



HEIDENHAIN



Operating Instructions

ND 1300 QUADRA-CHEK

(QC 320)

CNC Setup –
Video and Optical
Edge Detection Systems

English (en)
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QC-320 Series
CNC Setup Guide

QC-320 Series CNC Setup Guide

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Preface

Who should use this guide

The use of this guide is limited to technically qualified distributors and OEMs. The procedures contained in this guide should never be attempted by end-users or inexperienced personnel.

Conventions & Terms

System refers to the QC-320 series control system, motor-driven CNC axes and the measuring devices connected to them.

Icons

This guide uses the following icons to highlight information:



WARNING

The raised hand icon warns of a situation or condition that can lead to serious equipment damage, personal injury or death. Do not proceed until the warning is read and thoroughly understood. Warning messages are shown in bold type.



DANGEROUS VOLTAGE

The lightning icon warns of the presence of a dangerous voltage within the product enclosure that might be of sufficient magnitude to cause serious shocks or death. Do not open the enclosure unless you are a qualified service person approved by Metronics, Inc., and never open the enclosure while power is connected.



CAUTION

The exclamation point icon indicates a situation or condition that can lead to equipment malfunction or damage. Do not proceed until the caution message is read and thoroughly understood. Caution messages are shown in bold type.



NOTE

The note icon indicates additional or supplementary information about an activity or concept. Notes are shown in bold type.

The safe operation of axis motors

The procedures contained in this guide might require some operation of axis motors under open-loop or uncontrolled conditions. These operations must be conducted while following these instructions with great care to avoid serious personal injury or equipment damage resulting from motor runaway.



WARNINGS

Always stay clear of axis motion paths.

Disconnect axis motor power when motor activities are not required.

Be prepared to depress an emergency off mushroom switch or other similar contact safety device quickly to stop axis motion in the event of an emergency when axis motors are active.

Follow the instructions provided by this guide carefully. Do not hurry through procedures or skip steps. If you are uncertain about any part of the CNC setup process, contact Metronics technical support for assistance before continuing.

Other Safety Considerations

General safety precautions must be followed when configuring, maintaining or operating the system. Failure to observe these precautions could result in damage to the equipment, or injury to personnel.

It is understood that safety rules within individual companies vary. If a conflict exists between the material contained in this guide and the rules of a company using this system, the more stringent rules should take precedence.

Additional safety information is included throughout the remainder of this guide.

Electrical

Do not allow any power cord to be located such that it can be walked on or create a tripping hazard.



WARNINGS

Disconnect the QC-300 from power before cleaning.

The QC-300 is equipped with a 3-wire power plug that includes a separate ground connection. Always connect the power plug to a 3-wire grounded outlet. The use of accessories that remove the third grounded connection such as a 2-wire power plug adapter create a safety hazard and should not be permitted. If a 3-wire grounded outlet is not available, ask your electrician to provide one.

**DANGEROUS VOLTAGE**

Do not open the enclosure unless you are a qualified service person approved by Metronics, Inc., and never open the enclosure while power is connected. There are no user-serviceable components or assemblies inside. Refer servicing to qualified service personnel.

Electrical surge suppressor

The QC-320 and CNC amplifier should be connected to power through an electrical surge suppressor to prevent damage to electrical circuits and anomalous system behavior caused by power line spikes.

Cleaning the enclosure

Use only a cloth dampened with water and a mild detergent for cleaning the exterior surfaces. Never use abrasive cleaners, and never use strong detergents or solvents. Only dampen the cloth, do not use a cleaning cloth that is dripping wet. Instructions for cleaning the touch screen are different and are given below.

Cleaning the touch screen

The touch screen should be cleaned as described below to prevent scratching or wearing the screen surface and to prevent liquids from leaking into the enclosure.

Use only a soft, lint-free cloth dampened with water for cleaning the touch screen. Never use abrasive cloths or paper towels. Never use abrasive cleaners, and never use detergents or solvents. Only dampen the cloth, do not use a cleaning cloth that is dripping wet. Never spray the screen.

If the screen is badly soiled, the cloth can be dampened with a 50:50 mixture of isopropyl alcohol and water. Remember, only dampen the cloth, do not use a cleaning cloth that is dripping wet, and never spray the screen.

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Chapter 1: Introduction

CNC measuring systems include a wide variety of electro-mechanical designs that satisfy an even wider variety of applications. Servo or stepper motors move large or small masses to perform precision measurements using optical edge detection or video edge detection probes. Always, users strive to maximize throughput and minimize downtime.

The trade-offs regarding throughput and downtime become important as a CNC system is operated near its performance limits. Generally, more robust electro-mechanical systems can be tuned to operate closer to their limits than systems with less mechanical stability and lower performance motor drive systems. However, operating any system close to its performance limits can result in:

- Difficult PID loop tuning
- Increased PID retuning due to environmental changes or equipment aging
- Accelerated equipment wear

These problems are minimized when systems are tuned to meet, but not far exceed the performance required by their measurement applications.

This guide contains the following information:

Chapter 2: Setting CNC motor direction

Chapter 3: CNC setup



Safety first!

The procedures contained in this guide might require some operation of axis motors under open-loop or uncontrolled conditions. These operations must be conducted while following these instructions with great care to avoid serious personal injury or equipment damage resulting from motor runaway.

The following procedures are generic in the sense that they are intended to be applied to a wide variety of CNC systems. Safety was always a first priority in the creation of this guide, and while the procedures have been tested and shown to have eliminated potential safety hazards, it is ultimately the responsibility of the person using this guide to make decisions related to safety. Whenever there is a conflict between the material in this guide and the judgments of the user or the safety policies of the user's company, the more stringent safety rules should take precedence.

**WARNINGS**

Always stay clear of axis motion paths.

Disengage axis motor power when motor activities are not required.

Be prepared to depress the emergency off mushroom switch or other similar device quickly to stop axis motion in the event of an emergency when motor axes are active.

Follow the instructions provided by this guide carefully. Do not hurry through procedures or skip steps. PID loop tuning can be accomplished most effectively and most quickly by proceeding carefully and methodically.

Chapter 2:

Setting Motor Direction

The QC-320 program drives CNC axis motors through external cables and amplifiers. It is often impractical to determine the resulting motor polarity and direction of rotation prior to applying motor power. However, the QC-320 program includes tools that make it simple to determine motor direction and configure the system to accommodate it.



WARNINGS

Motors that are reversed due to wiring or amplifier configuration will run away when driven at normal levels by the QC-320. Motor runaway can result in serious personal injury and equipment damage. This procedure will drive the axis motors at very low levels to determine motor direction. Follow the procedure carefully before proceeding to other topics in this guide.

Be prepared to quickly disconnect power from the motors using the Stop button in the CNC Setup screen or an emergency mushroom switch or other contact device provided in your system in an emergency.

Determining motor direction

This procedure determines the rotation direction of one CNC axis motor. The images included in the instructions show the X-axis, however all axis screens are identical and this procedure must be repeated for all axes.

- 1 Confirm that power is disconnected from all axis motors and launch the QC-320 program.
- 2 Set units of measure to millimeters.
- 3 Navigate to the CNC Setup screen to enter initial values.



WARNING

The initial CNC Setup screen values severely limit axis velocity and acceleration and provide only a small amount of loop gain. These limitations make the possibility of motor runaway extremely unlikely. However, any possibility of motor runaway, no matter how unlikely should be treated as a potential hazard.

5 Enter the following initial values into the X-axis data fields:

- Max velocity = 10
- Acceleration = 10
- Jerk = 0
- Max following error = 30
- Continuation zone = 0.5
- Drift offset = 0
- Proportional factor

For servo system = 20

For stepper system = 5

- Derivative factor = 0
- Integral factor = 0
- Integral limit = 0
- Reverse motor = box empty
- Stepper motor = box checked *only if a stepper motor is used* on this axis
- Enable = box checked
- Test distance = 10

Setup: CNC Setup

Axis: X

Max. velocity (/s):	10.0000	Proportional factor:	10
Acceleration (/s/s):	10.0000	Derivative factor:	0
Jerk (/s/s/s):	0.0000	Integral factor:	0
Max. following error:	30.0000	Integral limit:	0
Continuation zone:	0.5000	Reverse motor:	<input type="checkbox"/>
Drift offset (v):	0	Stepper motor:	<input type="checkbox"/>
Test Distance:	0	Enable:	<input checked="" type="checkbox"/>

Buttons: Test, Set home, Drift test, STOP!

Current position: 0.0000 Current velocity: 0.0000
 Average velocity: 0.0000 Maximum velocity: 0.0000
 Current following error: 0.0000 Max. following error: 0.0000
 Current voltage: 0.000000

The remainder of this procedure will initiate tests that move the axis a 10 mm test distance. During these CNC moves, the **Current position value** will be observed at the bottom of the CNC Setup screen. It is unlikely that any significant axis motion will occur until the motor amplifier gain (**Proportional factor**) is increased, so the procedure usually becomes an iteration of touching the **Test button**, observing the **Current position value**, increasing the **Proportional factor** and touching the **Test button** again until definite axis motion is observed.

When the axis moves in response to the test, the following determination of motor direction can be made:

- The motor *is not reversed* when the **Current position value** moves to or near the 10 mm target position and stops.
- The motor *is reversed* when the **Current position value** continues beyond or away from the 10 mm target at increasing velocities.



CAUTION

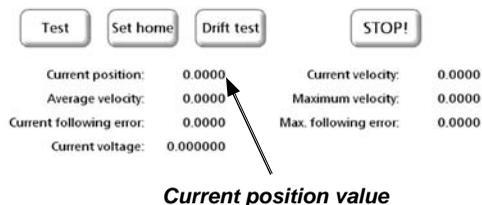
Reversed axes can move very quickly. If an axis begins to run away, touch the Stop button immediately.

The Stop button is not intended as a substitute for hard-contact emergency stop switches. While touching the Stop button is a convenient way to halt axis motion, do not rely completely on this software interface - always be prepared to use the emergency stop button to halt motion.

Review the text and flow chart completely before performing this procedure.

1 Touch the **Stop button**, then the **Set home button** to start the **Current position value** shown at the bottom of the screen at zero.

2 Small axis movements are clearly shown by changing **Current position values**. Touch the **Test button** to start motion and observe the **Current position value**. It might be necessary to touch **Test** twice. Be prepared to touch the **Stop button**.

