis encoder steps over which the secondary axis will accelerate (independent of the primary axis' speed). The secondary axis always travels the same number of motor steps during acceleration while the primary encoder moves Dp_{acc}.

The **TF** command allows you to set the sample period of the primary axis' encoder. It is programmable from 1 - 32 ms. The default is 4 ms. **TF** simply scales the **FAC** and **FEN** values. In the **FAC** and **FEN** equations, **TF** is used in units of ms—the constant of 1000 converts it to seconds so that the units cancel properly. Typically you will want **TF** to be as fast as your system will allow (1 ms). If the primary encoder is moving slowly, you may need to increase the sample rate to more than 1 ms because the actual encoder count does not change by much in a sample period and thus you have coarser resolution on the changes in encoder counts. For example, if your sample period is 1 ms and the maximum speed is 1 rps, the encoder count only changes by 4 counts each sample period. If there is a slight variation in speed and you read a change of 3 counts, there is a 25% variation. This may cause choppier secondary axis motion. Changing the encoder sample period can have a smoothing effect.

Calculating FAC & FEN with Axis #2 Data

You may know only the maximum acceleration rate of your secondary axis. You can determine Dp_{acc} using A_{max} and the following speed percentage that you are accelerating to.

Dp_{acc} Equation

$$Dp_{acc} = \frac{Vp_{max}^2}{As_{max}} \cdot FOR \cdot \frac{FOL}{100}$$

The acceleration is in units of secondary motor steps/sec^2. The maximum velocity of the primary axis is in primary motor steps/sec.

Using this value for Dp_{acc}, you can use the **FAC** and **FEN** equations. Remember to enable the Following Synchronized Acceleration mode (**FSF1**) to enable following acceleration.

How Following Acceleration Works

The concept of accelerating the secondary axis over a known distance with respect to a known primary axis distance (independent of the primary axis' speed) is based on analogies drawn between following and time-based motion. In time-based motion, the velocity describes the rate of change of the position with respect to a change in time. In following-based motion, the secondary axis moves at a ratio of the primary axis' velocity. This following ratio is of the same units as the velocity it is following, but is scaled (*the following ratio is analogous to a velocity*). Similarly, an acceleration in the time domain is defined as the rate of velocity change. The analogy in following would be to have a following acceleration that is a rate of change of the following ratio. Time-based motion is based on sampled time whereas following is based on the sampled primary axis encoder pulses (for digital systems).

☞ ***Helpful Hint:*** Following Acceleration Example

- ❑ Primary axis encoder fi 4000 counts/revolution
- ❑ Secondary axis fi 4000 steps/revolution
- ❑ Primary axis speed = 1 rps
- ❑ Secondary axis following speed percentage = 100%
- ❑ Distance that secondary axis accelerates = 2000 primary axis encoder steps
- ❑ Primary axis encoder sample period = 1 ms

The secondary axis must now accelerate over 2000 primary encoder steps to a following percentage of 100% or a speed of 1 rps. Specifying the number of primary encoder pulses and the final speed that the secondary axis must attain after acceleration defines the acceleration ramp. If the secondary axis' acceleration is based on time, you can calculate an acceleration ramp that will accelerate the secondary axis properly.

$$\text{Acceleration time} = \frac{2000\ \text{steps}}{4000\ \frac{\text{steps}}{\text{sec}}} = 0.5\ \text{seconds}$$

$$\text{Change in velocity} = 4000\ \text{steps/sec} - 0\ \text{steps/sec} = 4000\ \text{steps/sec}$$

$$\text{Acceleration} = \frac{4000\ \frac{\text{steps}}{\text{sec}}}{0.5\ \text{sec}} = 8000\ \frac{\text{steps}}{\text{sec}^2} = \frac{8\ \frac{\text{steps}}{\text{sec}}}{\text{ms}}$$

If velocity is changed by 8 steps/sec every sample period (TF - 1 ms), you will achieve the desired acceleration ramp. *The problem is that the application is time dependent.* If the primary axis' speed changes, the secondary axis would no longer accelerate over 2000 primary encoder steps.

☞ ***Helpful Hint:*** The application requires a following acceleration that is based on encoder pulses rather than time.

$$\text{Change in Following Percentage} = 100\% - 0\% = 100\%$$

$$\text{Following Acceleration time} = \frac{2000\ \text{steps}}{4000\ \frac{\text{steps}}{\text{sec}}} = 500\ \text{ms} = 500\ \text{sample periods}$$

$$\text{Following Acceleration} = \frac{100}{500} = 0.2\ \text{(FAC)}$$

The application is still time dependent. To remove the time dependency and make the acceleration dependent on the encoder pulses, replace the time sample period by an encoder period. In the previous example, the following percentage was based on changing the following percentage by 0.2 every sample period. It will take 500 sample periods to achieve a 100% following percentage. At 4000 steps/sec, the primary encoder is changing at a rate of 4 steps per ms or 4 steps/sample period.

1 sample period = 4 steps (encoder period—FEN).

Instead of changing the following percentage every sample period, change it every time the encoder count changes by 4 steps. If the primary encoder is moving at the maximum velocity, the acceleration ramp will be equal to the maximum acceleration provided. However, if the primary encoder velocity is less than the maximum velocity, the acceleration will also be reduced. The distance that the secondary axis accelerates and travels (with respect to the primary axis' moves during this acceleration) will remain unchanged. If the primary axis exceeds the maximum velocity, the acceleration ramp would also increase and exceed the maximum acceleration, which may cause an overcurrent or related servo error.

In the ZXF, the following percentage changes by the **FAC** value for each change in encoder steps of **FEN** steps. Several different combinations of **FAC** and **FEN** can achieve the same acceleration ramp. However, only unique **FAC** and **FEN** values will satisfy a specific maximum velocity and maximum acceleration. **FAC** and **FEN** can easily be determined with the equations and examples discussed earlier.

Decelerating

The ZXF decelerates to zero speed using the **AD** value. Although you may expect that this will diminish the positional relationship, this is usually not a concern at the endpoint in a profile. The following move is usually started by a trigger, which indicates that the primary axis is at a particular location. The move could also be started based on the primary axis' encoder position. The move is typically of a preset distance. ***The important point is that the secondary axis is at a known position with respect to the primary axis when the profile begins***. This positional relationship is maintained during acceleration. After the secondary axis moves the appropriate distance, it will normally return the same distance it just traveled at a high speed to prepare for a repeat move. This is why the deceleration is not important. However, in cases where the ZXF must perform electronic cam profiles, a deceleration's positional relationship may be necessary. In this case, the ZXF can decelerate to a stop using the **FAC** and **FEN** values by setting the following ratio to Ø (**FOLØ**) while in Mode Position Profile mode. To terminate this move, a stop command must be issued after the secondary axis reaches zero speed.

Position and Velocity Following Examples

In this example, you will perform a preset move using following acceleration (with the parameters and motion requirements listed below).

- ❏ Primary axis encoder resolution = 4000 counts/rev
- ❏ Secondary axis motor resolution = 25000 steps/rev
- ❏ Maximum primary encoder speed = 2 rps
- ❏ Distance in primary encoder steps that the secondary axis must accelerate over = 2000 steps
- ❏ Desired speed ratio—**FOL** = 100% (1:1 ratio)
- ❏ Preset secondary axis move distance = 3 motor revolutions
- ❏ Encoder sample period—**TF** = 4 ms

A preset move of 75000 steps will be made. The secondary axis will accelerate over 2000 primary encoder steps up to the same speed as the primary encoder. A trigger will initiate motion. Follow these steps to perform the move profile. The encoder sampling period is set to the default of 4 ms.

Step ① Determine the values for **FAC** and **FEN** from the following equations.

$$\mathbf{FEN} = Vp_{max} \cdot \frac{\mathbf{TF}}{1000} = 2\ \frac{revs}{sec} \cdot 4000\ \frac{counts}{rev} \cdot \frac{4}{1000}\ \text{seconds} = 32\ \text{encoder counts}$$

$$\mathbf{FAC} = \frac{\mathbf{FOL} \cdot Vp_{max}}{Dp_{acc}} \cdot \frac{\mathbf{TF}}{1000} = \frac{100 \cdot 8000\ \frac{counts}{sec}}{2000\ counts} \cdot \frac{4}{1000}\ \text{seconds} = 1.6\ \text{percent}$$

Step ② Enter the values for **FEN** and **FAC**.

Command	Description
> FEN32	Number of encoder counts of change required to increment the following percentage by **FAC**
> FAC1.6	The amount the following percentage increments for each **FEN** change in encoder counts

If you want to change the primary encoder's sample period to 1 ms, scale both **FEN** and **FAC** by the change in the **TF** value. For example, if you go from 4 ms to 1 ms, divide **FAC** and **FEN** by 4 to get the following values.

FEN = 8
FAC = 0.4

If we went from **TF4** to **TF8**, multiply **FAC** and **FEN** by 2. ***Remember to change* FAC *and* FEN *if you change* TF.**

Step ③ Enable the following acceleration mode.

Command	Description
> FSF1	Enables following acceleration

Step ④ Start the primary axis, then enter the commands below to perform the following acceleration move. If the primary axis' speed exceeds 2 rps, the following acceleration will not work properly.

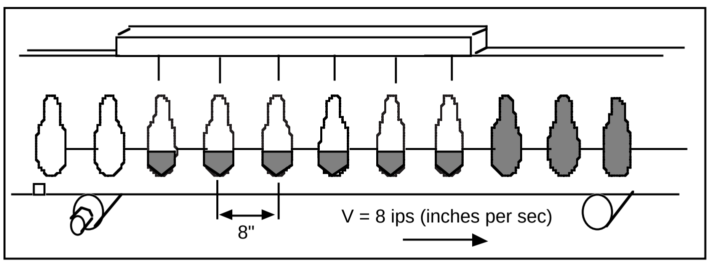
☞ ***Helpful Hint:***
Secondary axis accelerates over 2000 primary encoder steps. Secondary axis moves 1000 • **FOR** or 6250 motor steps over this acceleration ramp.

Command	Description
> MN	Sets ZXF to Normal mode
> FSI1	Enables following
> D75ØØØ	Sets the preset move distance to 75000 steps
> FOL1ØØ	Sets the following percentage to 100%
> G	Starts the following move

Following Acceleration Application: Bottle Filling

Typically, an application that requires position and velocity following will start the secondary axis from rest and accelerate it to 100% of the primary axis' speed (a 1:1 speed ratio). A trigger initiates motion on the secondary axis when a part or product is in a particular location on the primary axis. In this example, a conveyer belt moves bottles on a production line. The secondary axis is a filler that accelerates up to the conveyer's line speed and fills the bottles. It fills six bottles at a time and then returns to the start point to fill six more.

☞ ***Helpful Hint:***
In this application, the rate at which the bottles can be filled determines the maximum rate of the entire dispensing cycle.



Position & Velocity Following—Bottle Filling Application

One cycle of operation consists of the following steps.

① Secondary axis accelerates to the conveyer line speed.

② Secondary axis enables an output that prompts dispenser to fill bottles.

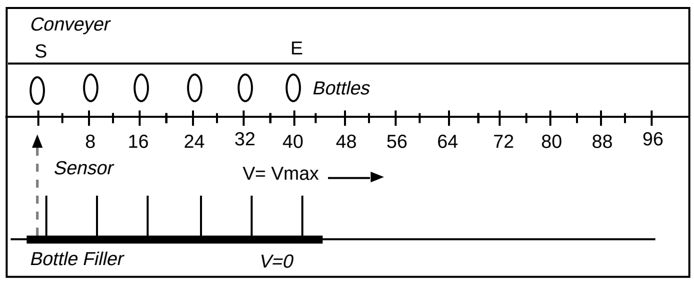
③ Secondary axis decelerates to a stop and returns to the starting point (at a high speed) to begin filling the next set of bottles.

☞ ***Helpful Hint:***
Application Information

Maximum conveyer speed: 8 ips
Time to bill bottles: 2.5 seconds
Primary encoder resolution: 4000 counts/rev
Primary encoder linear resolution: 2 revs/inch = 8000 counts/inch
Distance between bottles: 8 inches
Bottle filler motor resolution: 25000 steps/revolution
Bottle filler linear resolution: 1 revolution/inch = 25000 steps/inch
Distance over which bottle filler accelerates: 2 inches

An output must be activated at the point that the bottle filler is moving at the same speed as the conveyer to initiate the dispensing of fluid into the bottles. A photoelectric sensor detects a bottle and begins the filling cycle. The ZXF waits for the sensor as a trigger. When a bottle is detected, the ZXF accelerates to the line speed, turns on an output, fills the bottle stops, and returns to the starting point to wait for the next trigger. The figure below depicts the conveyer and the filler axis at the start of a filling cycle.

☞ ***Helpful Hint:***
The cycle begins when the bottle marked S crosses the trigger sensor.



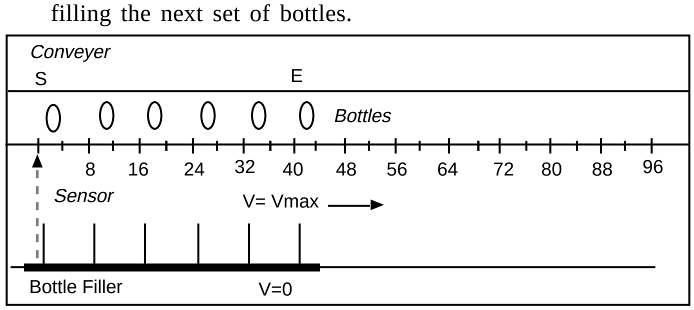
Start of A Filling Cycle

① Secondary axis accelerates to the conveyer line speed.

② Secondary axis enables an output that tells dispenser to begin filling bottles.

③ Secondary axis decelerates to a stop and returns to the starting point (at a high speed) to begin filling the next set of bottles.