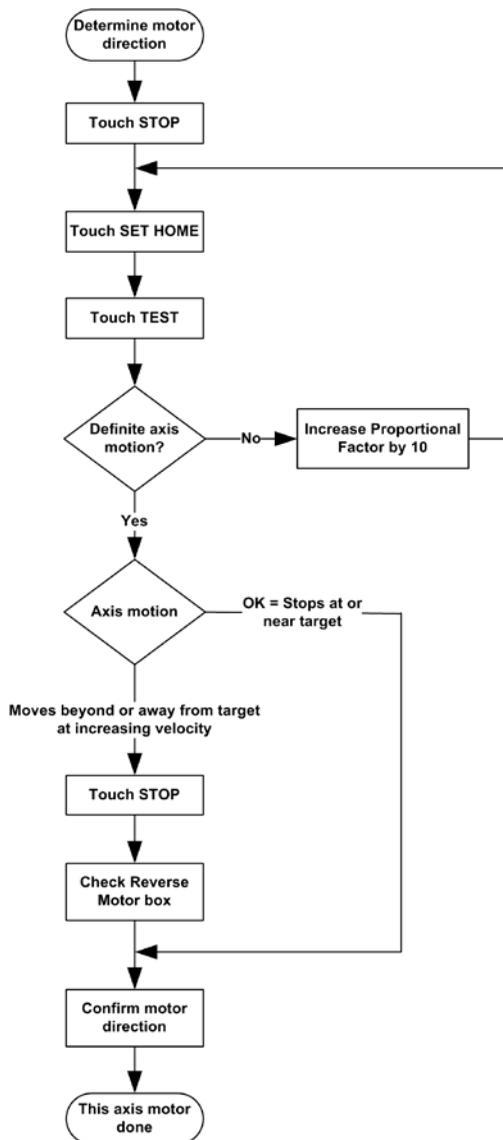


3 If no definite axis motion was noted, increase the **Proportional factor** by 10, touch **Set home** and retest until definite axis motion is observed. Be prepared to touch the **Stop button**.

4 If the **Current position value** moved to or near the 10 mm target position and stopped, the motor is not reversed.

If the **Current position value** continued beyond or away from the target at increasing velocity, the motor is reversed and the **Reverse Motor box** must be checked.

5 When the motor direction setting is confirmed on the current axis, use this procedure again to set the motor directions of the other CNC axes. When all CNC axis directions are configured, disconnect all motors from power and proceed to Chapter 3: CNC Setup.



Chapter 3: CNC Setup

This chapter contains instructions for setting up the CNC components of QC-300 video or optical edge detection systems. The instructions are intended to be followed in the order presented and include:

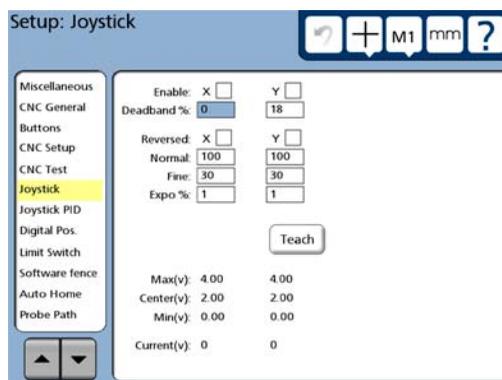
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Joystick setup and calibration

The Joystick screen contains fields calibrating and configuring joystick motion.

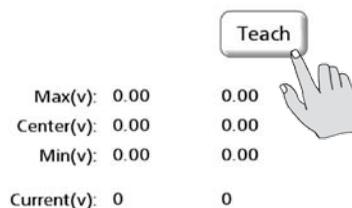
Enabling joystick motion

Check an axis Enable box Enable: X Y to enable joystick motion, or clear the box to disable joystick motion on that axis.



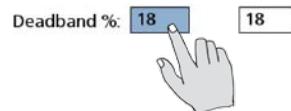
Teaching the Joystick range of motion

The system must measure the joystick range of motion before the joystick can be used. Touch the Teach button to start the calibration procedure, and then follow the instructions displayed on the screen. Joystick positions will be indicated by Max(v), Center(v), Min(v) and Current(v) voltage values.



Deadband

A deadband area of joystick inactivity is specified around the zero position of each axis to eliminate erroneous axis motion due to joystick vibration or noise. The default values are expressed as percentages of total motion and will satisfy the requirements of most environments, however these values can be increased or decreased by selecting the deadband field and entering the desired value.



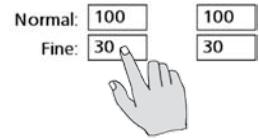
Reversed axis direction

The direction of motion controlled by the joystick on an axis can be reversed to accommodate different joystick and system hardware by checking the Reversed axis box.



Normal and fine axis velocity

The normal and fine axis velocities controlled by the joystick are specified by selecting a Normal or Fine velocity field and entering the desired percentage of maximum axis velocity. Normal and fine speed control is assigned to a joystick button in the Buttons setup screen.



Exponential (Expo%) joystick motion control

The axis velocity controlled by the joystick is changed from linear to varying degrees of exponential by entering values into the axis Expo% fields. Expo % values are entered from 0 (linear) to 100 (very exponential). Two examples and a graph are shown below.

Linear example (Expo % = 0):

For each percent of Joystick displacement, the axis velocity increases a percent:

When the joystick is at 50%, the axis velocity is 50%

When the joystick is at 80%, the axis velocity is 80%

When the joystick is at 100%, the axis velocity is 100%

Nonlinear example (Expo % = 60):

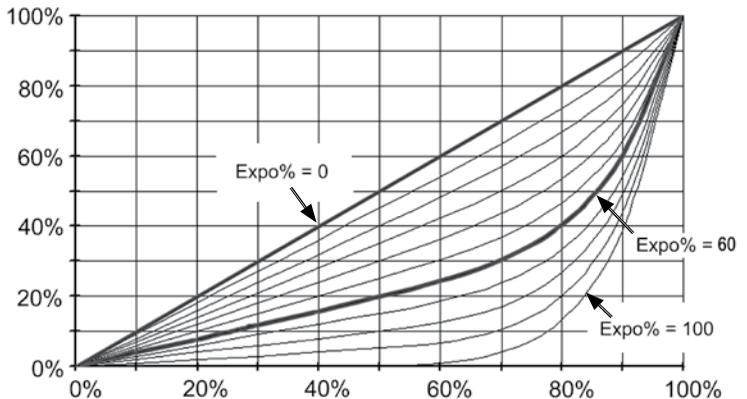
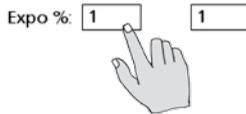
At first, increased Joystick displacements do not cause the axis velocity to increase much, but then as the Joystick displacement continues to increase, the axis velocity increases at a higher and higher rates:

When the joystick is at 50%, the axis velocity is 20%

When the joystick is at 80%, the axis velocity is 25%

When the joystick is at 100%, the axis velocity is 100%

Select an axis Expo % field and enter the desired value.

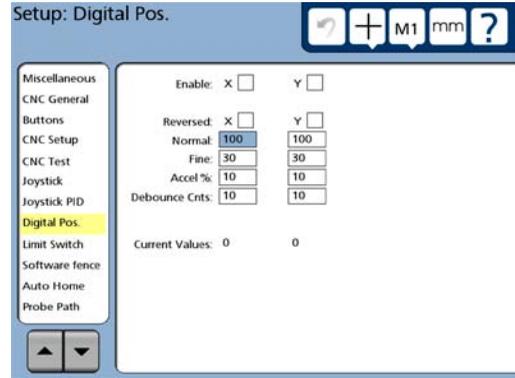
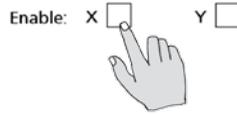


Digital positioner setup

The Digital positioner screen contains fields for calibrating and configuring digital positioner motion.

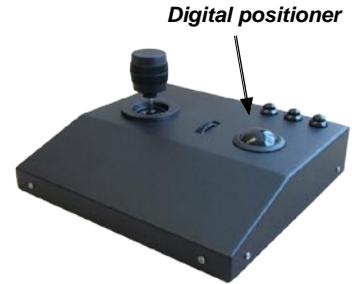
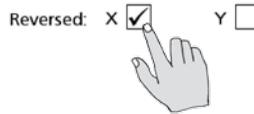
Enabling digital positioner motion

Check an axis Enable box to enable digital positioner motion, or clear the box to disable digital positioner motion on that axis.



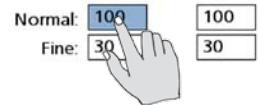
Reversed axis direction

The direction of motion controlled by the digital positioner on an axis is reversed to accommodate different digital positioner and system hardware by checking the Reversed axis box.



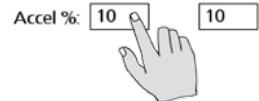
Normal and fine axis velocity

The normal and fine axis velocities controlled by the digital positioner are specified by selecting a Normal or Fine velocity field and entering the desired percentage of maximum axis velocity. Normal and fine speed control is assigned to a joystick button in the Buttons setup screen.



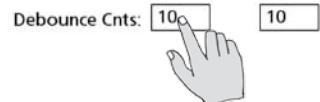
Acceleration (Accel%)

The axis acceleration controlled by the digital positioner is specified by selecting an axis field and entering the desired percentage of maximum axis acceleration.



Debounce counts

An area of digital positioner inactivity is specified around the current rest position of each axis to eliminate erroneous axis motion due to digital positioner vibration or noise. The default values are expressed as positioner counts and will satisfy the requirements of most environments, however these values can be increased or decreased by selecting the Debounce Cnts field and entering the desired value.



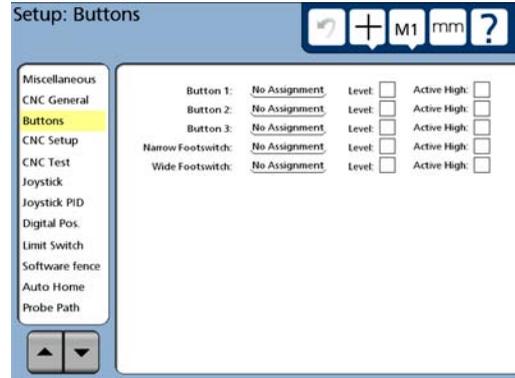
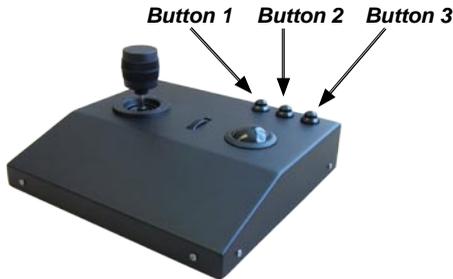
Current values

The axis current values change as the digital positioner is moved. This display is only provided as a convenience for the user.

Current Values: 0 0

Button function assignments

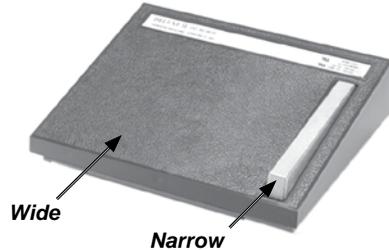
The Buttons screen contains fields for assigning frequently used QC-300 functions to joystick and foot switch buttons. Using preassigned buttons saves the time normally required to navigate menus. Each of the joystick and foot switch buttons can be assigned to functions shown in the choice fields. Thereafter, pressing the button invokes the assigned function.



Button functions

Button functions include:

No Assignment	Nothing happens
Enter	Enters data point
Finish	Completes a measurement
Cancel	Erases the last measurement point or erases a character
Quit	Quits a measurement
Axis Lock	Engages CNC axis lock - prevents diagonal motion
Speed toggle	Toggles the joystick speed between fast and slow
Go to Here	Performs CNC move to the selected feature
Part Follow	Engages CNC conversion from machine coordinates to part coordinates for joystick-controlled motion
Motors On/Off	Toggles axis motors on and off
Auto Focus	Performs an auto focus
Swap Z Joystick	Toggles vertical joystick motion between Y-axis and Z-axis
Swap Z DP	Toggles vertical trackball motion between Y-axis and Z-axis



To select a button function, repeatedly touch the button's choice field until the desired function is displayed.

Button 1:	<u>Enter</u>
Button 2:	<u>No Assignment</u>
Button 3:	<u>No Assignment</u>
Narrow Footswitch:	<u>No Assignment</u>
Wide Footswitch:	<u>No Assignment</u>

Level

All button responses are either momentary or toggle. Momentary functions are level-based and are active only while the button is pressed and held. Toggle functions are activated when the button is pressed and released, and deactivated when the button is pressed and released again. Configure any of the button responses as momentary (level-based) by checking the button's Level box. Clear the Level box to configure the button response as toggle.

Level: 

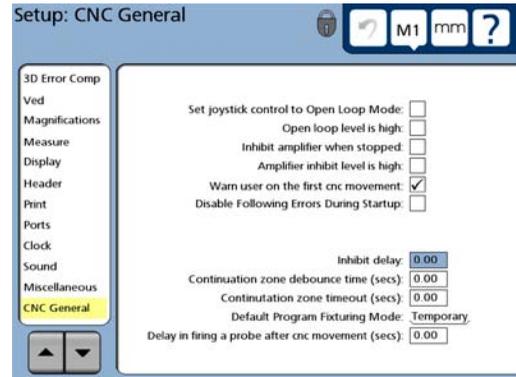
Active high

All button logic is either active high or active low. Configure each button to match the input requirement by checking the Active High box for positive logic, or clearing it for negative logic. This is only relevant for level-based buttons.

Active High: 

Initial CNC setup

The CNC General screen contains fields for configuring CNC amplifier characteristics prior to PID loop tuning.



Open loop mode

The PID and other CNC control parameters found on CNC Setup and Joystick PID screens can be bypassed to run the CNC motor drives in open loop configurations. This allows finer levels of position adjustment and can be useful during the initial setup of CNC systems. Check the Set joystick and trackball control to open loop Mode box to bypass CNC control loops for the joystick.

Set joystick control to Open Loop Mode:



Open loop level

The amplifier open loop line logic is either active high or active low. Configure the open loop control line to match the CNC amplifier input requirement by checking the Open loop level is high box for positive logic, or clearing it for negative logic.

Open loop level is high:



Inhibit amplifier when stopped (steppers)

A CNC move is complete only after it crosses into the target's continuation zone. Upon crossing into the continuation zone, the axis control system stops axis motion. Stepper motor amplifiers can be inhibited until the next CNC move to eliminate the possibility of unwanted axis motion near the target location due to system noise. Check the Inhibit amplifier when stopped box to inhibit stepper drives between CNC moves.

Inhibit amplifier when stopped:



Amplifier inhibit level

The amplifier inhibit level logic is either active high or active low. Check the Amplifier inhibit level is high box if your amplifier requires a high logic level on the inhibit line to prevent operation, clear this box if it requires a low logic level.

Amplifier inhibit level is high:



Warn users on first CNC movements

Users can be warned of first CNC movements as a means of avoiding collisions. Enabling this warning is strongly recommended. To enable the warning, Check the Warn user on the first CNC movement box.

Warn user on the first cnc movement:



Disable following errors during startup

When auto homing is used during startup, the CNC homing sequence moves the stage to read encoder reference marks and determine machine zero. Following errors developed during the homing sequence can be large enough to cause error messages to be displayed under typical operating conditions. However, these messages would have little meaning during the homing sequence and can be disabled as a convenience to the user. Check the Disable following errors during startup box to suppress following error messages during the homing sequence.

Disable Following Errors During Startup:



Inhibit delay

Normally, the CNC amplifier responds immediately to high and low level transitions on its inhibit control line. However, a delay can be applied to motor drive outputs to accommodate special hardware requirements. Enter the inhibit control delay into the Inhibit delay data field in milliseconds.

Inhibit delay:



Continuation zone debounce time

When a CNC move crosses into the target's continuation zone, a debounce time is initiated to eliminate indecision at the continuation zone boundary. The move is not complete until the final position remains inside the continuation zone for the duration of the debounce time. Enter the debounce time into the Continuation debounce time data field in seconds.

Continuation zone debounce time (secs):



Continuation zone timeout

When a CNC move crosses into the target's continuation zone and stops, a timeout is initiated to notify the user if the probe should fail to fire. Enter the continuation zone timeout into the Continuation zone timeout data field in seconds.

Continuation zone timeout (secs):



NOTE

The continuation zone timeout must be longer than the *delay in firing after CNC movement* described later in *Specifying a probe firing delay* on the next page.

Default program fixturing mode

The part fixturing for CNC systems must be specified to insure that program runs will include the correct measurement reference and datum. Three fixturing modes are available:

None

No part fixturing is used, a measurement reference and datum must be created by the user for each program execution.

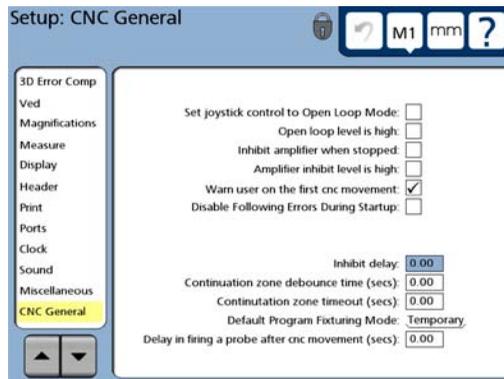
Temporary

Temporary part fixturing is used, a measurement reference and datum must be created for the first part by the user, thereafter the system will perform measurement reference and datum measurements automatically for each program execution.

Permanent

Permanent part fixturing is used; this is a dedicated fixture. The system retains the measurement reference and datum as part of the program, no user interaction is required to create a measurement reference or datum prior to execution.

To specify the desired fixturing mode, repeatedly touch the Default Program Fixturing Mode choice field until the desired mode is shown.



Default Program Fixturing Mode: Temporary



Delay firing a probe after CNC move

When a CNC move crosses into the target's continuation zone, a firing delay insures that the probe fires on a stable target. Enter the probe firing delay into the Delay in firing a probe after CNC movement data field in seconds.

Delay in firing a probe after cnc movement (secs): 0.01

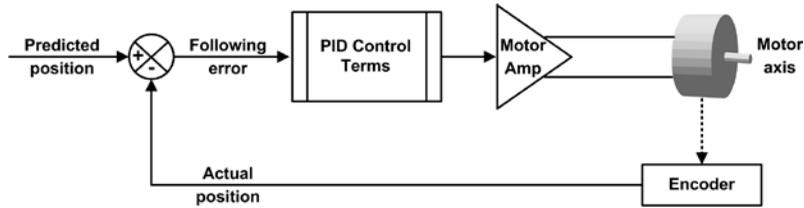


NOTE

The probe firing delay must be shorter than the *continuation zone timeout* described earlier in this section.

CNC PID control loops

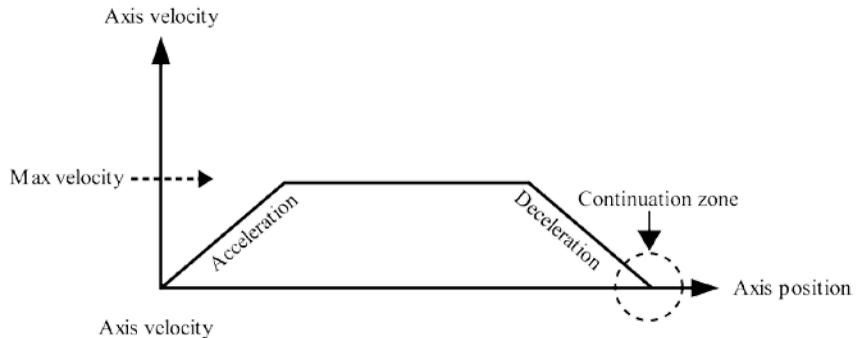
The QC-320 software includes independent PID (**P**roportional **I**ntegral **D**ifferential) loops to control acceleration, velocity and position on each CNC axis. When a new position is requested by a CNC program, joystick or digital positioner, the QC-320 program predicts a series of points along the axes to the requested position. The program then compares the predicted positions to the actual positions measured by the encoder as the axes are moved. The differences between predicted and actual positions (following errors) are processed by PID control terms, amplified and drive the axis motors to minimize the difference. A simplified PID feedback control loop is diagrammed here.



Simplified PID control loop diagram

Axis motion occurs roughly as the trapezoidal velocity outlined and diagrammed below.

- A new position is predicted by the CNC module of the QC-320 program
- A following error is generated by the difference between the predicted and actual positions
 - Following error = Predicted position - Actual position provided by encoder
- The following error is processed by the PID control terms, amplified and used to drive the motor (and encoder) in the direction of the predicted position
- The motor accelerates the axis to a specified maximum velocity at a nearly constant rate
- As the axis position approaches the final predicted position, the motor decelerates the axis at a nearly constant rate
- Axis motion finally stops within a specified radius around the final position (continuation zone) and the following error becomes insignificant



Trapezoidal CNC axis motion

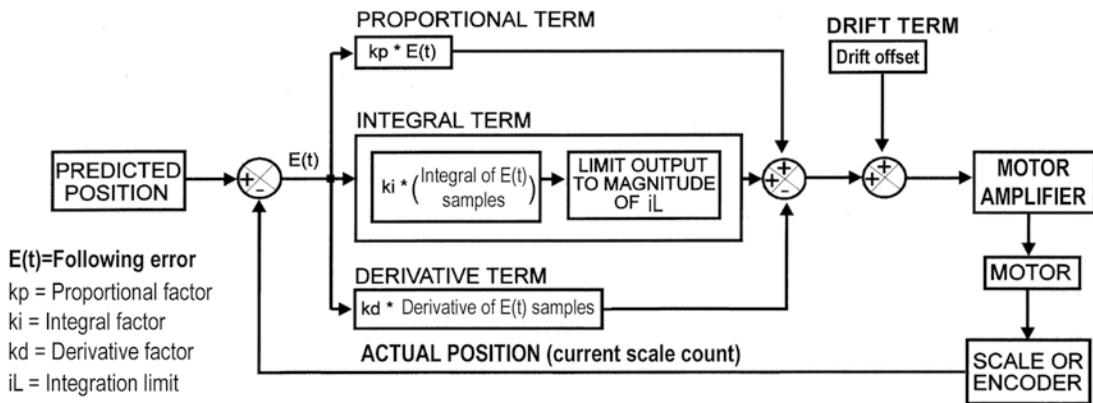
**NOTE**

Once the final target position is reached, no further drive signals are applied to the motors of stepper systems. However, drive signals continue to be applied to the motors of servo systems to hold the final position. This requirement for actively holding a stable position in servo systems contributes to the increased complexity of tuning servo motor systems.