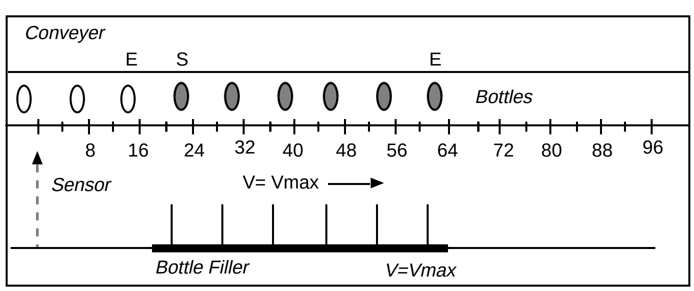
☞ ***Helpful Hint:***
This figure shows the two axes after the bottle filler reaches line speed and is ready to begin dispensing.



Bottle Filler Has Accelerated to Line Speed

A bottle can be filled in 2.5 seconds. At a maximum conveyer speed of 8 ips, the conveyer will move the bottles 20 inches. The figure below shows the bottle's location after the first six bottles have been filled.

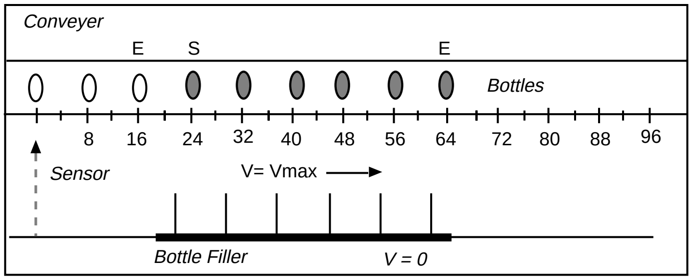
☞ ***Helpful Hint:***
Note the location of the next set of bottles to be filled.



Dispensing is Completed

The bottle filler must now stop and return to the start location before the bottle marked **S** crosses the trigger point. It must now return 22 inches to the start before the bottles have moved 20 inches. The bottle filler will be in place, ready for the next trigger from the next set of bottles. It will arrive in place 4 inches before the next bottle. At 8 ips, 500 ms will elapse before the next bottle.

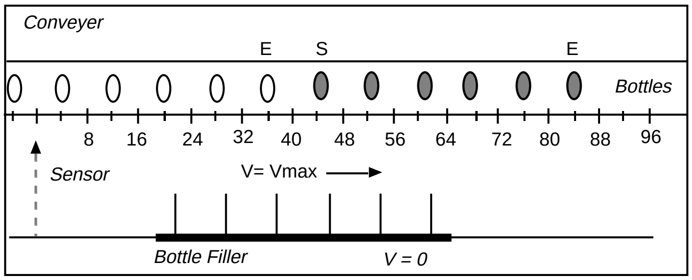
☞ ***Helpful Hint:*** This figure the location of the bottle filler after it has stopped.



Bottle Filler Stops

To get back to the starting point before the conveyer has moved 20 inches, the bottle filler must return at a speed faster than the conveyer. It will accelerate at the same following acceleration set for the first part of the cycle. After the conveyer travels 4 more inches, the cycle will resume.

☞ ***Helpful Hint:*** This figure shows the bottle filler after it returns to the starting point.



Bottle Filler Ready to Start a New Cycle

To program the application, use the following steps.

Step ①

Determine the **FOR** value.

Primary conveyer axis steps per inch = 8000

Secondary bottle filler axis steps per inch = 25000

$$\textbf{FOR} = \frac{25000}{8000} = 3.125$$

Step ②

Determine the **FAC** and **FEN** following acceleration parameters. The encoder sample period time (**TF**) is 1 ms.

$$\textbf{FEN} = 8000 \frac{\text{steps}}{\text{inch}} \bullet 8 \frac{\text{inches}}{\text{second}} \bullet \frac{1}{1000} = 64 \text{ steps}$$

$$\textbf{FAC} = \frac{100\% \bullet 8000 \frac{\text{steps}}{\text{inch}} \bullet 8 \frac{\text{inches}}{\text{second}}}{16000 \text{ steps}} \bullet \frac{1}{1000} = 0.4$$

Step ③

Determine how far the primary and secondary axes will move during the dispensing part of the cycle. This includes the bottle filler's acceleration and deceleration moves when no fluid is dispensed.

$$Vp_{max} = 64000 \frac{\text{steps}}{\text{sec}}$$

The dispensing takes 2.5 seconds. During the time that a constant following percentage occurs, the conveyer will have moved:

$$Dp_{con} = 64000 \frac{\text{steps}}{\text{sec}} \bullet 2.5 \text{ sec} = 160000$$

The secondary axis will move this distance • **FOR**:

$$Ds_{con} = 160000 \text{ primary encoder steps} \bullet 3.125 \frac{\text{secondary motor steps}}{\text{primary encoder steps}} = 500000 \text{ secondary motor steps}$$

The secondary axis or bottle filler axis will accelerate over 2 inches of the conveyer at maximum speed and decelerate over two inches. If the conveyer moves slower, the dispensing part of the process will become a smaller percentage of the total cycle. The distance the secondary axis travels during acceleration will be one half of the distance the conveyer or primary axis travels. The secondary axis starts from rest and accelerates to match the primary axis' speed. The secondary axis will move 1 inch during acceleration and 1 inch during deceleration. The total distance of the bottle filler move is:

$$D_{sec} = 500000 + 2 \cdot \left(1 \text{ inch} \cdot 25000 \frac{\text{steps}}{\text{inch}}\right) = 550000 \text{ steps (secondary mtr steps)}$$

The value to be entered for the **AD** command for deceleration is:

$$\mathbf{AD} = \frac{V^2}{2 \cdot D} = \frac{\left(8 \frac{\text{inches}}{\text{sec}}\right)^2}{2 \cdot 1 \text{ inch}} = 32 \frac{\text{inches}}{\text{sec}^2} \cdot 1 \frac{\text{revolution}}{\text{inch}} = 32 \frac{\text{revs}}{\text{sec}^2}$$

If the primary axis' speed changes, the ZXF will still decelerate at this rate. The distance that the bottle filler moves will be identical, regardless of the primary axis' speed, so the bottle filler will still have to make a 22-inch move *back* while the primary axis moves 20 inches.

Step ④

You have determined the parameters necessary for the first part of the move. Next, you must determine the following percentage required to move the secondary axis back 22 inches while the primary axis moves 20 inches. Use the following equation to determine **FOL**.

FOL Equation

$$\mathbf{FOL} = \frac{D_{prim}}{200 \cdot K} \sqrt{\left(\frac{D_{prim}}{200 \cdot K}\right)^2 \frac{D_{sec}}{\mathbf{FOR} \cdot K}} \quad \text{Where } K = \frac{\mathbf{FEN}}{100 \cdot \mathbf{FAC}}$$

$$\mathbf{FOL} = \frac{160000}{200 \cdot 1.6} \sqrt{\left(\frac{160000}{200 \cdot 1.6}\right)^2 \frac{550000}{3.125 \cdot 1.6}} = 500 - 374.2 = 125.8\%$$

125.8% is the return following percentage.

Step ⑤

Enter the sequence below to implement the motion.

Command	Description
> XE1	Erases sequence #1
> XD1	Defines sequence #1
FOR3.125	Sets motor to encoder steps per unit travel ratio
FAC.4	Sets the following acceleration increment to .4 % per encoder period
FEN64	Sets the encoder period, which increases the percentage to 64 steps
D55ØØØØ	Sets the secondary axis move for the cycle to 550000 motor steps
FSI1	Enables following mode
AD32	Sets the deceleration to 32 rps^2
IN1A	Defines input 1 as a trigger input
IN2D	Defines input 2 as a stop input
L	Starts a continuous loop
FOL1ØØ	Sets the initial following percentage to 100%
TR1	Waits on the input trigger
G	Starts motion
FOL125.8	Sets return move following percentage to 125.8%
H	Changes the direction
G	Starts the return following move
H	Changes direction again
N	Ends the loop—the following cycle will repeat
> XT	Ends the sequence

To decelerate using the **FAC** and **FEN** values, modify the program as follows:

Command	Description
> XE1	Erases sequence #1
> XD1	Defines sequence #1
SSH1	Sets save buffer on stop
FOR3.125	Sets motor to encoder steps per unit travel ratio
FAC.4	Sets the following acceleration increment to .4 % per encoder period
FEN64	Sets the encoder period, which increases the percentage to 64 steps
D55ØØØØ	Sets the secondary axis move for the cycle to 550000 motor steps
FSI1	Enables following mode
AD32	Sets the deceleration to 32 rps^2
IN1A	Defines input 1 as a trigger input
IN2D	Defines input 2 as a stop input
L	Starts a continuous loop
FOL1ØØ	Sets the initial following percentage to 100%
TR1	Waits on the input trigger
MPP	Enters the profiling mode
G	Starts motion
FP176ØØØ	Waits until 176000 encoder pulses have passed
FOLØ	Stops the motion of the secondary
FP16ØØØ	Waits for the decel ramp distance
STOP	Stops the move itself
FOL125.8	Sets return move following percentage to 125.8%
H	Changes the direction
G	Starts motion
FP139782	Waits until 139782 encoder pulses have passed

FOLØ	Stops the motion of the secondary
FP2Ø218	Waits for the decel ramp distance
STOP	Stops the move itself
H	Changes direction again
N	Ends the loop—the following cycle will repeat
> XT	Ends the sequence

The value for **FP** during the return move is determined by calculating the distance the primary axis will move during acceleration and the constant following percentage portion and determining the distance it moves during the deceleration portion. This is determined from:

$$Dp_{acc} = \mathbf{FOL} \bullet \frac{\mathbf{FEN}}{\mathbf{FAC}} = 125.8\% \bullet \frac{64}{0.4} = 20218 \text{ encoder steps}$$

$$Dp_{dec} = Dp_{acc} = 20218 \text{ inches}$$

$$Dp_{con} = D_{prim} - Dp_{dec} - Dp_{acc} = 119564$$

$$D_{prim} = 20 \text{ inches } = 160000$$

The *first* **FP** = Dp_{con} + Dp_{acc} = 119564 + 20218 = 139782. The *second* **FP** = Dp_{dec} = 20218. The second **FP** (20218 steps) measures the deceleration ramp. After deceleration, the move stops. The acceleration and deceleration ramps are based on the primary axis' speed.

Recede and Advance While Following

Receding and advancing while following requires position and velocity following. In this type of application, the secondary motor follows the primary encoder at a 1:1 ratio or at the same speed. The secondary motor has a specific positional or phase relationship with the primary encoder. This type of application is used when multiple operations (such as welds) must be performed on one moving part. The operations are performed at various places on the part, requiring the secondary axis to advance or recede.

In an ***advance application***, the secondary axis must accelerate and move a specific distance beyond the primary axis, then decelerate to a 1:1 ratio. The secondary axis moves a specific distance with respect to the primary axis while both axes are moving. In a ***recede application***, the secondary axis decelerates until it recedes a specific distance behind the primary axis and then resumes a 1:1 speed ratio with the primary axis.

The point at which the advance or recede move occurs is based on a specific position on the primary axis or an input trigger. This type of application requires the following ratio be changed on-the-fly while based on either an input or the primary encoder's position. It also requires the secondary axis to move a specific distance while the primary axis moves a corresponding specific distance. In this manner, the secondary can advance or recede a specific distance with respect to the primary axis.

To change the following ratio on-the-fly, you must use Motion Profiling (**MPP**) mode. You will need to measure the distance traveled by the primary encoder. Use the set of commands below.

Command	Description
> FPn	Delays command processing for n primary encoder steps
> FPAn	Delays command processing until the absolute count of the primary encoder has reached the value of n
> VAR1=FEP	Allows you to read the Following Encoder Position's value into variable 1

Advance Following Example

In this example, the primary axis has a 4000 count per revolution encoder. The secondary motor has a 4000 step per revolution motor. Therefore, the value for **FOR** is 1. The application requires that the secondary axis:

① Accelerate over 4000 primary encoder steps

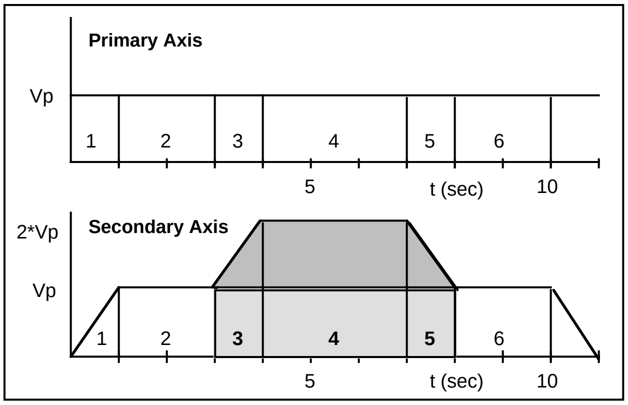
② Move at a 1:1 ratio for 2 primary encoder revolutions

③ Advance (with respect to primary axis) 12000 primary encoder steps

④ Move 2 more primary encoder revolutions at 1:1 after advancing

⑤ Stop

☞ ***Helpful Hint:*** This figure shows the move profiles. The dark shaded area is the distance the secondary axis advances with respect to the primary axis. The light shaded area is the distance that both axes move during the *advance portion* of the profile.



Advancing with Respect to the Primary While Following

In these types of applications, the phase relationship or positional relationship is set with the **FAC** and **FEN** values (for as long as the following acceleration is performed). When the secondary axis accelerates from the 1:1 ratio to the 2:1 ratio, it will again accelerate at the following acceleration set. When it decelerates back to the 1:1 ratio, it decelerates in the same manner as it accelerates (using the **FAC** and **FEN** following acceleration rate). When the secondary axis decelerates back to *rest or zero speed*, it will decelerate at the **AD** rate. If the secondary axis must decelerate to zero speed at the **FAC** and **FEN** values, you must use **FOLØ** and set the following ratio to zero to make it stop.

Before programming this move profile, we will completely analyze the motion of the secondary and primary axes and then describe the sequence of commands necessary for performing the move.