CNC system performance depends on the mechanical, electrical and PID loop characteristics of each axis of motion. The mechanical characteristics of the axes are usually different and include variables such as mass, static and dynamic friction, motor torque, lead screw pitch, system inertia and mechanical backlash. Electrical characteristics include variables such as amplifier gain, amplifier offset, tachometer gain and encoder resolution. The PID loop characteristics of the axes are also usually different and depend on the PID control terms specified during loop tuning.

PID loop performance should only satisfy the actual application requirements of the system. Well designed systems are usually capable of exceeding the application requirements that they are intended to fill. This additional performance margin should not be used unnecessarily. It is included by system designers to insure system stability and as a resource to be used in the future as the equipment or environmental conditions change and the system must be retuned to remain in compliance. Systems that are tuned to provide unnecessarily high levels of performance tend to be less stable, more difficult to tune and require retuning more often.

A detailed diagram of the simplified PID loop shown earlier is presented below. This diagram shows the individual PID control terms of the loop. Descriptions of the individual control terms and more detailed discussions of trade-offs between performance and application requirements are included in subsequent pages.



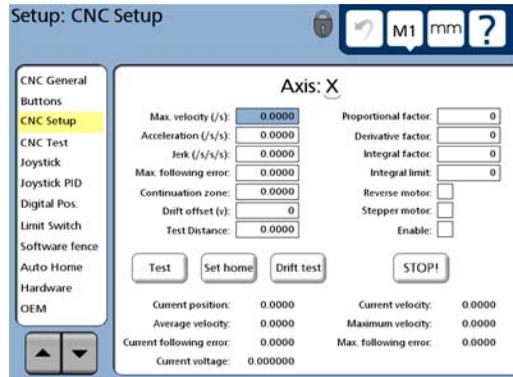
Detailed PID control loop diagram

Discussion of PID control parameters

The motion and positioning performance of each axis are determined by PID control terms and other axis setup parameters contained in the CNC Setup screen.

PID control terms and other axis setup parameters are identical for all axis screens. Since the screens are identical, only the X-axis screen is shown in these pages, but the descriptions of PID control terms apply equally well to all axis screens.

The brief description of the PID control terms provided here. Additional detailed information regarding the interactions and trade-offs between PID control parameters is included later in this chapter.



CAUTION

This discussion is only intended to familiarize you with control parameters used in the PID loop tuning procedure provided later in this chapter. Refer to the PID loop tuning procedure before entering setup data into the CNC Setup screen.

Max velocity

When the QC-320 performs CNC moves, vector velocities can be limited to prevent exceeding the maximum capability of the machine axis. Enter the desired maximum velocity value for an axis into the Max velocity field to satisfy the specific hardware requirements and accommodate physical limitations of each system.

Max. velocity (/s):



Acceleration

When the QC-320 performs CNC moves, vector accelerations can be limited to prevent exceeding the maximum capability of the machine axis. Enter the desired acceleration value for an axis into the Acceleration field to satisfy the specific hardware requirements and accommodate physical limitations of each system.

Acceleration (/s/s):



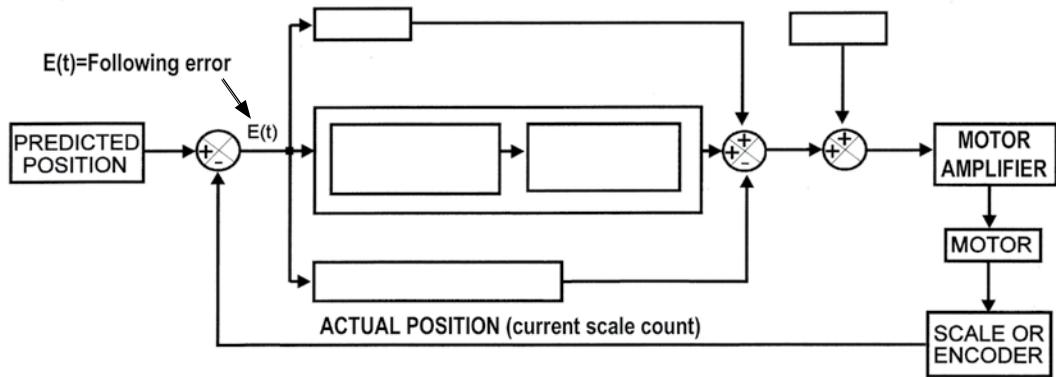
CAUTION

Specifying axis velocities and accelerations that are close to or equal the capability of the machine can cause excessive following errors that halt the machine and result in premature wear.

Max following error

Following errors are the differences between predicted and actual positions and are processed by PID control terms, amplified and used to drive the axis motors. Following errors occur naturally during CNC moves as the machine is instructed to change position. Excessive following errors indicate that the required move is beyond the capability of the system, or that the system has encountered an obstruction.

All CNC systems should include primary safeguards such as slip-clutches and limit switches to prevent stage over-travel and collision damage. The maximum following error term is assigned only as a secondary safeguard that will halt motion if an obstruction is encountered.



Following error = Predicted position - actual position

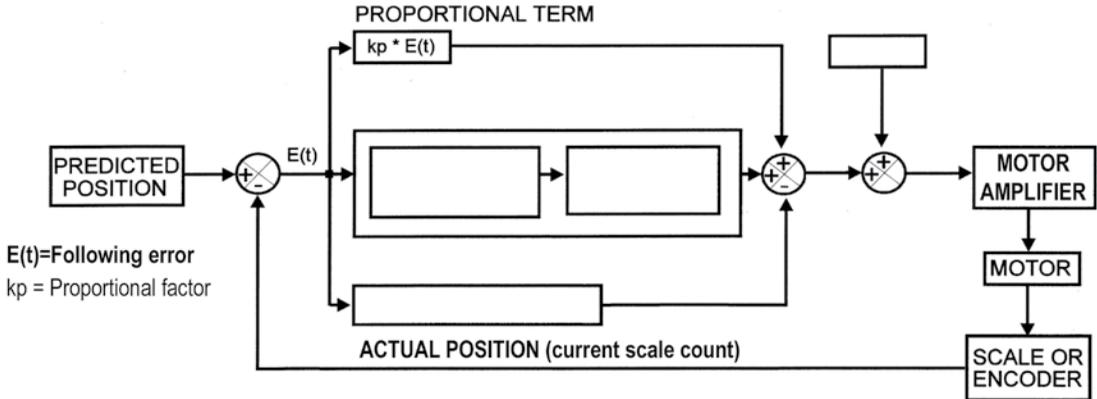
The assignment of a maximum following error value is an empirical process and depends on the physical system characteristics. Maximum following errors are displayed at the bottom of the CNC Setup screen during CNC moves. Following errors will be shown in the Max following error field during PID loop tuning and testing. The Max following error assigned in the Max following error field should be about twice the maximum shown during test, and can be allowed to reach high levels without degrading the performance of systems. Enter the desired maximum following error into the Max following error field.

Max. following error: 0.0000
 Max. following error:



Proportional factor

The Proportional factor is the linear loop gain term, and amplifies the following error to drive axis motors. As the Proportional factor term is increased, position accuracy and stability is improved. However, if the Proportional factor is increased beyond the system’s ability to provide mechanical damping, axis oscillations can occur.



In stepper motor systems and many servo motor systems, the proportional factor can be increased incrementally until the desired position accuracy is achieved. However, in systems that include high-mass stages, or stages with significant static friction, the proportional factor might need to be increased into unstable gain regions to achieve accurate positioning. In these cases, a derivative factor term might be required to eliminate axis oscillation and an integral term might be required to complete moves to the target position. Enter the required proportional factor into the Proportional factor field.

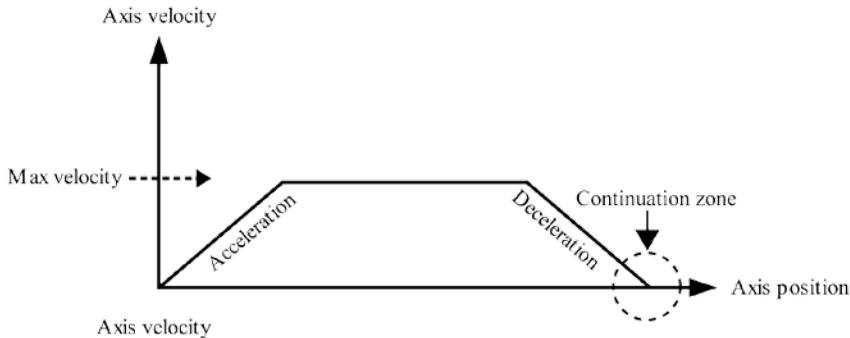
Proportional factor:



Continuation zone

Stage motion is halted and the probe is fired a short time (continuation zone debounce time) after the probe moves into the continuation zone. The continuation zone is a diameter specified around the target. The minimum should be 5 scale counts. For example, a 0.001 um resolution axis should have a minimum continuation zone of 0.005 um. The zone can be larger. Enter the desired continuation zone radius into the continuation zone field.

Continuation zone:

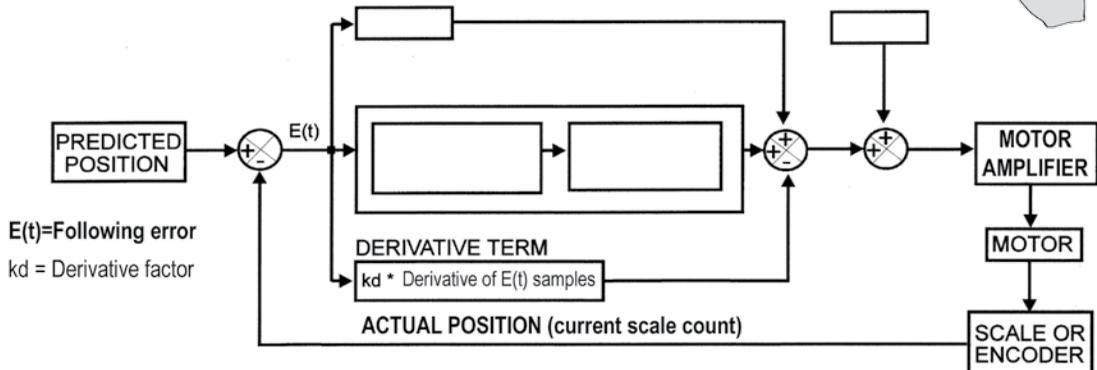


Derivative factor

The derivative gain term is used in *servo systems* and reduces PID loop gain for rapidly changing following errors caused by under-damped motion or axis oscillation. This gain reduction for rapidly changing signals increases system damping and eliminates oscillations without decreasing loop gain for the smoother trapezoidal portions of the CNC move.