In the figure above, assume that the primary axis is moving at a maximum speed of 4000 steps/second. The area of each 1-second block represents 4000 primary encoder counts. Starting with Section #1, the primary encoder begins the section at a speed of $Vp_{max} = V_p =$ 4000 steps/sec. Therefore, the primary encoder moves 4000 counts during this section. From Section #1 of the secondary profile's plot, you can see that the secondary motor starts from rest and accelerates to a 1:1 speed ratio over 4000 counts of the primary encoder, $Dp_{acc} =$ 4000 steps. You can calculate the desired **FAC** and **FEN** values to create such an acceleration ramp. This following acceleration will be used throughout the profile when changing from one following ratio to another. Set the encoder sample rate, **TF**, to 1 ms.

Vp_{max} = 4000 steps/sec

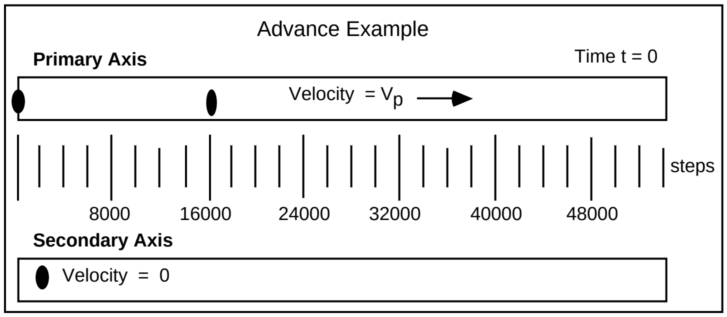
Dp_{acc} = 4000 steps

$$\mathbf{FEN} = Vp_{max} \cdot \frac{\mathbf{TF}}{1000} = 4000 \frac{\text{steps}}{\text{sec}} \cdot \frac{1}{1000} \text{ sec} = 4 \text{ encoder counts}$$

$$\mathbf{FAC} = \frac{FOL \cdot Vp_{max}}{Dp_{acc}} \cdot \frac{\mathbf{TF}}{1000} = \frac{100\ \% \cdot 4000 \frac{\text{steps}}{\text{sec}}}{4000 \text{ steps}} \cdot \frac{1}{1000} \text{ sec} = 0.1 \text{ percent}$$

By calculating the area under the secondary axis profile curve, you can determine that the secondary motor has moved 2000 motor steps. If the secondary axis is accelerating to the same speed as the primary axis, it will always travel half of the primary axis' distance. The secondary axis will be physically aligned with this point when it reaches a 1:1 speed ratio. The figure shows two conveyer belts—primary and secondary axes.

☞ ***Helpful Hint:*** This figure shows the locations of spots on the axes at different times during the move profile.



Advance Example at the Start of Section # 1

Usually, you will use an equation, not a graphic, to determine the distance traveled. The Ds_{acc} equation calculates the distance the secondary axis travels for any acceleration, even if the secondary axis starts acceleration while it is already moving at a given ratio to the primary axis.

Ds_{acc} Equation

$$Ds_{acc} = \mathbf{FOR} \cdot \left(\frac{1}{2} \cdot \Delta\,\mathbf{FOL}^2 \cdot \frac{\mathbf{FEN}}{100 \cdot \mathrm{FAC}} + \Delta\,\mathbf{FOL} \cdot \mathbf{FOL}_1 \cdot \frac{\mathbf{FEN}}{100 \cdot \mathbf{FAC}} \right)$$

FOL = The change in following percentage

Δ**FOL**$_I$ = The initial following percentage

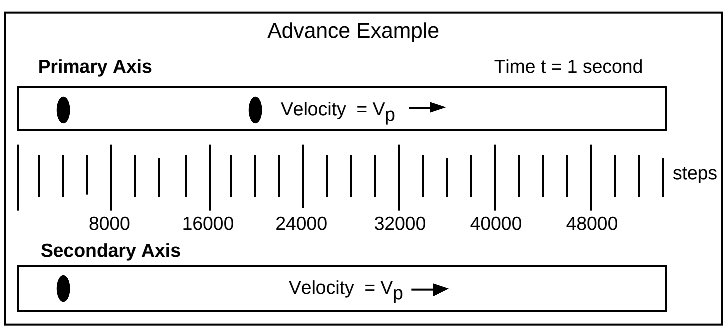
In the Ds_{acc} equation, the change in following percentage is the difference between the final following percentage that you are accelerating to and the following percentage you are starting from. If you are starting from rest, the initial following percentage is Ø and the change in following percentage is **FOLØ** or **FOL**. If you are at **FOL1ØØ** and want to accelerate to a following percentage of **FOL2ØØ**, the change in following percentage is 100 and the initial following percentage is 100. **FAC** and **FEN** are the values calculated from the equations for **FAC** and **FEN** using the Vmax and primary encoder acceleration distance.

The equation has two parts. The first part has the square of the following percentage change and the second part has a single following percentage change term. The first term determines the distance that the secondary axis travels due to the acceleration ramp portion of the curve. The second term gives the distance that the secondary axis travels due to its initial velocity. In this case, the secondary axis starts from rest (the second term contributes zero to the distance traveled). From the plot of the profile (Section # 1), the initial following percentage is Ø and the final percentage is 100, or the same speed as the primary axis. Using the general equation above, you should get 2000 steps, which is the area under the curve.

$$Ds_{acc} = 1 \cdot \left(\frac{100^2}{2} \cdot \frac{4}{100 \cdot 0.1} + 100 \cdot 0 \cdot \frac{4}{100 \cdot 0.1} \right) = 2000 \text{ secondary mtr steps}$$

Therefore, in Section #1, the primary axis moved 4000 encoder counts and the secondary axis moved 2000 motor steps. We have determined the values for **FAC** and **FEN** based on the plots of the primary and secondary axes' profiles and the fact that V_{max} is 4000 steps/sec.

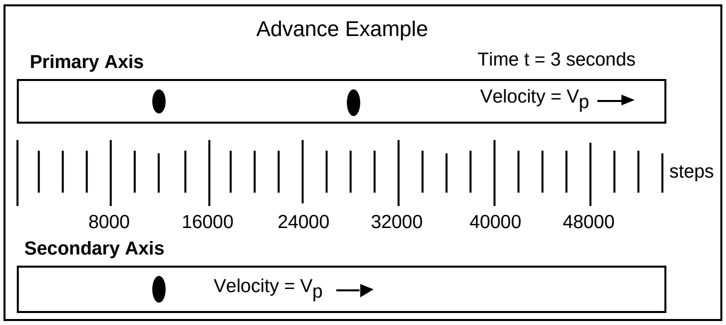
☞ ***Helpful Hint:*** At the end of Section #1, the spots will be in the locations shown in this figure .



Advance Example—End of Section #1

In Section #2, the primary axis is moving at V_{max} and the secondary axis is moving at the same speed because the ratio is 1:1 (**FOL1ØØ**). Section #2 lasts for 2 seconds. The primary axis travels 8000 steps during this section. The secondary axis travels 8000 steps too. This can be determined from the profile plot by calculating the area beneath the curve for the section. The primary and secondary axes are lined up at the start of Section #2 and they travel at a 1:1 ratio for the duration of the section. At the end of Section #2, the primary axis has moved 12000 steps and the secondary axis has moved 10000 steps (thru Sections #1 and #2).

☞ ***Helpful Hint:*** This figure shows the relative location of the spots at the end of Section #2 (t = 3 seconds).



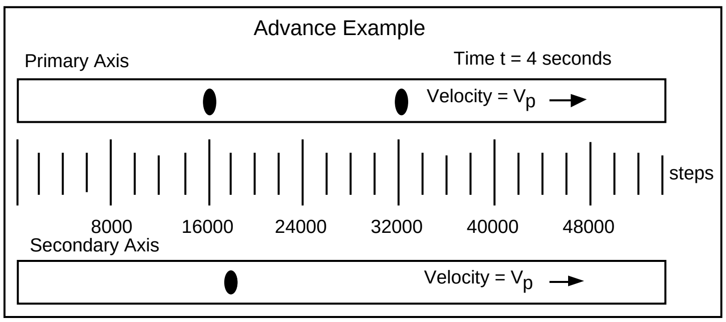
Advance Example—End of Section #2

In Section #3, the advance portion of the secondary profile begins. The secondary axis accelerates from a following percentage of 100% to 200% (a 2:1 ratio). Look at the plot of the profiles to graphically determine the distance that the primary and secondary axes have traveled. The primary axis moves 4000 steps and the secondary axis moves 6000 steps. The secondary axis' distance can also be determined from the equation above.

$$Ds_{acc} = 1 \bullet \left(\frac{1}{2} \bullet 100^2 \bullet \frac{4}{100 \bullet 0.1} + 100 \bullet 100 \bullet \frac{4}{100 \bullet 0.1} \right) = 6000 \text{ steps}$$

At the end of Section # 3, the primary axis has moved 4000 steps since the beginning of the advance portion of the profile. The secondary axis has advanced 2000 steps with respect to the primary axis.

☞ ***Helpful Hint:*** This figure shows the location of the spots after Section #3.



Advance Example—End of Section #3

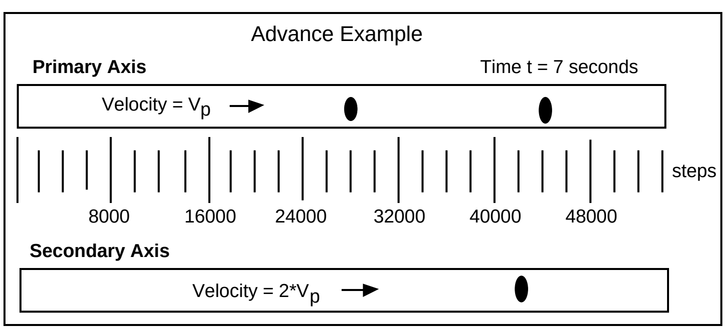
At the start of Section #4, the secondary axis is at a following percentage of 200% and is moving at 2 • Vp (a 2:1 ratio). Section #4 lasts 3 seconds. The primary axis moves 12000 steps, while the secondary axis moves 24000 steps. The distance the secondary axis traveled can be determined from the equation below.

Ds_{con} Equation

$$Ds_{con} = \mathbf{FOR} \bullet \frac{\mathbf{FOL}}{100} \bullet D_{prim} = 1 \bullet \frac{200}{100} \bullet 12000 = 24000$$

Since the start of the advance portion, the primary axis has moved a total of 16000 steps and the secondary axis has moved 30000 steps.

☞ ***Helpful Hint:*** The secondary axis has advanced 14000 steps with respect to the primary axis. This figure shows the location of the spots after Section #4.



Advance Example—End of Section #4

During Section #5, the secondary axis decelerates to a following percentage of 100% (a 1:1 ratio). After it decelerates, it will have completed the advance portion of the profile. The primary axis travels 4000 steps in Section #5. The secondary axis travels 6000 steps. When the secondary axis accelerates from one following percentage to another, then decelerates to the original following percentage (as in this example), ***the secondary axis' acceleration distance will always equal the deceleration distance***. However, the deceleration distance can also be calculated from the following equation.

Ds_{dec} Equation

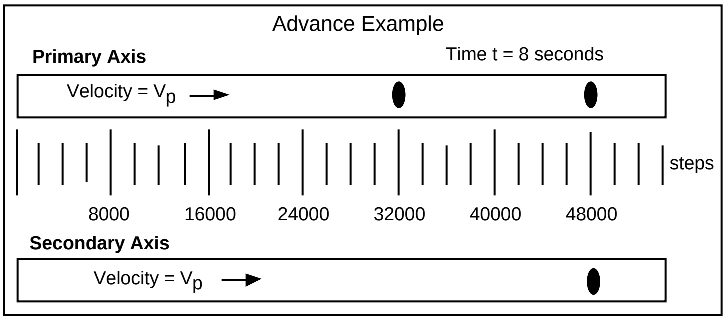
$$Ds_{dec} = FOR \cdot \left(\frac{1}{2} \cdot \Delta FOL^2 \cdot \frac{FEN}{100 \cdot FAC} + FOL \cdot FOL_I \cdot \frac{FEN}{100 \cdot FAC} \right)$$

When decelerating, the initial following percentage is the percentage you are at when you begin deceleration. In this example, it is 200%. The final following percentage is 100%. Therefore, the change in following percentage is a negative number (-100%).

$$Ds_{dec} = 1 \cdot \left(\frac{1}{2} \cdot (-100)^2 \cdot \frac{4}{100 \cdot 0.1} + -100 \cdot 200 \cdot \frac{4}{100 \cdot 0.1} \right) = -2000 + 8000 = 6000 \text{ steps}$$

At the end of Section #5, the advance portion of the move profile is complete. The secondary axis is moving at a 1:1 speed ratio with the primary axis. The secondary axis has moved 36000 steps and the primary axis has moved 20000 steps during the advance portion. The secondary axis has advanced 16000 steps with respect to the primary axis.

☞ ***Helpful Hint:*** **This figure shows the locations of the axes after Section #5.**



Advance Example—End of Section #5

During Section #5, the secondary axis travels at a 1:1 ratio until the deceleration ramp begins. If the move is preset, it will begin the deceleration ramp as defined by the **AD** command. It will be at rest at the exact distance of the preset move. If the move is continuous, it will decelerate according to the **AD** value when a Stop (**S**) or Kill (**K**) command is reached. From within a sequence, use the buffered Stop command. If you want the deceleration ramp to use the following acceleration value to decelerate, use **FOLØ**.

After the secondary axis rests, a Stop command must be used to terminate the move. In the move profiles, the secondary axis moves at a 1:1 ratio for 8000 more steps, then decelerates to zero. During this time, the primary axis also moves 8000 steps. Programming this profile requires the Following Encoder Distance Point (**FP**) or Following Encoder Absolute Point (**FPA**) command. **FP** is a delay-based on an incremental encoder distance. **FPA** is a delay-based on an absolute encoder distance.

FP Delay Examples

To perform the advance move profile, breakpoints are needed to indicate when the secondary axis should accelerate to new following percentages. The **FP** and **FPA** commands define these breakpoint. These changes are performed on-the-fly and require the Motion Profiling mode. The breakpoints are the points at which acceleration or deceleration begin. This example will show the program using the **FP** command.

Step ①

Set up the ZXF with the proper encoder interface and enable Following mode.

Command	Description
> FSI1	Enables ZXF's Following mode

Step ②

Set up the velocity following portion of the application. The number of secondary motor steps per unit of travel is 4000. The number of primary encoder steps per unit of travel is also 4000. Therefore, the **FOR** value is 1. The **FOL** command will be set up in the sequence for running the profile.

Command	Description
> FOR1	Relates the number of secondary motor steps for a distance to the number of primary encoder pulses for the same distance

Step ③

Set up the following acceleration value and enable Following Acceleration mode. The values are taken from the previous example.

Command	Description
> FAC.1	Increases the following percentage to 0.1 for every change in encoder pulses by FEN
> FEN4	Sets the number of encoder pulses required before the following percentage is incremented by FAC.
> FSF1	Enables the use of following acceleration

Step ④

The breakpoints in this profile occur at the end of Section #2, and the end of Section #4. *If **FAC** and **FEN** are used for deceleration, a breakpoint is also set at the end of Section #6.* If your **FOR** command differs from this example, the distance command is entered in terms of your secondary motor. The following sequence performs the desired profile. Each step of the sequence is explained. Enter the sequence.

Command	Description
> XE1	Erases Sequence #1
> XD1	Begins the definition of Sequence #1
D56ØØØ	The total distance the secondary moves is 56000 steps.
FOL1ØØ	The first following percentage to accelerate to is 100%.
MPP	Enters Motion Profiling mode so changes can be made on the fly.
G	The secondary motion begins.
FP12ØØØ	The first breakpoint occurs after the **primary axis** moves 12000 steps. **FP** causes command processing in the sequence to delay until 12000 primary encoder steps have been counted.
FOL2ØØ	After 12000 primary encoder steps the following percentage is changed to 200%. The **secondary axis** begins to accelerate at the following acceleration. Distance is known from previous analysis.
FP16ØØØ	Right after the command to begin acceleration to an **FOL** of 200%, the command processing is delayed until the **primary axis** has moved 16000 more pulses (from when **FP** is encountered and thus is an incremental encoder distance).
FOL1ØØ	After 16000 more primary encoder pulses, the following percentage changes to 100% and the **secondary axis** decelerates to a 1:1 ratio.
FP12ØØØ	Command processing is delayed 12000 more steps.
FOLØ	The secondary axis decelerates to an FOL of 0.
FP4ØØØ	It takes 4000 primary encoder steps to decelerate
STOP	A Stop command is needed because the ZXF would still think it was in a move and that the current following ratio was set to zero.
NG	Exits the Motion Profiling mode.
XT	Ends the definition of Sequence #1

Step ⑤

In applications that require velocity and position following, the method of decelerating to a stop does not matter (moving from a synchronized state to rest). At the end of such a move, you must reverse direction and return to the starting location to repeat the profile. The optimal profile is as follows:

① Accelerate to a known positional relationship

② Perform the operation required at the synchronized speed

③ When it is complete, decelerate as fast as possible to repeat the cycle

You must decelerate at a rate unrelated to the primary encoder speed. The ZXF allows you to do this. This will also simplify the programming. The same profile is programmed below using the **AD** deceleration value.

Command	Description
> XE1	Erases Sequence #1
> XD1	Defines Sequence #1
D56ØØØ	The total distance the secondary moves is 56000 steps
FOL1ØØ	The first following percentage to accelerate to is 100%
MPP	Enters Motion Profiling mode so changes can be made on the fly
G	The secondary axis' motion begins
FP12ØØØ	Delays processing until primary axis moves 12000 encoder pulses
FOL2ØØ	Change to 200% following percentage
FPA16ØØØ	Delays processing until primary axis moves 16000 encoder pulses
FOL1ØØ	Change ratio back to 100%
NG	Exits the profiling mode
XT	Ends Sequence #1 definition

In this sequence, only two breakpoints are needed, the breakpoint to accelerate to 200% and then to decelerate back to 100%. Since the ZXF will decelerate at the value in **AD**, it will automatically decelerate to a distance of exactly 56000 secondary motor steps at the appropriate time.

Step ⑥

This step uses **FPA** instead of **FP**. **FPA** delays processing until the absolute value of the following encoder counter exceeds the **FPA** value.

Command	Description
> XE1	Erases Sequence #1
> XD1	Defines Sequence #1
D56ØØØ	The total distance the secondary moves is 56000 steps.
PFZ	Zero the following encoder counter.
FOL1ØØ	The first following percentage to accelerate to is 100%.
MPP	Enters Motion Profiling mode so changes can be made on the fly.
G	The secondary motion begins.
FPA12ØØØ	Delay command processing until primary encoder count exceeds 12000 encoder pulses.
FOL2ØØ	Change to 200% following percentage.
FP28ØØØ	Delay command processing until primary encoder counter exceeds 28000 encoder pulses or an incremental change of 16000 pulses.
FOL1ØØ	Change ratio back to 100%.
NG	Exits the profiling mode.
XT	Ends Sequence #1 definition

In Steps ⑤ and ⑥, the encoder is counting in the positive direction. If the encoder is counting in the negative direction, a negative sign is required for the **FP** and **FPA** commands. Use **FP** or **FPA**, depending on your application.

*Use **FPA** when repetitive cycles of the same move profile are done without a trigger to start each cycle*. By making the delays dependent on an absolute encoder position, there is no accumulative error. In many cases, a trigger input from a sensor is used to start the move profile that is repeated. *If you use a trigger to start the move each time, use **FP** and the trigger will remove any accumulative error*. The following sequence illustrates the uses of the **FPA** command and a variable to perform a repetitive move that does not use a trigger to start it. This case is more like a cam cycle and the position relationship must be maintained while the cycle repeats.

Command	Description
`> XE1`	Erases Sequence #1
`> XD1`	Defines Sequence #1
`VAR1=12ØØØ`	Sets variable 1 equal to the first breakpoint.
`VAR2=28ØØØ`	Sets variable 2 equal to the second breakpoint
`VAR3=Ø`	Sets variable 3 equal to the primary reference point
`D56ØØØ`	Sets distance of secondary axis move to 56000 steps
`PFZ`	Zeroes the following encoder counter
`L`	Begins the continuous loop of the profile cycle
`FOL1ØØ`	The first following percentage to accelerate to is 100%
`MPP`	Enters Motion Profiling mode so changes can be made on-the-fly
`FPA(VAR3)`	Variable 3 synchronizes the move start with the primary axis. For the first 40000 primary steps, the secondary axis is moving, then it moves back during the next 40000 steps of the primary then it repeats.
`G`	Begins secondary axis motion.
`VAR3=VAR3+8ØØØØ`	Sets variable 3 equal to the start of the next cycle
`FPA(VAR1)`	Delays command processing until primary encoder count exceeds 12000 + 56000*n* encoder pulses, *n* = # of times through the loop.
`FOL2ØØ`	Changes following percentage to 200%.
`VAR1=VAR1+8ØØØØ`	Sets variable 1 equal to the first breakpoint for the next cycle
`FPA(VAR2)`	Delays command processing until primary encoder count exceeds 28000 + 56000*n* encoder pulses, *n* = the # of times through the loop.
`FOL1ØØ`	Changes ratio back to 100%.
`VAR2=VAR2+8ØØØØ`	Sets variable 2 equal to the second breakpoint for the next cycle
`NG`	Exits the profiling mode and complete the 56000 step move
`FOL2ØØ`	Sets the following ratio to a higher speed to move back to the starting point at a fast speed
`H`	Changes direction
`G`	Moves back to the starting point.
`H`	Changes direction
`N`	Repeats the cycle
`XT`	Ends Sequence #1 definition

In this example, the move profile is repeated.

☞ ***Helpful Hint:*** One cycle consists of the following events.

① Secondary axis moves 56000 steps while primary axis moves 40000 steps.

② The secondary axis retreats to the start and after another 40000 primary encoder steps the cycle is repeated.

③ No operation during the secondary axis' retreat.

④ The retreat is set to a high following ratio to get the secondary axis back to the start before the primary axis moves 40000 steps.

This cycle is very similar to a cam cycle (described in the next section). You can load the **FP** command with a variable (like **FPA**). You can check the following encoder counter value any time by loading it into a variable.

Command	Description
`> VAR1=FEP`	Loads variable 1 with the value of the following encoder counter

Calculating FOL, FP, or FPA For An Advance or Recede Application

The advance example explained how an advance move is made and how the different commands (**FOL**$_I$, **FAC**, and **FEN**) contribute to the move. This section provides some simple formulas that you can use to set up such a profile. To do position and velocity following, the secondary axis must be able to accelerate to a known position with respect to the primary axis. This is what determines the **FAC** and **FEN** following acceleration values. Once you determine these values, you will use them to calculate the acceleration ratio that you must use to make the advance move. The following data will help you understand the move profile in the example.

- ❑ **FAC**: Following speed percentage increment
- ❑ **FEN**: Change in primary encoder pulses to cause an increment of **FAC**
  - **D**$_{prim}$: The distance the primary axis will travel during the advance portion of the secondary move profile. This is 20000 primary encoder steps in the example above.
  - **D**$_{sec}$: The distance the secondary must advance with respect to the moving primary, measured in primary encoder steps. In the example above this is 16000 primary encoder steps.
  - **FOL**$_I$: The initial following percentage that you will accelerate from to the new following percentage.

In applications that require an advance move, you will usually know the distance that you want to advance with respect to the primary axis and the distance the primary axis will move during the advance. The distance that you want the secondary axis to advance with respect to the primary axis is given in terms of primary encoder steps. The distance can be converted from secondary motor steps to primary motor steps (and vice versa) with the **FOR** command. After determining the parameters listed above, you can use the following formula to determine the following percentage you must accelerate to.

First, determine a following acceleration constant (**K**) to simplify the equations.

Following Constant Equation

$$K = \frac{\mathbf{FEN}}{100 \bullet \mathbf{FAC}}$$

The constant **K** is used in the following equation to determine **FOL**.

FOL Equation

$$\mathbf{FOL} = \mathbf{FOL}_1 + \frac{D_{prim}}{200 \bullet K} - \sqrt{\left(\frac{D_{prim}}{200 \bullet K}\right)^2 - \left(\frac{D_{sec}}{K}\right)}$$

With an advance move, the value of $\mathbf{FOL}_I$ will always be 100. Apply the formula to the example above (the following percentage should be 200%). This is the following percentage that you must attain to advance 16000 steps with respect to the primary axis, while the primary axis moves 20000 steps.

D_{prim} = 20000 primary encoder steps

D_{sec} = 16000 primary encoder steps

FAC = 0.1

FEN = 4

$\mathbf{FOL}_I$ = 100

We will first determine the following acceleration constant K.

$$K = \frac{4}{100 \bullet 0.1} = 0.4$$

We will now determine **FOL**.

FOL is the same as $\mathbf{FOL}_F$ in the equations used earlier for determining the distances traveled by the primary and secondary axes.

$$\mathbf{FOL} = 100 + \frac{20000}{200 \bullet 0.4} - \sqrt{\left(\frac{20000}{200 \bullet 0.4}\right)^2 - \left(\frac{16000}{0.4}\right)}$$

$$= 100 + 250 - \sqrt{(250)^2 - 40000} = 350 - \sqrt{22500} = 350 - 150 = 200 = \mathbf{FOL}_F$$

The following percentage that must be accelerated to is 200%. Now calculate what the breakpoint is for decelerating back to a 1:1 ratio or 100%. The **FP** value will be determined from the following equation:

Following Breakpoint Equation

$$\mathbf{FP} = D_{prim} - \frac{\mathbf{FEN}}{\mathbf{FAC}} \bullet (\mathbf{FOL}_F - \mathbf{FOL}_I) = 20000 - \frac{4}{0.1} \bullet (200 - 100) = 16000 \text{ steps}$$

The value you would use for **FP** is 16000. The breakpoint at which you begin the advance portion of the move profile was not calculated. This value varies from application to application and you may want to use a trigger to begin the advance move rather than **FP**. An example of using a trigger to begin an advance move is described below.

Step ①

Configure an input as a trigger input with the **IN** command.

Command	Description
> IN1A	Configures input #1 as a trigger input
> IN2D	Configures input #2 as a stop input
> XD1	Defines Sequence #1
MC	We will make this a continuous move
FOL1ØØ	The first following percentage to accelerate to is 100%
MPP	Enters Profiling mode so changes can be made on-the-fly
G	Initiates motion
TR1	Command processing pauses until input #1 (trigger input) is activated. The secondary axis will move continuously at a speed percentage of 100% (with respect to the primary axis)
FOL2ØØ	The following percentage is changed to 200%. Acceleration begins.
FP16ØØØØ	Command processing will delay 16000 primary encoder steps.
FOL1ØØ	The following percentage is changed to 100%. Deceleration begins.
NG	Ends the Profiling mode.
XT	End Sequence #1 definition

In this sequence, the secondary axis begins moving at a 100% speed percentage. When trigger input #1 is activated, the secondary axis will advance 16000 steps with respect to the primary axis. It will then decelerate to a 100% or 1:1 ratio and continue until the stop input (input

#2), is activated (or a Stop [**S**] command is issued).

Recede vs. Advance

Recede moves are similar to advance moves. In the illustration of the spots for the advance example, the secondary axis synchronized with the first primary axis, then receded while the primary axis moved. This motion can be analyzed in the same manner as the advance move with the exception that a different equation is used to determine the required value for **FOL**. Again, you will have to provide the distance that the primary axis will move during the recede move and the distance with respect to the primary axis that the secondary axis must recede (measured in terms of primary encoder steps). For example:

- ❑ A primary encoder has a resolution of 4000 steps/rev (1 rev = 1 inch)
- ❑ The secondary motor has 25000 steps/rev (1 rev = 1 inch)
- ❑ The **FOR** command is set to 6.25.