High levels of derivative can cause loop instability, so the derivative term should be incrementally increased. Adding derivative sometimes requires a process of alternately adjusting proportional and derivative gains until the best balance of accurate positioning and smooth motion is achieved. When this balance is achieved, but the final position has still not reached the target, the integral term is also required to complete the CNC move. Enter the derivative value into the derivative factor field.

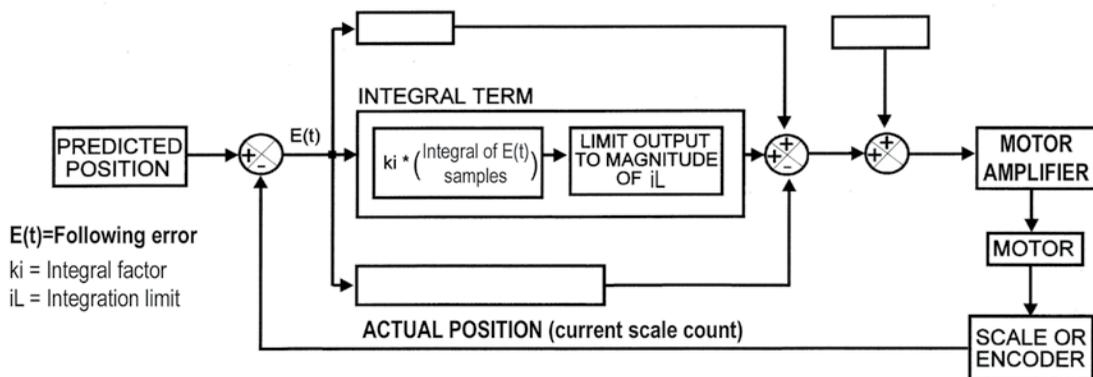
Derivative factor:



Integral PID control term

In some *servo systems*, as an axis approaches its final predicted position, the following error falls to such small values that the proportional gain term alone is inadequate to drive the axis the final small distance to its target. This is usually due to high-mass stages, or stages with significant static friction. The integral PID control term is added to increase PID loop gain for very small following errors. This additional gain is achieved by summing a series of small following error samples at the end of the CNC move to create a total motor drive capable of moving the axis into the continuation zone.

The integral term consists of the Integral factor and the Integral limit. The integral factor is a multiplier that increases the value of small following error samples, and the Integral limit defines the maximum value of integral term that will be used.



The size of the integral factor determines how quickly the motor will be driven by a series of small following error samples. Large integral factors quickly add up to significant motor drive signals. This has the advantage of moving the last small distance into the continuation zone quickly, but has the disadvantage that too much drive might be created, causing the axis to move through the continuation zone. If the axis moves through the continuation zone, it must be driven back into the continuation zone again from the other direction. Very large integral factors can lead to axis oscillations around the continuation zone at the end of the CNC move. Enter the required integral factor into the integral factor field.

Integral factor:



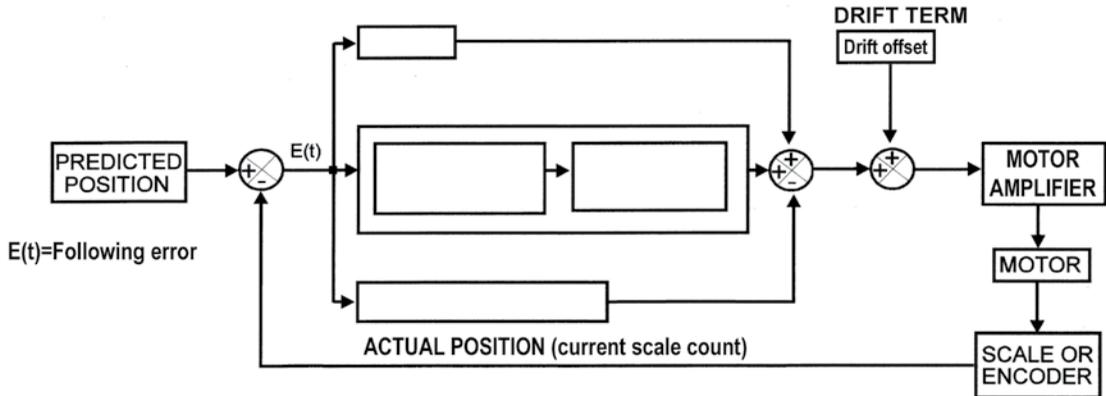
The integral limit prevents unstable PID loop behavior by limiting the overall integral PID control term to a specified maximum value. Limiting the total drive of the integral term has the advantage of allowing relatively large integral factors that produce rapid moves into the continuation zone while preventing the excess drive that could drive the axis through the continuation zone and lead to axis oscillations. Enter the integral limit into the Integral Limit field.

Integral limit:



Drift offset

Motor amplifier offset is the positive or negative voltage that can appear at a *servo amplifier* output when the amplifier input is zero. Since this offset appears inside the PID control loop, it is amplified and can prevent the axis from reaching its final target. The drift offset parameter compensates for amplifier offset by inserting another offset of the opposite polarity into the loop.



Drift offsets are displayed at the bottom of the CNC Setup screen during CNC loop tuning and testing in the Current voltage field. Enter this value into the Drift offset field. When the offset is very high, the separate Drift test and amplifier adjustment described later in this chapter might be necessary.

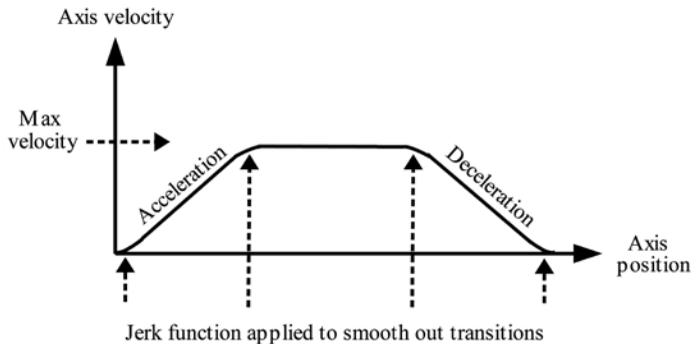
Current voltage: 0.000000

Drift offset (v):



Jerk factor

The jerk factor smooths abrupt axis velocity transitions by preventing excess acceleration. Adding jerk can extend the life of motors and mechanical axis components. The amount of smoothing is inversely proportional to the jerk factor value; large values of jerk provide small amounts of transition smoothing. A value of 0 disables jerk. Small amounts of smoothing have little or no impact on PID loop performance and should be included before tuning the PID loop as a means of reducing system wear. An initial value of 7500 is recommended. Systems with large axis masses might benefit from more smoothing (lower Jerk factor values). Enter the jerk



factor value into the Jerk field.

Jerk (/s/s/s):



Reversing motor direction

The drive direction of axis motors can be reversed to accommodate reversed motor wiring or amplifier connections. The Reverse motor box is checked if it is necessary to reverse motor direction at the time of installation. Please refer to [Chapter 2: Setting CNC Motor Direction](#) for more details regarding motor reversals.

Reverse motor:



Stepper and servo motor selection

Each axis can be driven by a servo motor or a stepper motor. The stepper motor box is checked if the axis is driven by a stepper motor.

Stepper motor:



Enabling or disabling axis motion

Enable or disable motion on the displayed axis by checking or clearing the Enable box.

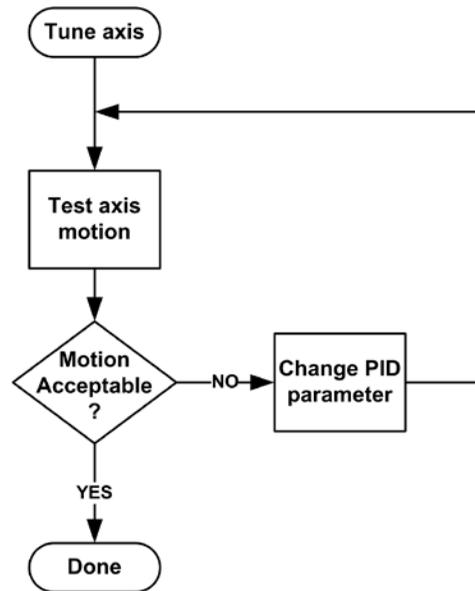
Enable:



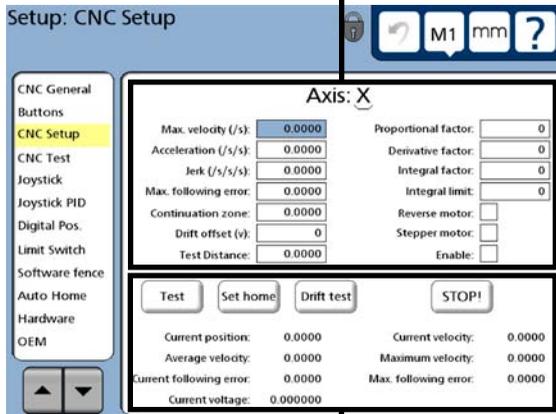
PID loop tuning

PID loop tuning is an iterative process of adjusting a PID control parameter and testing the resulting axis motion. Some systems, such as low-mass, low-friction stepper motor systems, are relatively easy to tune and require only a few iterations. Other systems, such as large servo motor systems, require many iterations that include the adjustment of nearly every PID parameter. In either case, changes should be made to only one parameter at a time, in relatively small amounts, and the resulting change in axis motion should be observed carefully.

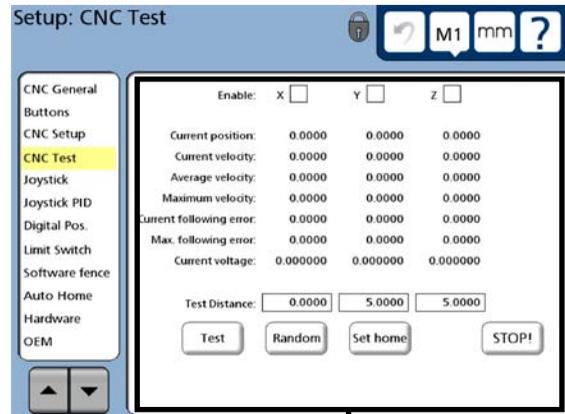
When each axis has been tuned and tested separately, multiple axes can be tested simultaneously and final adjustments made to the control parameters of individual axes if required. Individual axes are adjusted and tested using the CNC Setup screen. Multiple axes are tested using the CNC test screen.



PID control parameters for a single axis



Test functions for a single axis



Test functions for multiple axes

CNC test functions for a single axis

Individual axes are adjusted and tested using the CNC Setup screen before vector moves are attempted with multiple axes. Test functions include:

Test distance

An axis test consists of the CNC move on the current axis. The test distance is entered into the test distance field in millimeters or inches before starting the test.



Set home



Touch the Set home button to set the current position of the stage to home (zero). Test moves are made from this home position to the specified test distance.

Test



Touch the Test button to initiate a test move. Repeatedly touching the Test button alternately moves the stage from home to the Test distance and from the Test distance back to home. Observe the axis motion and position on the CNC Setup screen.