You will usually know what distance you want the secondary axis to recede. If the secondary is to recede 1.5 inches with respect to the primary axis while the primary axis moves 3.5 inches, set D_{prim} and D_{sec} equal to:

$$D_{prim} = 3.5" = 3.5" \bullet 4000 \frac{steps}{inch} = 14000 \text{ primary steps}$$

$$D_{sec} = 1.5" = 1.5" \bullet 25000 \frac{steps}{inch} = 37500 \text{ secondary mtr steps} = \frac{37500}{6.25} = 6000 \text{ primary enc steps}$$

Both distances are provided in primary encoder steps. The two terms are used to determine the required **FOL** in the following Equation.

FOL Equation

$$FOL = FOL_I - \frac{D_{prim}}{200 \bullet K} + \sqrt{\left(\frac{D_{prim}}{200 \bullet K}\right)^2 - \frac{D_{sec}}{K}}$$

Where K is the following acceleration constant.

$$K = \frac{FEN}{100 \bullet FAC}$$

To calculate the **FOL** value, determine a value for **FAC** and **FEN**. This will depend on your application's maximum velocity and either the maximum acceleration for the secondary axis or the distance the primary axis travels while the secondary axis must accelerate. Use the same **FAC** and **FEN** values from the advance example.

FAC = 0.1

FEN= 4

In an advance or recede application, the initial following percentage FOL_I will always be 100.

☞ ***Helpful Hint:*** The value for FOL produced by the FOL equation is:

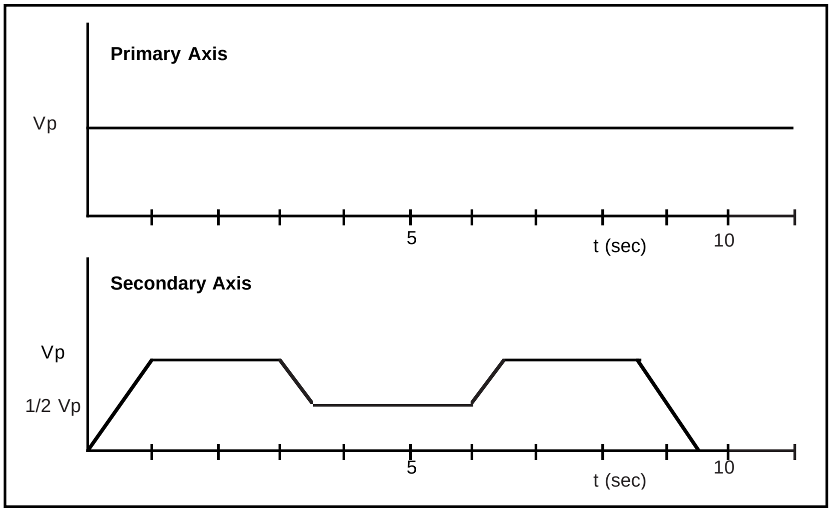
$$\mathbf{K} = \frac{4}{100 \bullet 0.1} = 0.4$$

$$\mathbf{FOL} = 100 - \frac{14000}{200 \bullet 0.4} + \sqrt{\left(\frac{14000}{200 \bullet 0.4}\right)^2 - \frac{6000}{0.4}} = 100 - 175 + \sqrt{(175)^2 - 15000} = 50\%$$

The value needed for **FP** can be determined from the following equation.

FP Equation

$$\mathbf{FP} = D_{prim} + \frac{\mathbf{FEN}}{\mathbf{FAC}} \bullet \left(\mathbf{FOL}_F - \mathbf{FOL}_I\right) = 14000 + \frac{4}{0.1} \bullet (50 - 100) = 12000 \text{ primary enc. steps}$$



Recede While Following Profile

The sequence that will execute this profile is provided below:

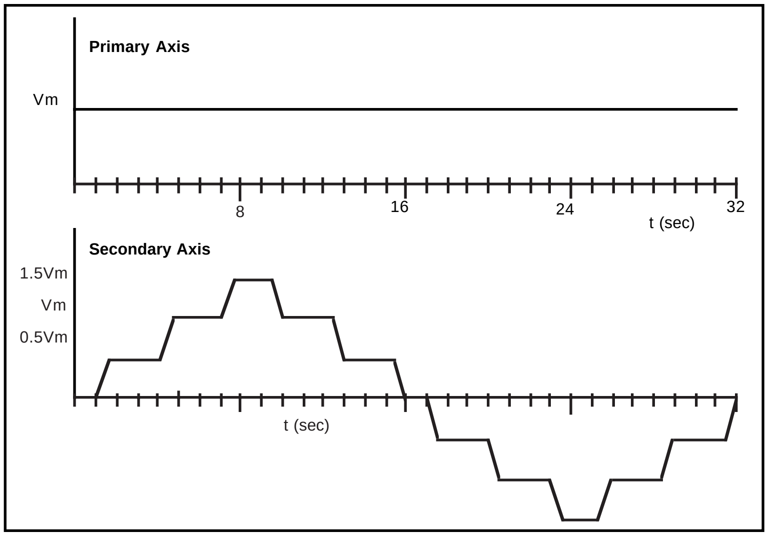
Command	Description
`> FACØ.1`	Sets the percentage increment to 0.1
`> FEN4`	Sets the number of encoder counts for an increment to 4
`> FSF1`	Enables following acceleration
`> FOR6.25`	Sets the secondary motor steps per unit distance to primary encoder steps per unit distance ratio
`> XD1`	Defines Sequence #1
`MN`	Normal mode
`D175ØØØ`	Sets distance to 175000 steps
`FOL1ØØ`	The first following percentage to accelerate to is 100%
`MPP`	Enters Motion Profiling mode so changes can be made on-the-fly
`G`	Initiates motion
`FP12ØØØ`	The command processing will pause here until the primary encoder has moved 12000 steps. The secondary will then decelerate to 50%
`FOL5Ø`	Changes following percentage to 50%—the recede portion begins
`FP12ØØØ`	Command processing will delay 12000 primary encoder steps.
`FOL1ØØ`	The following percentage is changed to 100%—deceleration begins
`NG`	Ends the Motion Profiling mode
`XT`	End sequence definition

Cam Following

A common application that requires velocity and position following is the simulation of a cam or an electronic cam. To simulate the motion produced by a cam, you must satisfy the following requirements:

- ❏ Follow both the position and the velocity of a primary encoder.
- ❏ You must also be able to change following ratios during motion and still maintain a positional relationship.
- ❏ Change ratios based on primary encoder distance.
- ❏ Must be able to keep track of the primary encoder position even if the secondary axis is not moving.
- ❏ Must be able to continuously repeat a cam cycle without developing accumulative error.

You can simulate a cam profile electronically using the commands and equations developed earlier. Motion Profiling mode (**MPP**) is required for cam following. For more information on Motion Profiling mode, refer to *Chapter ④ Application Design*.



Cam Following

In this example, the encoder is a 4000 pulse per revolution encoder and it is mounted on the primary axis. The *secondary axis* will perform an electronic cam cycle, which consists of the following steps:

① Sitting at rest for one primary encoder revolution, then executing a step profile of 3 following percentages from 50% to 100%, then to 150%, and back to 0%.

② It will then delay 1 primary encoder revolution and perform the same profile in the opposite direction.

③ This cycle is to be repeated until a stop is issued. The secondary axis will accelerate at its maximum rate when the primary axis is at its maximum velocity. The table below defines the cam cycle for this profile.

Segment	Primary Position		Secondary Position		Following %
	Absolute	Incremental	Absolute	Incremental	
①	0	0	0	0	0%
②	4000	0	0	0	50%
③	16000	12000	5500	5500	100%
④	28000	12000	17000	11500	150%
⑤	38000	10000	31500	14500	100%
⑥	50000	12000	44000	12500	50%
⑦	62000	12000	50500	6500	0%
	68000	6000	51000	500	

Cam Cycle

The following percentage is given for each segment. Each of the distance points is a breakpoint where the following percentage changes. Use the following acceleration to change from one following percentage to the next. The data needed to program this type of profile is listed below.

Vp_{max} : Maximum velocity of the primary axis

As_{max} : Maximum acceleration of the secondary axis

FOR: Relative resolutions per unit of distance for the primary and secondary axes

FAC: Following acceleration value, percentage increments

FEN: Following acceleration value, encoder counts for an increment

For each ratio segment, you must know the distance the primary axis will travel and the corresponding distance the secondary axis will travel. The breakpoints can be determined from the graph. Usually, you will not be able to graphically describe the motion relationship, and will simply know that you want the primary axis to move ***x*** steps and the secondary axis to move ***y*** steps in the same time frame.

After you determine **FAC** and **FEN** from your maximum acceleration and maximum velocity, or from the distance you want the secondary axis to accelerate over and the maximum velocity, you can use **FAC** and **FEN** and the primary and secondary axes' travel distances to determine the following percentages and the values for the breakpoints to change to new following percentages. When accelerating to a higher following percentage, you can use the **FOL ACCEL** Equation to determine the required **FOL** percentage that you must accelerate to using the **FAC** and **FEN** values you have determined.

FOL ACCEL Equation

$$\mathbf{FOL} = \mathbf{FOL}_I + \frac{D_{prim}}{100 \cdot K} - \sqrt{\left(\frac{D_{prim}}{100 \cdot K}\right)^2 + \frac{2 \cdot \mathbf{FOL}_I \cdot D_{prim}}{100 \cdot K} - \frac{2 \cdot D_{sec}}{\mathbf{FOR} \cdot K}}$$

Where K is the following acceleration constant determined by **FAC** and **FEN**.

$$K = \frac{\mathbf{FEN}}{100 \cdot \mathbf{FAC}}$$

If you are decelerating to a lower following percentage, use the **FOL DECEL** Equation to determine the following percentage you must use to move the secondary axis the specified number of steps for the corresponding motor steps.

FOL DECEL Equation

$$\mathbf{FOL} = \mathbf{FOL}_I + \frac{D_{prim}}{100 \cdot K} + \sqrt{\left(\frac{D_{prim}}{100 \cdot K}\right)^2 - \frac{2 \cdot \mathbf{FOL}_I \cdot D_{prim}}{100 \cdot K} + \frac{2 \cdot D_{sec}}{\mathbf{FOR} \cdot K}}$$

In both the accelerating and decelerating equations, the terms listed below for the primary encoder steps and the secondary motor steps are required.

D_{prim} = The number of primary encoder steps that the motor will move in the segment.

D_{sec} = The number of corresponding secondary motor steps that the secondary will move during which time the primary encoder will move D_{prim}.

To illustrate the programming of the profile above, we will assign values to the application's requirements. The maximum velocity, acceleration and the **FOR** value are to be determined by the application. The **FAC** and **FEN** values are calculated. The maximum velocity and acceleration are given below. The example below has the following parameters:

- ❏ Primary encoder resolution = 4000 steps/revolution
- ❏ Secondary motor resolution = 25000 steps/revolution
- ❏ 1 encoder rev = 1 motor rev
- ❏ **FOR** 6.25
- ❏ Vp_{max} = 4000 steps/second
- ❏ As_{max} = 1 rev/second ^{2}
- ❏ Encoder sample period TF= 1 ms

From the equations in the Velocity and Position following section **FAC** and **FEN** are determined:

$$\mathbf{FEN} = V_{max} \cdot \frac{\mathbf{TF}}{1000}$$

$$\mathbf{FAC} = \frac{\mathbf{FOL} \cdot Vp_{max}}{Dp_{acc}} \cdot \frac{\mathbf{TF}}{1000}$$

Since we are starting with Vp_{max} and As_{max}, we must determine D_{acc} for the equations above.

$$Dp_{acc} = \frac{Vp_{max}^2 \cdot FOR \cdot FOL}{As_{max} \cdot 100} = \frac{\left(4000 \frac{steps}{sec}\right)^2 \cdot 6.25 \cdot 100}{25000 \frac{steps}{sec^2} \cdot 100} = 4000 \text{ primary encdr steps}$$

Vp_{max} is in primary enc. steps/sec

As_{max} is in secondary motor steps/sec^2

The **FOR** term converts the acceleration units to primary encoder steps units. **FAC** and **FEN** can now be calculated.

$$FEN = 4000 \frac{steps}{sec} \cdot \frac{1 \text{ ms}}{1000} = 4 \text{ steps}$$

$$FAC = \frac{100 \cdot 4000 \frac{steps}{sec}}{4000 \text{ steps}} \cdot \frac{1 \text{ ms}}{1000} = 0.1$$

You can now use these equations to determine the **FOL** value for each segment of primary encoder distance and secondary motor distance. The **FOL** values are already given in the previous table, but it may be necessary to determine the **FOL** required for some of the segments. Evaluate **FOL** for Segments #4 and #6. Typically, you will know the distance you want the primary axis to move and the corresponding distance that you want the secondary axis to move. With this data, you can create a table like the one shown. You will have to enter the **FOL** values for the table from the equations given in this chapter.

Segment ④

D_{prim} = 10000 primary encoder steps

D_{sec} = 90625 secondary motor steps

Using the acceleration equation, we can calculate the value for **FOL** in Segment #4.

The acceleration constant $K = \frac{4}{100 \cdot 0.1} = 0.4$

$$FOL = 100 + \frac{10000}{100 \cdot 0.4} - \sqrt{\frac{2 \cdot 100 \cdot 10000}{100 \cdot 0.4} + \left(\frac{10000}{100 \cdot 0.4}\right)^2 - \frac{2 \cdot 90625}{6.25 \cdot 0.4}}$$

$$= 100 + 250 - \sqrt{50000 + (250)^2 - 72500} = 150\%$$

The breakpoint is given automatically by the table and is 10000 for FP and is 38000n for **FPA** where n is the number of cycles completed thus far.

Segment ⑥

D_{prim} = 12000 primary encoder steps

D_{sec} = 40625 secondary motor steps

Using the deceleration equation, we can calculate the value for **FOL** in Segment #6.

$$FOL = 100 - \frac{12000}{100 \cdot 0.4} + \sqrt{\left(\frac{12000}{100 \cdot 0.4}\right)^2 - \frac{2 \cdot 12000 \cdot 100}{100 \cdot 0.4} + \frac{2 \cdot 40625}{6.25 \cdot 0.4}}$$

$$= 100 - 300 + \sqrt{(300)^2 - 60000 + 32500} = 50\%$$

The breakpoints for **FP** and **FPA** are 12000 and 62000***n*** steps respectively. In many cases involving a cam cycle, a trigger is not used to start each cycle and the repetition of the cycle is based on the primary encoder. In these situations, use the **FPA** command (it is based on the following encoder's absolute count). The absolute count comes from a hardware counter that can be accessed by assigning it to a variable:

> VAR1 = FEP **FEP** is the value in the hardware counter, it is a read only value

The following sequence will perform the cam profile. The secondary axis will be put in a continuous move. Two parts occur in a cycle. The first part moves the stepped profile in one direction. The second part reverses direction and returns to the start to repeat the cycle.

Command	Description
> FOR6.25	Sets the secondary motor steps to primary encoder steps ratio
> FAC0.1	Sets the change in following percentage for following acceleration
> FEN4	Sets the number of encoder pulses required to change by **FAC**
> FSF1	Enables following acceleration
> FSI1	Enables following
> SSH1	Saves buffer on stop
> VAR1=64ØØØ	Variable for the incrementing the cycle
> VAR2=4ØØØ	Breakpoint 1
> VAR3=16ØØØ	Breakpoint 2
> VAR4=28ØØØ	Breakpoint 3
> VAR5=38ØØØ	Breakpoint 4
> VAR6=5ØØØØ	Breakpoint 5
> VAR7=62ØØØ	Breakpoint 6
> VAR8=64ØØØ	Breakpoint 7
> 1XE1	Erases Sequence #1
> 1XD1	Defines Sequence #1
MC	Enables continuous mode
FOLØ	Sets the current following percentage to 0%
L	Begins the loop cycle
MPP	Enters the Motion Profiling Mode
G	Initiates motion
FPA(VAR2)	Pauses execution until absolute primary encoder counter value exceeds breakpoint 1
FOL5Ø	Following % is changed to 50% or 1/2 as fast as the primary motor
VAR2=VAR2+VAR1	Set variable 2 to the breakpoint value for the next cycle
FPA(VAR3)	Pauses execution until primary encoder counter absolute value exceeds breakpoint 2
FOL1ØØ	Speed ratio is changed to 1:1
VAR3=VAR3+VAR1	Set variable 3 to the breakpoint value for the next cycle
FPA(VAR4)	Pauses execution until primary encoder counter absolute value exceeds breakpoint 3
FOL15Ø	Speed ratio is changed to 1.5:1
VAR4=VAR4+VAR1	Set variable 4 to the breakpoint value for the next cycle
FPA(VAR5)	Pauses execution until absolute value of the primary encoder counter exceeds breakpoint 4
FOL1ØØ	Speed ratio is changed to 1:1
VAR5=VAR5+VAR1	Set variable 5 to the breakpoint value for the next cycle
FPA(VAR6)	Pauses execution until absolute value of the primary encoder counter exceeds breakpoint 5
FOL5Ø	Speed ratio is changed to 5:1
VAR6=VAR6+VAR1	Set variable 6 to the breakpoint value for the next cycle
FPA(VAR7)	Pauses execution until absolute value of the primary encoder counter exceeds breakpoint 6
FOLØ	Speed ratio is changed to 0
VAR7=VAR7+VAR1	Set variable 7 to the breakpoint value for the next cycle
FPA(VAR8)	Pauses execution the absolute value of the primary encoder counter exceeds breakpoint 7
STOP	Ends the move (this is required)
NG	Ends Motion Profiling mode
VAR8=VAR8+VAR1	Set variable 8 to the breakpoint value for the next cycle
H	change the direction
N	Ends the loop cycle
XT	Ends Sequence #1 definition

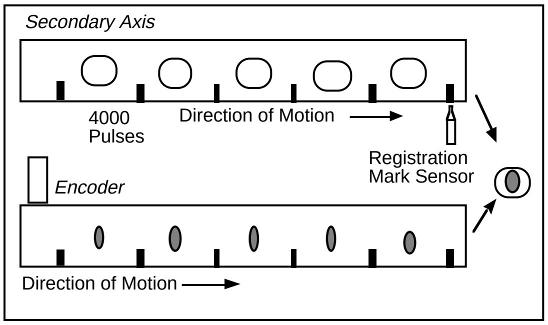
This sequence is an example of a complex following profile. Position and velocity are synchronized and the positional relationship is maintained.

Synchronization

The ZXF can synchronize its speed and phase with respect to a primary axis. In many applications, it is necessary to have the position and speed of a secondary axis synchronized with the speed and position of the primary axis with registration marks on the secondary axis parts or material. These marks must be evenly spaced so that at a constant speed (with respect to the primary axis) the number of primary axis encoder steps recorded between registration marks is an expected constant number. If these marks should come further apart (e.g., the material stretches) the ZXF will adjust the speed ratio to correct for the error between the registration marks. The synchronization figures illustrate this process.

In the figure below, a secondary axis has parts that are to be synchronized to the primary axis' parts. The registration sensor detects the location of the parts with respect to the primary axis. This sensor goes to the ZXF. It indicates the start of the part.

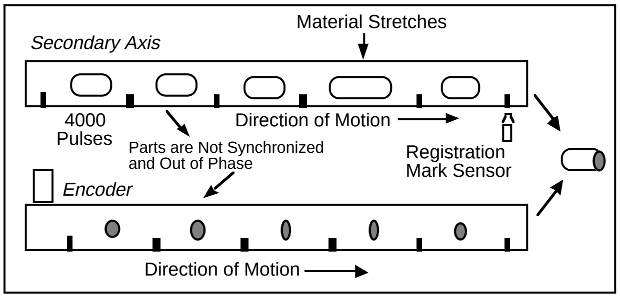
☛ Helpful Hint:
The ZXF then counts the encoder pulses from the primary axis that occur between registration marks.



Secondary Parts Synchronized With the Primary Axis

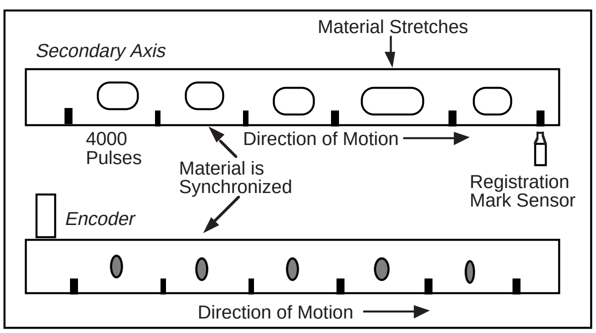
If the material on the secondary axis stretches, as indicated in the figure below, all parts after the stretched material will no longer be synchronized with the primary axis' parts.

☛ Helpful Hint:
The figure below depicts the result of not using Synchronization mode.



Material Stretches—Parts Out of Sync

With the ZXF's Synchronization mode, the secondary axis accelerates to re-synchronize with the primary axis. It removes the phase shift between the two axes. The ZXF detects that the number of pulses between the registration marks has increased (due to stretching). The speed ratio is increased, so the secondary axis speeds up. The material after the stretched portion is good material, so the pulses between the next two registration marks will be slightly less than 4000 because the speed ratio is now higher. The speed will now be reduced. The secondary and primary axes will be synchronized again. Every time a registration mark is encountered, a new actual count is latched and the speed ratio is adjusted to synchronize the axis. Corrections will continue until the secondary axis again has the expected number of pulses between registration marks.



ZXF Synchronizes Parts (After Stretching)

You can determine and program the amount of correction that is applied to the speed ratio between each registration mark to fit your application. Use the following commands to program a synchronization application.

Command	Description
> **FC**	Expected encoder count between Registration marks
> **FBS**	Normalizing count for determining new speed ratio to move at
> **FIN**	Increment used to determine the new following speed
> **FSL**	Enables the Synchronization mode
> **FSK**	Enables the expected encoder count teach mode

> **INnI**	Defines an input as the Registration mark synchronization input
> **TF**	Sets the sample rate of the encoder input
> **FOR**	Motor to encoder count ratio
> **FOL**	Primary to Secondary Speed ratio
> **FSI**	Enables following mode

The **FOL** and **FOR** commands determine the number of secondary motor steps that will be commanded for the encoder pulses that are received. The **FBS** and **FIN** commands determine the amount of correction that will be applied to the **FOL** and **FOR** motor to encoder ratio. **FC** is the number of encoder pulses that are expected between the registration marks if the speeds are synchronized properly. This number is compared to the actual number of pulses that are counted between each registration mark. The difference between these two values represents the error. The **FIN** and **FBS** numbers are applied to this error to determine the new speed ratio.

The **INnI** command configures an input to the ZXF for accepting the signal from the sensor that detects the registration marks on the parts or material. The **TF** command is the rate at which the encoder interface is sampled. The **FSL** command enables the Synchronization mode. When Synchronization mode is enabled the first time, the Synchronization input is toggled, the encoder counter is started. The next time it is toggled, the count is latched and the counter is reset to zero. The latched count is the actual number of encoder pulses counted between registration inputs. This is compared to the expected value (**FC**). The difference is multiplied by the correction factor (**FIN** and **FBS**) to determine the speed ratio to run at until the synchronization input is toggled again. This process is continuous as long as the synchronization mode (**FSL**) is enabled.

If you do not know the expected encoder count between registration marks, use the Self Learn mode (**FSK**) to determine the expected count (**FC**). To determine the expected count using Self Learn mode, you must start the process at the speed ratio that you want to run at, turn on Self Learn mode. The ZXF will count the pulses between the registration marks. When the secondary axis stops, the last recorded number will be placed in the expected count (**FC**) number. This will be used when you are in Synchronization mode.

As an example, the process in the previous figures use an encoder that has 4000 pulses per revolution and the secondary motor has 25000 steps per revolution. The **FOR** command is set to 6.25. The motor is mounted on the secondary conveyer belt so that one revolution is 4 inches. The encoder is mounted on the primary axis so that one encoder revolution is 4 inches. The **FOL** command must be set to 100% (**FOL1ØØ**) for the secondary axis to move at the same speed as the primary axis. If the primary axis moves at 1 rps, the secondary axis must move at 1 rps. In the first synchronization figure, the two axes start moving at the same speed. The registration marks are 4 inches apart on the secondary axis. Use the Self Learn mode to determine how many encoder pulses are between the registration marks on the material on the secondary axis.

☞ ***Helpful Hint:*** The following steps show how to program the sample registration application.

① Set up the Self-Learn mode.

Command	Description
> **FOR6.25**	Set the motor to encoder ratio to 6.25
> **FOL1ØØ**	Set the motor to encoder ratio speed percentage to 100%
> **FSI1**	Enable the Following mode
> **FSK1**	Enable the Self Learn mode
> **TF1**	Set the encoder sample rate to 1 ms
> **A5ØØ**	Set the acceleration of 500 rps^2
> **AD5ØØ**	Set the deceleration of 500 rps^2
> **MC**	Place the ZXF in the continuous mode
> **IN1I**	Defines input number 1 as a synchronization input

② The registration sensor should be wired to the synchronization input. The primary and secondary axes should now be started. After the ZXF has passed more than 3 registration marks, it can be stopped. The number of encoder pulses between registration marks can be checked with the **FC** command. In this example, the number that is determined is 4000 counts.

Command	Response
> **1FC**	*4000

If you know the number of encoder pulses you expect to record between registration marks, this number can be entered directly for the **FC** command and will override the number determined in the self learn mode.

Command	Description
> **1FC4ØØØ**	Manually entering the expected count

③ The ZXF now has the number of counts expected between registration marks. The next step is to determine the correction gain desired. The correction will be applied to the difference between the expected count that was just determined and the actual counts that will be counted during actual operation.

Correction Equation

$$\text{Correction} = \frac{(\text{Actual encoder count - Expected encoder count}) \bullet \textbf{FIN}}{\textbf{FBS}}$$

This motor-to-encoder step ratio is determined by the following equation.

Speed Ratio Equation

New Speed Ratio = **FOR** • **FOL** + Correction

To determine the number of motor steps that will be commanded for the number of encoder pulses received, use the following equation.

Motor Step Correction Equation

Motor Steps = Encoder Steps • (**FOR** • **FOL** + Correction)

You must determine the amount of correction you want to have for a given amount of error. Once this has been determined, you can enter the **FIN** and **FOR** commands.

Command	Description
> **1FIN3.12**	The following increment is 3.12
> **1FBS1ØØ**	The following base number is 100

④ Disable Self Learn mode and enable Synchronization mode.

Command	Description
> **1FSKØ**	Disable Self Learn mode
> **1FSL1**	Enable Synchronization mode

⑤ Orient the primary and secondary axes to attain the desired phase relationship. Start both axes at once, or start the ZXF first and then the primary axis.

The ZXF will correct any errors in the phase relationship between the two axes and maintain a synchronized speed. The new speed ratio will be applied for the entire period between registration marks. The time between the registration marks is effectively the sample period. A correction is made for each sample period.

Another method for synchronization is to use the inputs to the ZXF for increasing and decreasing the following speed ratio. The ZXF inputs can be defined to increase or decrease the following ratio. By setting one input for increasing the following ratio and one input for decreasing the following ratio, synchronization can be achieved. In this case, use an external circuit to determine whether the secondary axis should accelerate (increase ratio) or decelerate (decrease ratio) the secondary axis.