Current position:	0.0000	Current velocity:	0.0000
Average velocity:	0.0000	Maximum velocity:	0.0000
Current following error:	0.0000	Max. following error:	0.0000
Current voltage:	0.000000		

Observe the axis motion and position



CAUTION

Axes can move very quickly. To avoid damage to the equipment, when performing a test, be prepared to touch the *Stop button*. If an axis begins to run away, touch the *Stop button* immediately.

Stop



Touch the Stop button to halt axis motion.



CAUTION

The Stop button is not intended as a substitute for hard-contact emergency stop switches. Touching the Stop button is a convenient way to halt axis motion, but do not rely completely on this software interface - always be prepared to use the emergency stop button to halt motion.

Drift test

A rectangular button with rounded corners, a grey gradient, and the text "Drift test" in a sans-serif font.

Servo amplifier systems often require adjustment to minimize or eliminate amplifier offset output voltages that can lead to offset (unbalanced) stage positioning around target locations. The drift test facilitates amplifier offset adjustment by applying zero volts to the amplifier input. The test is performed as follows:

- Touch the Drift test button
- Adjust the amplifier offset potentiometer to achieve a *Current voltage* reading as close as possible to zero

Current voltage: 0.000000



NOTE

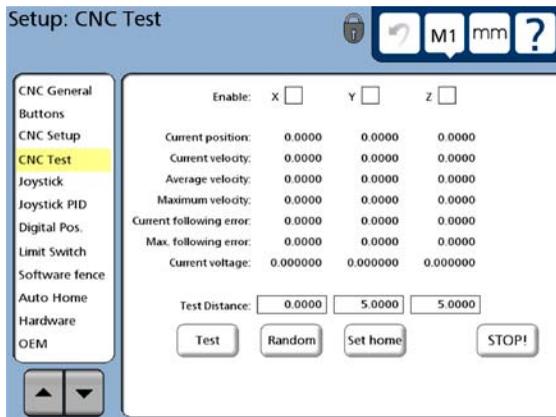
Output balancing is part of the PID loop tuning procedure provided later in this chapter. Drift testing and offset adjustment is necessary only when the servo amplifier output offset is so high that the loop tuning procedure is unable to achieve adequate output balancing and target positioning.

CNC test functions for multiple axes

Multiple axes are tested together in vector moves after the individual axes have been tuned. Multiple axes are tested using the CNC test screen. Test functions include:

Enable

Any combination of axes can be tested together. Check the Enable boxes of the axes that you want to test. Enable: X Y Z



Test distance

A multiple axis test consists of the CNC move on all axes simultaneously. The test distances are entered into the test distance fields before starting the test.

Test Distance: 20.0000 10.0000 10.0000



Set home



Touch the Set home button to set the current position of the stage to home (zero) on all enabled axes. Vector test moves are made from this home position to the test distances specified for the enabled axes.

Current position:	0.0000	0.0000	0.0000
Current velocity:	0.0000	0.0000	0.0000
Average velocity:	0.0000	0.0000	0.0000
Maximum velocity:	0.0000	0.0000	0.0000
Current following error:	0.0000	0.0000	0.0000
Max. following error:	0.0000	0.0000	0.0000
Current voltage:	0.000000	0.000000	0.000000

Observe combined axis motion and position

Test



Touch the Test button to initiate a test move. Repeatedly touching the Test button alternately moves the stage from home to the test distance and from the test distance back to home. Observe the combined-axis motion and position using performance indicators on the CNC Test screen. If the combined axis motion includes oscillation or is unsatisfactory in some way, return to the CNC setup screen and readjust one or more single axis until the combined-axis motion is acceptable.



CAUTION

Axes can move very quickly. To avoid damage to the equipment, when performing a test, be prepared to touch the Stop button. If the CNC motion begins to run away, touch the Stop button immediately.

Stop



Touch the Stop button to halt axis motion.



CAUTION

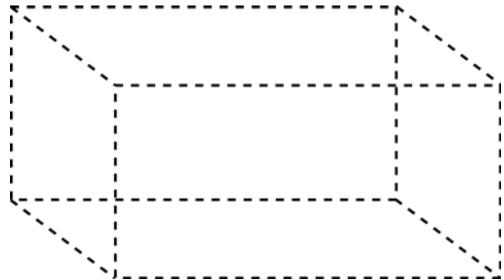
The Stop button is not intended as a substitute for hard-contact emergency stop switches. Touching the Stop button is a convenient way to halt axis motion, but do not rely completely on this software interface - always be prepared to use the emergency stop button to halt motion.

Random

Touch the Random button to initiate a final extended series of vector moves involving all axes. The stage will be moved random distances in random vector directions within the test volume defined by the Test distance values.

In this example, combined X, Y and Z axis vector moves will be made randomly inside a 20mm X 10mm X 10mm rectangular space. Moves will continue until the Stop button is touched or the system detects a following error higher than the Max following error specified in the CNC Setup screen.

Test Distance:



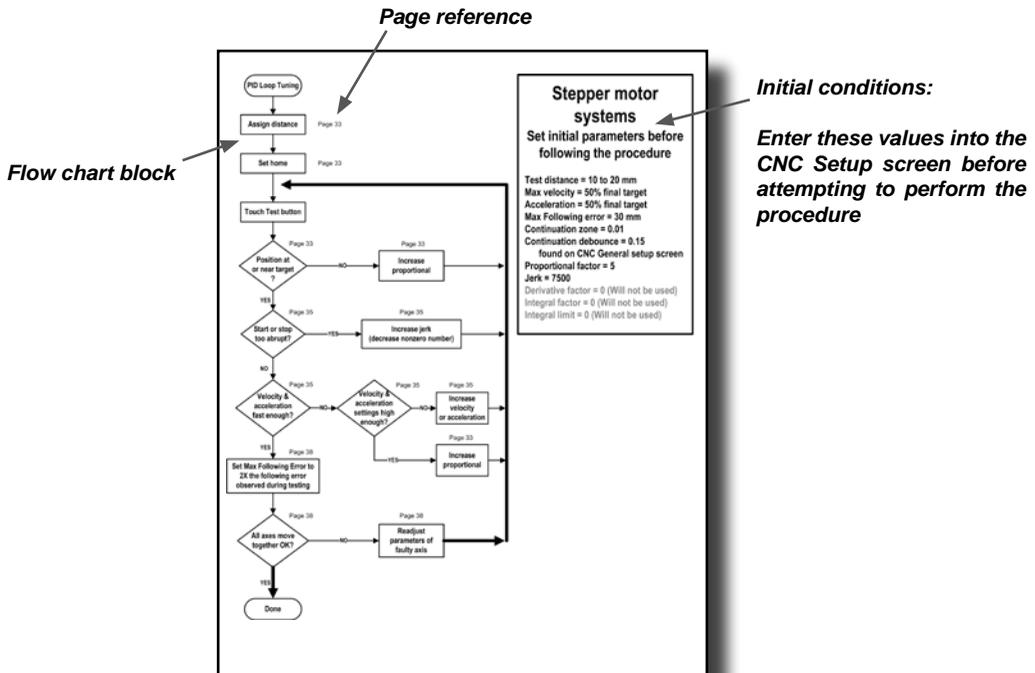
Random test volume

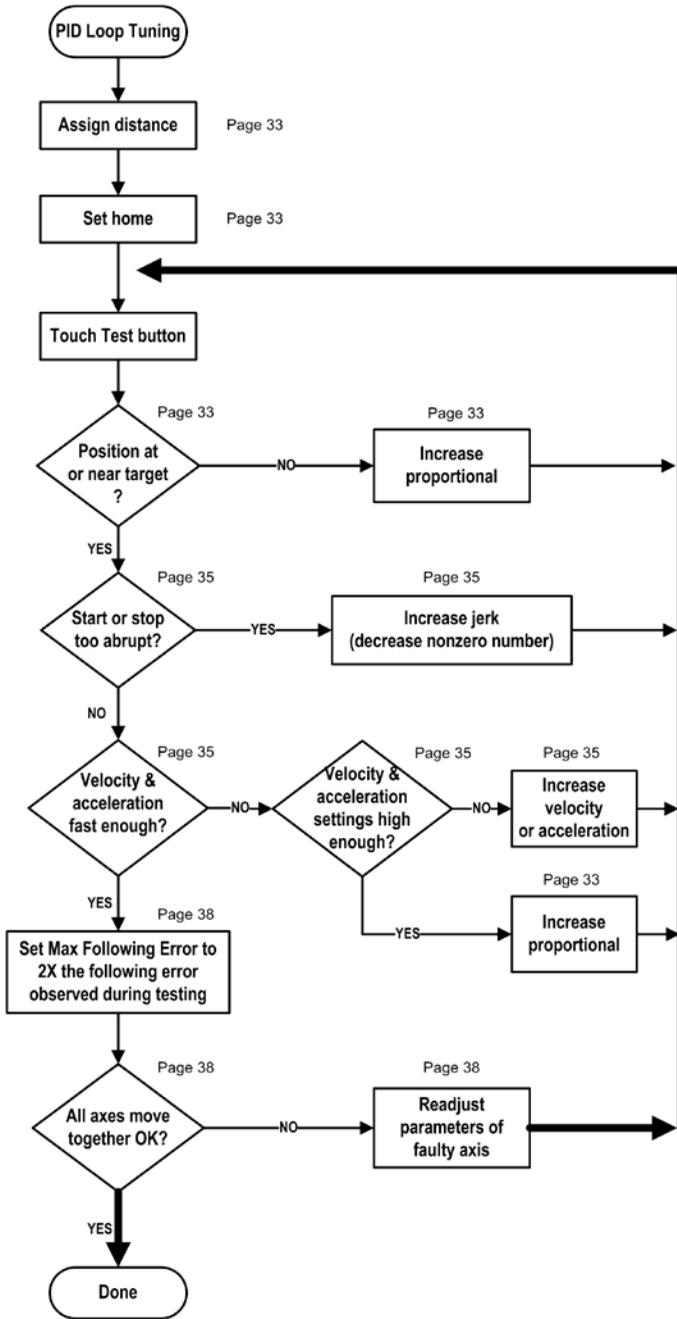
PID Loop tuning procedures

Independent PID Loops control the motion and position characteristics of each CNC axis. The PID Loop characteristics are often different for each machine axis and even more different for each CNC machine. Also, application requirements and operator preferences are generally different for each system. For these reasons, no detailed procedure can reliably describe an exact tuning process for all systems. However, enough is common to many systems to describe a generic process that will help users get started. The procedure is provided as two flow diagrams of iterative PID value adjustment and performance evaluation. One diagram pertains to stepper motor systems, and the other to servo motor systems.

PID Loop tuning procedure diagrams

The diagrams illustrate the PID Loop tuning process for stepper and servo motor systems and show the decisions required to make performance trade-offs. Each flow chart block is described in detail in the remaining pages of this chapter. References to these descriptions are shown on the diagrams near each block. The required initial setup parameters are shown in the upper-right corner of each diagram and must be entered into the CNC Setup screen before following a procedure.