Define the input with the **IN** command. **INnX** defines the input for increasing following ratio, **INnY** defines the input for decreasing the following ratio. The following ratio will be increased/decreased while the input is active. During the ZXF's sample periods, the ratio will increase or decrease while the inputs are active. The inputs have a 2 ms debounce time. If the input is active for 4 ms, the following ratio will be increased/decreased twice. The amount that the following ratio is increased/decreased is determined by the **FIN** command. If **FIN** is 1, **FOL** is increased/decreased by 1 during each sample period.

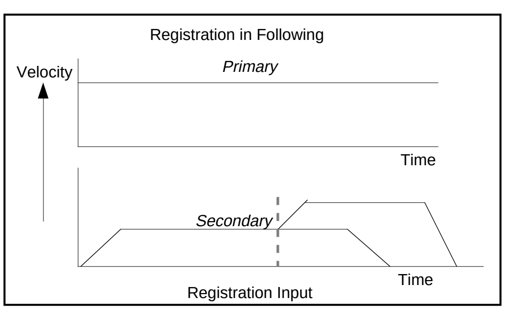
Other Following Features

This section discusses following features that the ZXF provides for special following requirements.

Registration in Following Mode

With the ZXF, registration can be performed in Following mode. It is like programming registration in the indexer version, *but the velocity term is replaced by* **FOL** *for the desired speed*. The graph below illustrates registration in the Following mode.

☞ **Helpful Hint:** Registration can only be performed if Following Synchronized Acceleration mode is disabled (FSFØ). For this example, re-attach the encoder to the primary axis.



Registration in Following Mode

① Repeat steps ① - ⑤ of the Velocity Following Example.

② Set up input #7 as a registration input

Command	Description
> IN7Q	Defines input #7 as a registration input

③ Define registration move #1 as follows:

> REG1,A1Ø,AD1Ø,FOL2ØØ,D25ØØØ

④ Begin motion on the primary axis, then begin motion with the ZXF.

Command	Description
> MC	Change to continuous mode
> G	Initiate motion

⑤ Toggle input #7. The motor will begin following at a speed ratio of 2:1 for 25,000 motor steps.

Jogging in Following Mode

In some applications, you may want to move the motor manually while in Following mode. This allows you to follow the primary axis at a following ratio by toggling a switch. You can configure the ZXF to allow you to follow the primary motor manually with the **IN** command. Jogging in Following mode does not require the **JHV** or **JVL** commands. In this case, you will jog at the **FOL** command's speed ratio. To use the inputs, you can either configure the input as a CW or CCW jog as with the preset indexer jog. However, you cannot use the high-speed/low-speed jog input because you can only jog at the **FOL**'s speed ratio.

Therefore, you use the two jog input functions: CW Jog input (**IN#J**) and CCW Jog Input (**IN#K**). You must also enable the jogging feature with the **OSE1** command. Once you set these parameters, you can attach a switch to the jog inputs (predefined) and jog the motor(s). The # character represents digits 1 - 13, which you enter. You must have the ZXF in Following mode to jog at a speed ratio of the primary. The following example shows you how to define power-up sequence #100 to jog.

① Define a power-up sequence. Position Tracking mode must be disabled (FSPØ) to enable direction jogging.

Command	Description
> XE1ØØ	Erases sequence #100
> XD1ØØ	Defines sequence #100
> LD3	Disables the limits(*not needed if you have limit switches installed*)
> JA25	Sets Jog Acceleration to 25 rps^2
> JAD25	Sets Jog Deceleration to 25 rps^2
> OSE1	Enables Jog function
> JVL.5	Sets low-speed jog velocity to 0.5 rps
> JVH5	Sets high-speed jog velocity to 5 rps
> IN1J	Sets **IN 1** as a CW jog input
> IN2K	Sets **IN 2** as a CCW jog input
> FOR6.25	Sets the motor to encoder steps
> FOL75	Secondary moves at 75% of the primary speed
> FSI1	Enables the following mode
> XT	Ends Sequence Definition

② Reset the ZXF. Move the primary or primary axis.

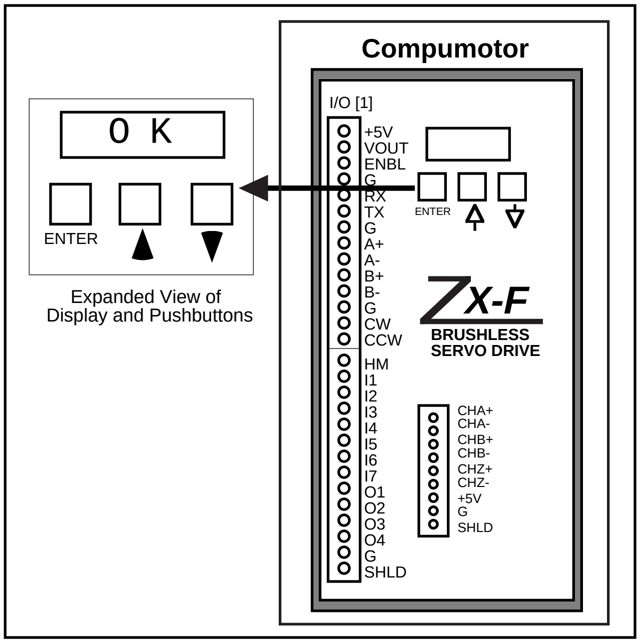
Command	Description
> **Z**	Resets the ZXF

③ Turn on **IN 1** to move the motor CW at 75% of primary axis' speed (until **IN 1** is turned off).

④ Turn on **IN 2** to move the motor CCW at 75% of primary axis' speed (until **IN 2** is turned off).

Changing Following Ratio Via Front Panel Pushbuttons

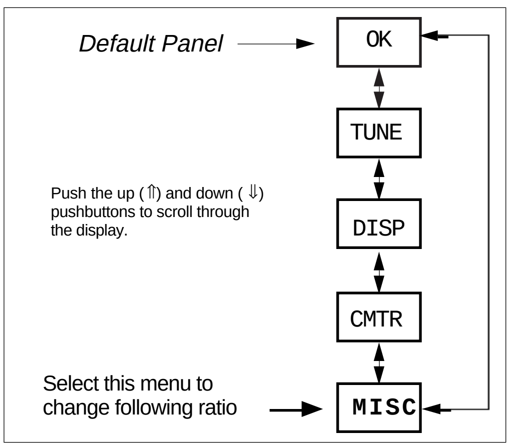
The ZX has a four-character, dot-matrix, alphanumeric display. You can modify the following ratio with the pushbuttons.



ZX Indexer/Drive Display and Pushbuttons

Pushbutton Operation

You can change the following ratio under the **MISC** menu. Only one panel is shown on the display at a time.



Main Menu Panel (Overview)

OK is the default message. Press the **DOWN** pushbutton to access the **MISC** menu. The table below shows the main menus and sub-menus. Select the **FOLL** option under the **MISC** menu.

O K	T U N E	D I S P	C M T R	**M I S C**
Home Panel	P P n n	D V E L	6 0 5	S A V E
	P I n n	D E R R	6 0 6	R F S
	P D n n	D C A	6 1 0	B R m m
	T G n n		6 2 0	A D p p
	V P n n		6 3 0	**F O L L**
	V I n n		6 4 0	S E Q U
	V F n n		F M C A	R E V #
				J O G

Main Menu Panel

To change the following ratio on the fly, press **ENTER** when **FOLL** is displayed. The four least significant digits of the **FOL** command will be displayed. The least significant digit is the following ratio in tenths (it should be blinking). This indicates that changes to the following ratio will be in 1/10 increments. To select a higher magnitude of ratio change, press **UP** or **DOWN** (moving the cursor left or right respectively). Any changes to the following ratio will be at the new digit's magnitude.

100s	10s	1s	0.1s	FOL weighting
a	b	c	d	Blinking digit location

To change the ratio at the blinking digits magnitude, simultaneously press **ENTER** with **UP** or **DOWN**. *Press **UP** and **DOWN** simultaneously to return to the Main menu.*

Following a Step and/or Direction Signal

The ZXF can follow a step (or pulse) and a direction signal rather than quadrature encoder pulses. The same incremental encoder interfaces used for quadrature following are used for the step and direction following. The **Phase A+** and **Phase A-** inputs are now the **Step+** and **Step-** inputs. The **Phase B+** and **Phase B-** inputs are now the **Direction+** and **Direction-** inputs. The only other requirement is to put the ZXF in the pulse and direction mode. This is accomplished with the **FSN** command. By typing **FSN1** the pulse and direction capability is enabled and the **Phase A** and **Phase B** inputs are now step and direction inputs. Once the pulse and direction capability is added, any following applications are performed exactly as if the input were quadrature signals. If your application requires pulse and direction, enable the Pulse and Direction mode and repeat the procedures in this following section.

Following Equation and Command Summary

This section provides a reference for the following equations and the ZXF software commands that are associated with following.

Following Command Summary

For more information on these commands, refer to the ***ZX Software Reference Guide***. *Set-up commands are required for any following application.*

FSA	Followed by a 1—enables instant acceleration between commanded velocities for each resulting velocity change after sampling the encoder and determining the ratio.
FSF	Followed by a 1—enables the use of following acceleration as determined by **FAC** and **FEN**.
FSI	Followed by a 1—enables following mode versus indexer mode.
FSJ	Followed by a 1—enables the encoder port labeled ABS/INC ENCODER for following.
FSK	Followed by a 1—enables the calculation of **FC** for Synchronization mode.
FSL	Followed by a 1—enables Synchronization mode.
FSN	Followed by a 1—enables a step/direction signal to be followed or just a pulse train if direction is not used in conjunction with **FSP**.
FSP	Followed by a 1—enables position tracking.
FOR	The number of secondary motor pulses per unit of travel divided by the primary encoder pulses per the same unit of travel.
FOL	The % of the primary encoder speed that the secondary axis moves at.
FAC	The change in following % for each change in encoder pulse count of **FEN** during following acceleration.
FEN	The number of encoder pulses that the encoder count must change by to increment the following percentage by **FAC.**
FP	In Motion Profiling (MPP) mode, command execution is paused for the number of following encoder steps set by the **FP** command.
FPA	In Motion Profiling (MPP) mode, the execution of commands pauses until the value in the encoder counter exceeds the **FPA** value.
FIN	The amount by which the following % changes when changed by inputs or by the pushbuttons.
FBS	In synchronization, used with **FIN** to determine the amount of following percentage correction.
FC	In synchronization, the expected number of encoder counts between registration marks.
TF	The following encoder sample period.
VARn=FEP	**FEP** is a read only variable of the actual encoder count. Set it equal to the variable to get the current value of the encoder counter.
PF	Gives you a report back of the encoder count.
PFZ	Clears the encoder counter.
SSP	Followed by a 1—enables you to modify the following percentage by the front panel pushbuttons.
INnX	An input function that lets you increase the following percentage by **FIN**.
INnY	An input function that lets you to decrease the following percentage by **FIN**.
INnI	An input function used for the registration mark sensor of the synchronization mode.

The commands are categorized according to the applications the support.

Velocity Following	*Velocity and Position Following*		*Special Function*
FOR	FOR	FSF	FSN
FOL	FOL	FEN	SSP
FSI	FSI	FAC	FSM
FSJ	FSJ	FSA	PF
TF	TF	FSP	PFZ

Advance and Recede		*Synchronization*		
FOR	FSF	FOR	FSF	FBS
FOL	FAC	FOL	FAC	FSK
FSI	FEN	FSI	FEN	FSL
FSJ	FP	FSJ	FC	INnI
TF	FPA	TF	FIN	INnX
		INnY		

Following Equation Summary

The following equations were discussed throughout this chapter. They are provided again here for reference and convenience

Velocity Following

Secondary Motor steps = Primary encoder count • **FOR** • $\frac{\textbf{FOL}}{100}$

Velocity and Position Following

Given V_{max} and D_{acc} :

FEN = $V_{max} \cdot \frac{\textbf{TF}}{1000}$ $V_{max} = \frac{\text{Primary encoder counts}}{\text{second}}$

TF = Primary Encoder Sample Period in ms

FAC = $\frac{\textbf{FOL} \cdot V_{max}}{D_{acc}} \cdot \frac{\textbf{TF}}{1000}$ $V_{max} = \frac{\text{Primary encoder counts}}{\text{second}}$

TF = Primary Encoder Sample Period in units of ms

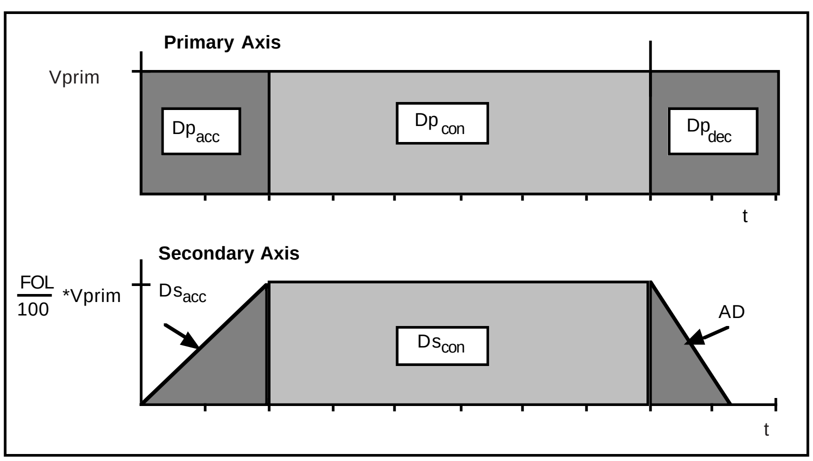
FOL = Following percentage in units of percent

D_{acc} = Distance primary axis moves during secondary axis acceleration in units of primary encoder counts

Given V_{max} and A_{max} Determine D_{acc} from $D_{acc} = \frac{V_{max}^2}{A_{max}} \cdot \textbf{FOR} \cdot \frac{\textbf{FOL}}{100}$

The acceleration is in units of secondary motor steps/sec^2 . The maximum velocity of the primary is in primary motor steps/sec.

The figure below illustrates the motion profiles of a secondary and the primary. The different parameters are shown on the profiles and the equations to determine the parameters are given below. **AD** is used for the deceleration.



Velocity and Position Following With AD Decel

$$Ds_{acc} = \textbf{FOR} \cdot \left(\frac{1}{2} \cdot \Delta\textbf{FOL}^2 \cdot \frac{\textbf{FEN}}{100 \cdot \textbf{FAC}} + \Delta\textbf{FOL} \cdot \textbf{FOL}_I \cdot \frac{\textbf{FEN}}{100 \cdot \textbf{FAC}}\right)$$

Δ**FOL** = The change in following percentage

FOL_I = The initial following percentage

The equations above can be simplified by defining a following acceleration constant determined by **FAC** and **FEN**.

$$K = \frac{\mathbf{FEN}}{100 \cdot \mathbf{FAC}}$$

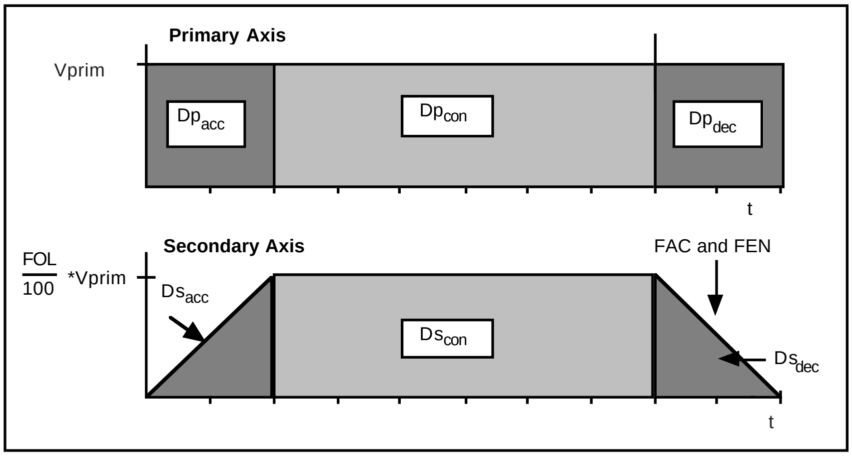
The equations can now be written as:

$$D_{sec} = \mathbf{FOR} \cdot K \cdot \left(\frac{1}{2} \cdot \Delta\mathbf{FOL}^2 + \Delta\mathbf{FOL} \cdot FOL_I \right)$$

$$D_{sec}\ (\text{Deceleration}) = -\ \mathbf{FOR} \cdot K \cdot \left(\frac{1}{2} \cdot \Delta\mathbf{FOL}^2 + \Delta\mathbf{FOL} \cdot FOL_I \right)$$

Use the equations/parameters in the following graph to make a trapezoidal move.

☞ ***Helpful Hint:*** Deceleration is done according to the FAC and FEN commands.



Velocity and Position Following With Following Decel

$$D_{prim} = Dp_{acc} + Dp_{con} + Dp_{dec}$$

$$D_{sec} = Ds_{acc} + Ds_{con} + Ds_{dec}$$

$$Ds_{acc} = \mathbf{FOR} \cdot K \cdot \left(\frac{1}{2} \cdot \Delta\mathbf{FOL}^2 + \Delta\mathbf{FOL} \cdot \mathbf{FOL_I} \right)$$

$$Ds_{dec} = -\ \mathbf{FOR} \cdot K \cdot \left(\frac{1}{2} \cdot \Delta\mathbf{FOL}^2 + \Delta\mathbf{FOL} \cdot \mathbf{FOL_I} \right)$$

$$Dp_{acc} = \Delta\mathbf{FOL} \cdot \frac{\mathbf{FEN}}{\mathbf{FAC}}$$

$$Ds_{con} = Dp_{con} \cdot \mathbf{FOR} \cdot \frac{\mathbf{FOL}}{100}$$

$$\mathbf{FOL} = \frac{D_{prim}}{200 \cdot K} - \sqrt{\left(\frac{D_{prim}}{200 \cdot K}\right)^2 - \left(\frac{D_{sec}}{K}\right)}$$

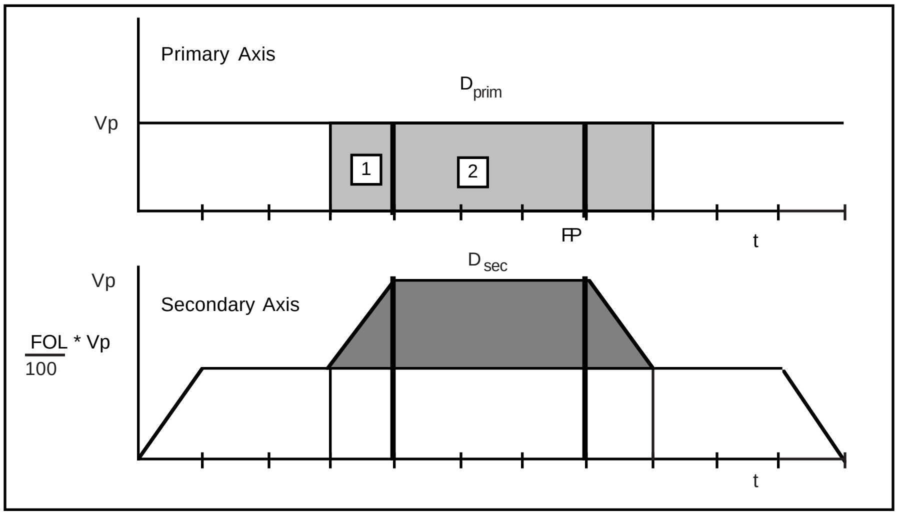
K is the following acceleration constant, D_{prim} and D_{sec} are the distances that the primary axis and secondary axes will move, respectively. $\mathbf{FOL_I}$ is the initial following percentage. In the case of a trapezoidal move, it will always be 0. The required sequence is:

<u>Command</u>	<u>Description</u>
> XE1	Erases Sequence #1
> XD1	Defines Sequence #1
FSI1	Enables Following mode
FORn	Sets motor to encoder steps per unit travel ratio
FACn	Sets the following acceleration increment
FENn	Sets the encoder period
Dn	Sets the secondary axis distance to n motor steps
FOLn	Sets the initial following percentage to n
TR1	Waits on the input trigger
MPP	Enters the Motion Profiling mode
G	Starts motion
FPa	Waits until a encoder pulses have passed
FOLØ	Stops the motion of the secondary
FPb	Waits for the decel ramp distance
STOP	Stops the move itself
> XT	Ends the Sequence #1 definition

The value for a in the first **FP** = $Dp_{acc} + Dp_{con}$

The value for b in the second **FP** = Dp_{dec}

Advance and Recede



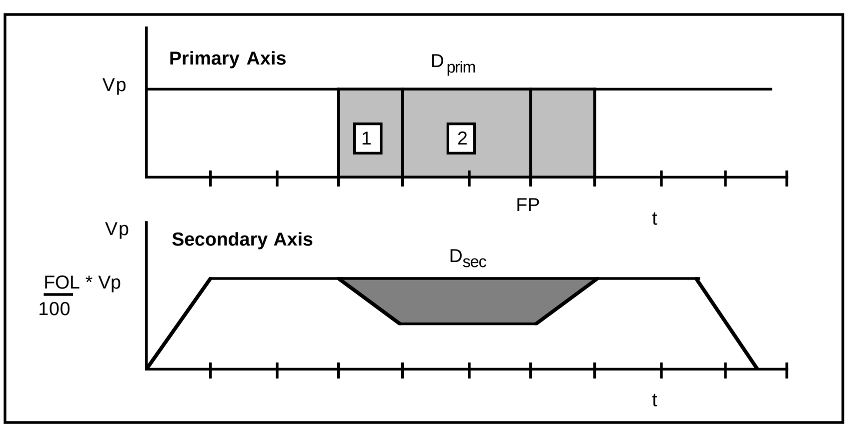
Advance Profile

In this figure, D_{prim} is the distance that the primary axis moves in encoder steps during the advance portion of the profile. It is the lightly shaded region. D_{sec} is the distance in secondary motor steps that the secondary axis advances with respect to the moving primary axis. This distance is the darkly shaded region.

$$\mathbf{FOL} = \mathbf{FOL}_I + \frac{D_{prim}}{200 \cdot K} - \sqrt{\left(\frac{D_{prim}}{200 \cdot K}\right)^2 - \left(\frac{D_{sec}}{\mathbf{FOR} \cdot K}\right)}$$

The breakpoint to decelerate to **FOL1ØØ** is entered for the **FP** value in the advance sequence. **FP** is a distance equal to the sum of areas 1 and 2 in the primary profile.

$$\mathbf{FP} = D_{prim} - \frac{\mathbf{FEN}}{\mathbf{FAC}} \cdot \left(\mathbf{FOL}_F - \mathbf{FOL}_I\right)$$



Recede Profile

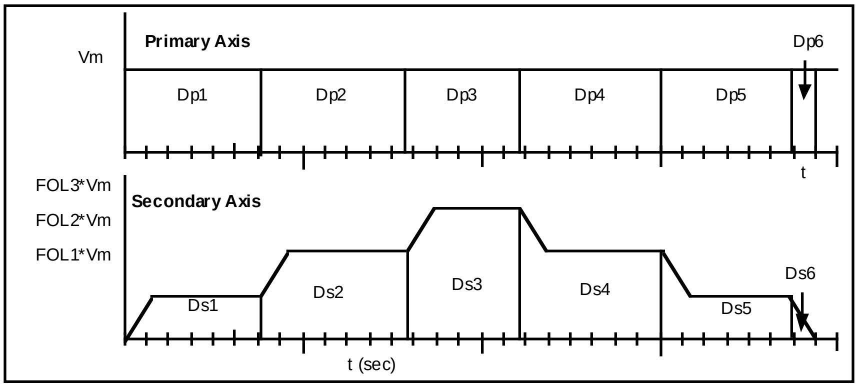
The dark shaded area is the distance that the secondary will recede with respect to the moving primary. The lightly shaded area is the distance the primary moves while the secondary recedes.

$$FOL = FOL_I - \frac{D_{prim}}{200 \cdot K} + \sqrt{\left(\frac{D_{prim}}{200 \cdot K}\right)^2 - \frac{D_{sec}}{FOR \cdot K}}$$

K is the following acceleration constant and is equal to: $\frac{\mathbf{FEN}}{100 \cdot \mathbf{FAC}}$

FP is equal to: $D_{prim} + \frac{\mathbf{FEN}}{\mathbf{FAC}} \cdot (\mathbf{FOL}_F - \mathbf{FOL}_I)$

Cam Following



Cam Profile

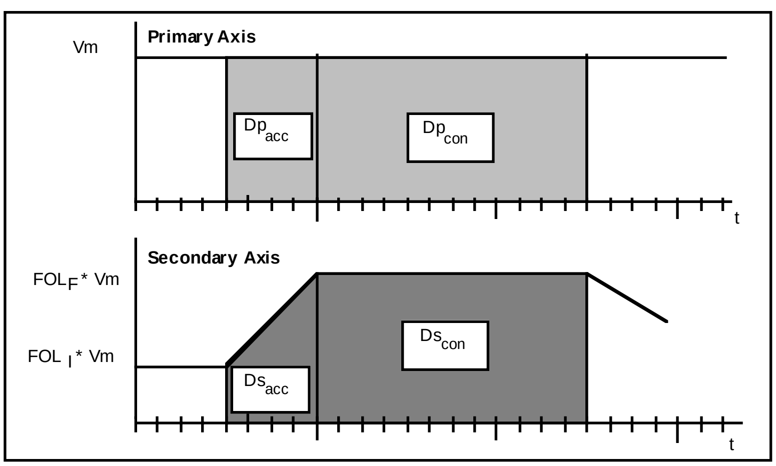
Each segment of the secondary and primary move profile is marked by a primary distance Dpn and a secondary distance Dsn. The following percentage required for each segment is determined from the equations below. D_{prim} and D_{sec} are equal to Dpn and Dsn for each segment. When accelerating to a higher percentage use:

$$\mathbf{FOL} = \mathbf{FOL}_I + \frac{D_{prim}}{100 \cdot K} - \sqrt{\left(\frac{D_{prim}}{100 \cdot K}\right)^2 + \frac{2 \cdot FOL_I \cdot D_{prim}}{100 \cdot K} - \frac{2 \cdot D_{sec}}{\mathbf{FOR} \cdot K}}$$

When decelerating to a lower percentage, use:

$$\mathbf{FOL} = \mathbf{FOL}_I - \frac{D_{prim}}{100 \cdot K} + \sqrt{\left(\frac{D_{prim}}{100 \cdot K}\right)^2 - \frac{2 \cdot \mathbf{FOL}_I \cdot D_{prim}}{100 \cdot K} + \frac{2 \cdot D_{sec}}{\mathbf{FOL} \cdot K}}$$

FP or **FPA** are equal to Dpn or the accumulative Dpn respectively. Each cam segment can be broken down and described with the equations below.



Cam Profile Segment

$$D_{prim} = Dp_{acc} + Dp_{con}$$

$$D_{sec} = Ds_{acc} + Ds_{con}$$

$$Ds_{acc} = FOR \bullet K \bullet \left(\frac{1}{2} \bullet (FOL_F - FOL_I)^2 + (FOL_F - FOL_I) \bullet FOL_I \right)$$

$$Dp_{acc} = (FOL_F - FOL_I) \bullet \frac{FEN}{FAC}$$

$$Ds_{con} = Dp_{con} \bullet FOR \bullet \frac{FOL}{100}$$

The distance for **FP** is $Dp_{acc} + Dp_{con}$, for **FPA** is the absolute value of the primary distance since the start of the cam cycle.