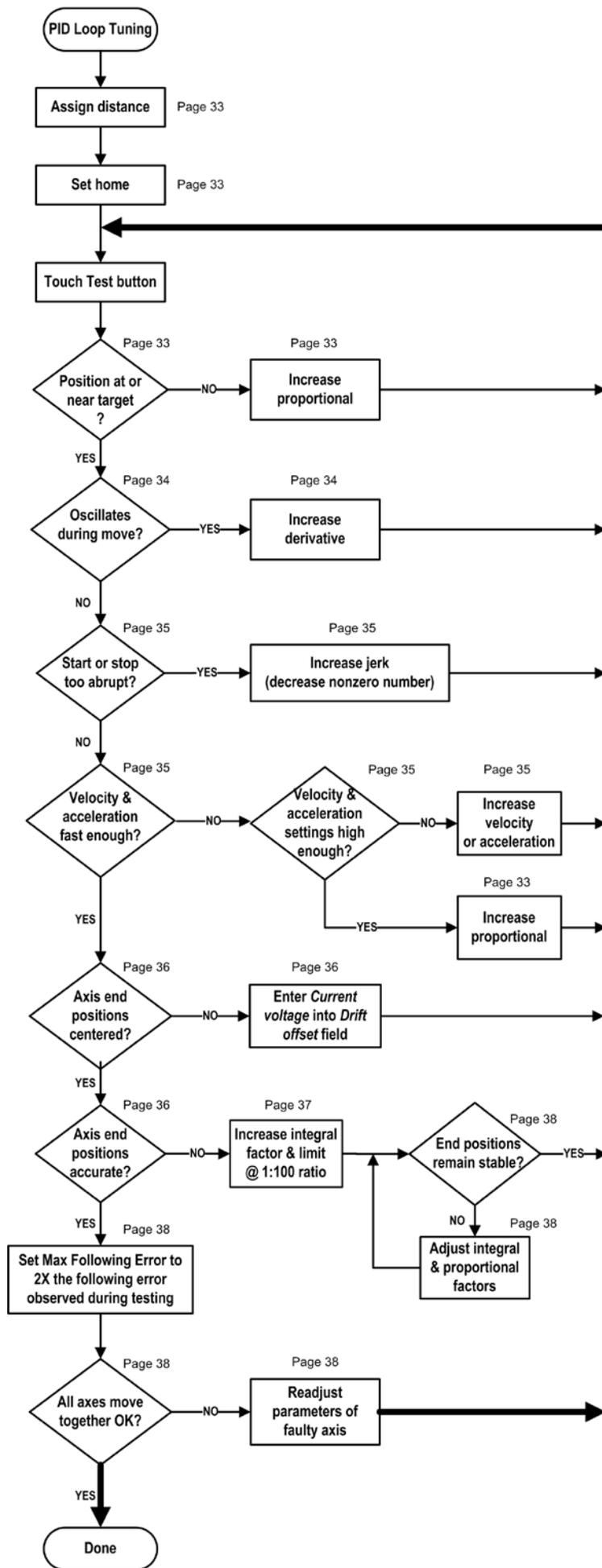


Stepper motor systems

Set initial parameters before following the procedure

Test distance = 10 to 20 mm
 Max velocity = 50% final target
 Acceleration = 50% final target
 Max Following error = 30 mm
 Continuation zone = 0.01
 Continuation debounce = 0.15
 found on CNC General setup screen
 Proportional factor = 5
 Jerk = 7500
 Derivative factor = 0 (Will not be used)
 Integral factor = 0 (Will not be used)
 Integral limit = 0 (Will not be used)

PID Loop Tuning Process for Stepper Motor Systems



Servo motor systems
 Set initial parameters before following the procedure

Test distance = 10 to 20 mm
 Max velocity = 50% final target
 Acceleration = 50% final target
 Max Following error = 30 mm
 Continuation zone = 0.01
 Proportional factor = 30
 Derivative factor = 0
 Jerk = 7500
 Integral factor = 0
 Integral limit = 0

Tuning flow chart block descriptions

The PID loop tuning flow chart blocks are explained in the following pages. Since the flow chart procedure is generic to address a wide variety of systems, instructions are intentionally general, and do not recommend exact values for any PID control parameter.

Assign distance

A Test distance must be assigned before conducting a CNC test. This is accomplished by entering a value into the Test distance field. Small distances (10 to 20 mm) are recommended at first to limit axis motion during the early stages of loop tuning. The test distance can be increased when the loop tuning is nearing completion and the axis is behaving satisfactorily.

Set home

A Test reference location must be established before conducting the first CNC test. This is accomplished by touching the Set home button. The first test move will travel from the home position to the test distance. Subsequent tests will alternately move between the test distance and home.

Position at (or near) final target?

It is unlikely that the initially low gain of the loop will allow much if any axis motion. As the proportional gain is increased, the axis will move more decisively, and will more closely approach the desired target of the CNC test move (home or test distance). In stepper systems, increasing the continuation zone debounce time can help. In servo systems, decreasing the continuation zone can help.

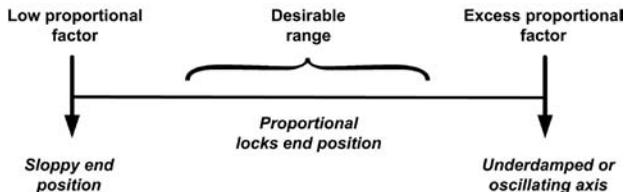
Increase proportional

Since the proportional factor is the primary loop gain used to control axis position, increasing the proportional factor will improve target positioning. However, excess loop gain can result in reduced loop stability which can cause vibration due to under damped axis motion or axis oscillation. Sloppy end-positioning and axis oscillation represent opposite ends of the proportional factor adjustment range.

The initially low proportional factor value is intended to start the loop tuning process at the low gain end of the adjustment range.

Increase the proportional factor in small increments to avoid excess gain and then retest the CNC move. Continue increasing the pro-

portional factor and retesting until accurate end-positioning is observed in the Current position field.



Oscillates during move?

CNC moves should be smooth in mechanically sound systems. Vibration, roughness or oscillation during a move is an indication of PID loop instability.



NOTE

Confirm that your system components can move smoothly and are free of mechanical problems before attempting to tune PID loops.

Axis vibration can be observed visually or heard as a buzzing or whining sound. However, low levels of vibration can often not be detected without lightly touching an axis component while the axis completes a CNC test move.

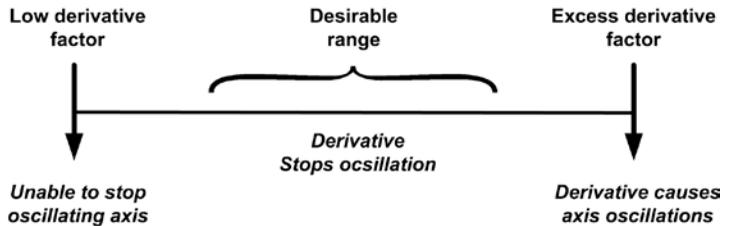


WARNING

Be extremely careful while touching an axis in motion. Stay clear of the axis path. Do not attempt to touch an axis in motion at all if it represents any risk of personal injury.

Increase derivative

The derivative factor reduces loop gain for the rapidly changing following error signals caused by under-damped axis motion or by axis oscillation. If axis vibration is observed during a CNC test move, increase the derivative factor a small amount and perform a new CNC test move. Continue increasing the derivative factor in small increments and retesting a CNC motion until the vibration disappears. A small number of systems might oscillate when adding integral to a loop that already contains derivative. In these cases it might be necessary to reduce the derivative factor to stabilize the axis, or to find a different mixture of proportional, derivative and integral terms altogether.



While small to moderate amounts of derivative can eliminate vibration due to PID loop instability, excess derivative can cause oscillation. Be careful to increase the derivative factor in small increments.

Start or stop too abrupt?

The start and stop acceleration and deceleration of CNC test moves should be decisive, but should not cause system vibration.

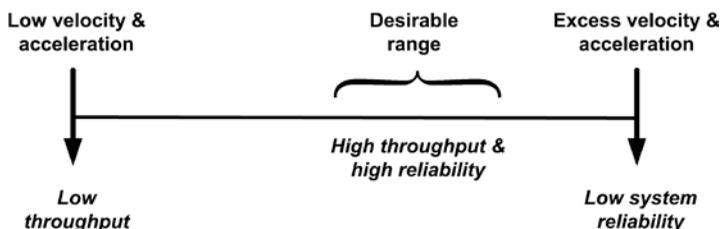
Increase Jerk (decrease nonzero number)

The jerk factor smooths abrupt axis start and stop transitions, by preventing excess acceleration. Adding jerk can extend the life of system components. The amount of smoothing is inversely proportional to the jerk factor value; large values of jerk provide small amounts of transition smoothing. Decrease the Jerk value in small increments to eliminate start or stop vibration. Low Jerk values can significantly degrade performance. A value of 0 disables jerk.

Velocity & acceleration fast enough?

Axis velocity and acceleration determine system throughput. The determination of acceptable velocity and acceleration is therefore subjective and also dependent on a variety of system components. Maximizing throughput should not be done at the expense of system reliability.

High throughput and system reliability represent the two ends of the velocity/acceleration range.



Increase velocity or acceleration

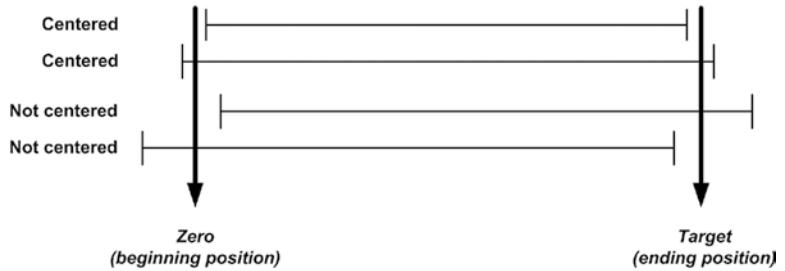
Some general guidelines for adjusting velocity or acceleration are listed below.

- Set a CNC test distance adequate to observe acceleration, velocity over a reasonable distance and then deceleration to the final target position.
- Set acceleration high enough to achieve the desired velocity quickly.
- Increase velocity and acceleration in small increments to observe the impact of the adjustments on PID loop performance.
- Avoid setting velocity and acceleration at the operational limits of the system. Leave some capability in reserve.

Following errors are generated when an axis is unable to keep up with the predicted axis path calculated by the QC-320. It is possible that following error warnings will be generated on some CNC test moves until the proportional gain is increased. Following error warnings are also more likely to be generated at high axis accelerations and velocities.

Axis end-positions centered?

When the axis end-positions are centered, repeated CNC axis tests will begin at or near zero and end at or near the target position. This range of motion will be centered as shown here.



Enter Current Voltage into Drift Offset field

Drift offset values are used to compensate for motor amplifier offset voltages in servo motor systems. Changing the Drift offset value shifts the zero and target end-positions of the entire range of motion. Centering the range of motion can relax the requirement for large integral terms and results in more accurate positioning. If the zero and target positions must be shifted to center the range of axis motion, begin by entering value shown by the Current voltage field into the Drift offset field, then conduct more test moves and increase or decrease the Drift offset value as necessary.



NOTE

Drift offset adjustments only apply to servo motor systems.

Axis end-positions accurate?

As an axis approaches its final target position, the following error drops to very small values. In some servo systems the frictional forces opposing axis motion cannot be overcome by proportional gain alone and the final axis position falls short of the target position. In these cases, some integral should be added to servo systems to achieve acceptable end positioning. If end positioning is a problem in stepper systems, increasing continuation debounce time can help.

User perception is a common reason for tuning systems to achieve levels of accuracy down to tenths or hundredths of Microns. Perceived system goodness is often based on position accuracy that is achievable but unnecessary for the applications they are intended to fill. The costs of ultra-high precision positioning for systems with high frictional forces are increased complexity and the requirement for more frequent PID loop retuning. Adding the integral term to PID loop control provides the additional gain for the small following errors required for precise positioning, but also has the potential to react with existing proportional and derivative terms to produce axis instability and oscillation. In these cases, it is likely that the entire tuning process will need to be repeated at least a few times until an acceptable balance of PID control terms is found. Ultimately, the decision regarding the perceived or actual need for very high end-position accuracy should be considered when applying integral.

Increase integral factor and limit

Often in servo systems, as an axis approaches its final target position, the following error falls to such small values that the proportional gain term alone is inadequate to drive the axis the final small distance to its target. This is usually due to frictional forces opposing motion on the axis. The integral PID control term can be added in these cases to increase PID loop gain for very small following errors. This additional drive is achieved by summing a series of small following error samples at the end of the CNC move to create a total motor drive capable of moving the axis to its final target position. The integral term consists of the integral factor and the integral limit. The integral factor is a multiplier that amplifies each of the following error samples, and the integral limit defines the maximum level of the sum of all amplified samples used to drive the motor.

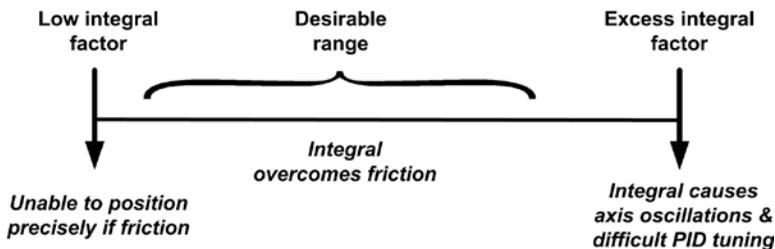


NOTE

Integral is used only in servo motor systems.

Integral factor

The size of the integral factor determines how quickly the motor will be driven by a series of small following error samples. Large integral factors quickly add up to significant motor drive signals. This has the advantage of moving the last small distance to the final target quickly, but has the disadvantage that too much drive might cause the axis to move through the target position. If the axis moves through the target, it must be driven back to the target again from the other direction. Very large integral factors can lead to axis oscillations around the target position. Integral factors are typically 1% to 10% of Integral limits. This ratio depends on the static and dynamic coefficients of friction on the axis and can vary greatly. Begin by entering a value of 1.



Integral limit

The integral limit prevents unstable PID loop behavior by limiting the overall integral control term to a specified maximum value. Limiting the total drive of the integral term has the advantage of allowing relatively large integral factors that produce rapid moves to the final target position while preventing excess drive that could lead to oscillations around the target.

End positions remain stable?

Integral factors can quickly add up to significant motor drive signals. These signals move the last small distance to the final target quickly, but might create too much axis motion, causing the axis to move through the target position. If the axis moves through the target, it must be driven back to the target again from the other direction, resulting in small axis oscillations around the target position. These oscillations can be observed in the Current position field as position instability.

Adjust integral and proportional factors

The end position instability described above can usually be eliminated by reducing the integral factor, and then sometimes increasing the proportional term to stabilize the axis position at the target. If this adjustment is not sufficient to reach the target and stabilize the end position, then it will be necessary to find a new mixture of proportional, derivative and integral terms, to relax the velocity or increase the continuation zone debounce time.

Set Max Following Error to 2X the amount observed during testing

CNC systems should include primary safeguards such as slip-clutches and limit switches to prevent stage over-travel and collision damage. The maximum following error term is assigned only as an secondary safeguard that will halt motion if an obstruction is encountered.

Following errors are shown in the Max following error field during CNC loop tuning and test. The Max following error assigned in the Max following error field should be about twice the maximum amount shown during test.

All axes moved together OK?

When the axes are tuned and tested individually, the combination of all axes must be tested simultaneously to ensure that combined axis CNC performance is satisfactory. This test is performed on the CNC Test screen.

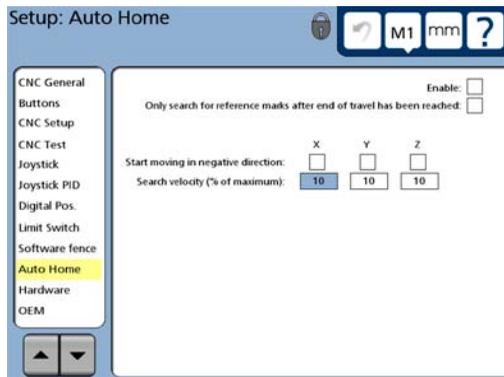
Readjust faulty axis

If combined axis vibration is observed, identify which axis is at fault, retune that axis, and retest the combined axis CNC movement again. If the problem persists, de-tune an axis (or axes) slightly and test again. Continue this process until the combined movement of all axes is satisfactory.

Auto home setup

When encoders are used that include reference marks, or when limit switches are used in place of encoder reference marks, the location of machine zero can automatically be found by the system when the QC-320 program is launched.

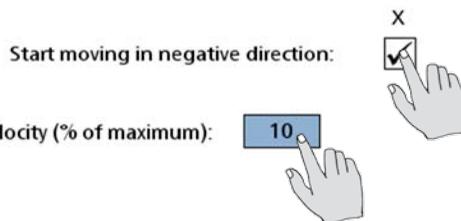
The Auto home screen provides fields for configuring CNC auto homing direction and search velocity for each axis.



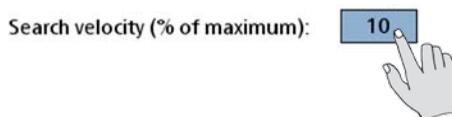
Configuring auto home

The process of configuring auto homing parameters is identical for all axes. To configure an axis for auto homing:

1 Check or clear the Start moving in negative direction box to specify the initial CNC search direction for the desired axes.



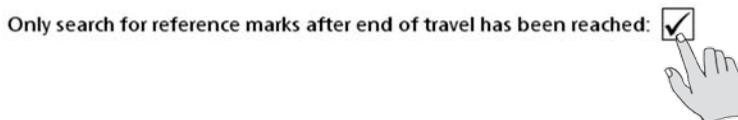
2 Enter the desired search velocity as a percentage of the maximum velocity directly into the desired Search velocity data field.



Only search for reference marks after the end of travel

Encoders with multiple reference marks (other than C-scales) must be driven to the end of travel prior to searching for the unique mark that will repeatedly be used to define machine zero.

1 To specify encoders with multiple reference marks, check the Only search for reference marks... box.



Enabling/disabling auto homing

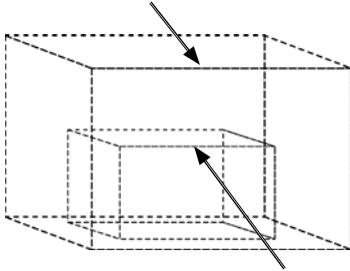
1 Check or clear the Enable box to enable or disable auto homing.



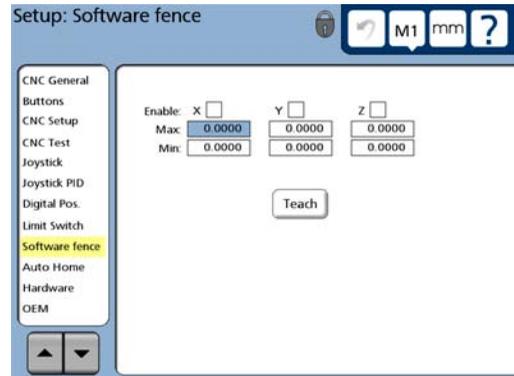
Software fence setup

The software fence screen provides fields for defining and enabling a user-defined area or volume range of CNC motion.

Machine CNC range of motion



Software fence CNC range of motion



Defining a software fence

A software fence is defined using the Teach function.



NOTE

A repeatable machine zero must be established prior to defining a machine or user software fence.

To define a software fence using the Teach function:

1 Click the Teach button and follow the instructions displayed on the screen. When the fence is defined, Min and Max locations will be displayed for each axis.



Max:	675.000	500.000	350.000
Min:	25.0000	15.0000	10.0000

Enabling or disabling the software fence

To enable or disable the software fence:

1 Check the enable boxes to enable, or clear the enable boxes to disable the software fence.

Enable: X

Y

Z



Probe path setup for optical edge detection systems

CNC probing parameters are specified in the Probe path screen to control CNC probing and non-probing velocities as well as data point approach and search distances during program execution.

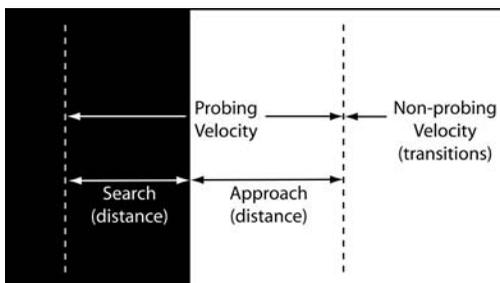
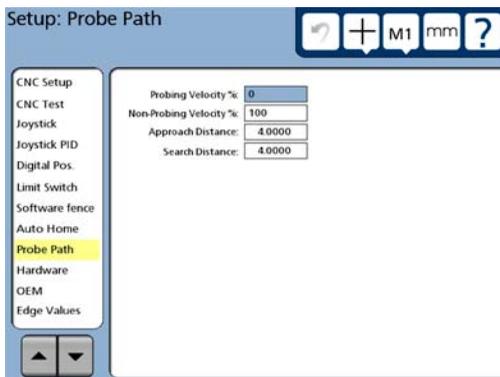
Probing and non-probing velocities

Transitions from one target to the next are made at relatively high non-probing velocities. When the approach distance from the new edge is reached, the system velocity is reduced to the slower probing velocity. If the edge is not recognized at the anticipated point, the system continues searching at the probing velocity until the end of the specified search distance is reached. If no edge is recognized within the approach and search distances, an error message is displayed.



NOTE

In general, the best probing accuracy is obtained at lower probing velocities.



To specify probing and non-probing velocities:

1 Select the Probing Velocity % field and enter the probing velocity as a percentage of the maximum CNC velocity.

Probing Velocity %: 5

2 Select the Non-probing Velocity % field and enter the non-probing velocity as a percentage of the maximum CNC velocity.

Non-Probing Velocity %: 75

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