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## Introduction:

For maintaining of the accuracy of contours in high speed machining, each axis must work with *ZERO Following Error*. Otherwise higher speeds create higher following errors which for example will decrease the radius of small circles. It is possible to have Zero Following Error with SERCOS system and with FFGAIN = 100% and ACFGAIN = YES and applying DERGAIN to compensate the effect of ACCTIME.

Usually Router machines are not rigid enough to have Zero Following Error with low ACC/DEC of axes and obviously large ACC/DEC values are not acceptable in JOG mode. In a non-rigid machine having Zero Following Error with small ACC/DEC may create jerky movement.

G51 (Look-ahead) will work very smooth in Zero Following Error mode. Applying second set of gains which create Zero Following Error only in EXE mode will allow machine to work smooth and precise. For having smooth movement, machine may need higher ACC/DEC time which can be applied by using second set of gains. Large ACC/DEC time may increase the Cycle Time of the program's execution. It is possible to measure it and compare it with lower ACC/DEC.

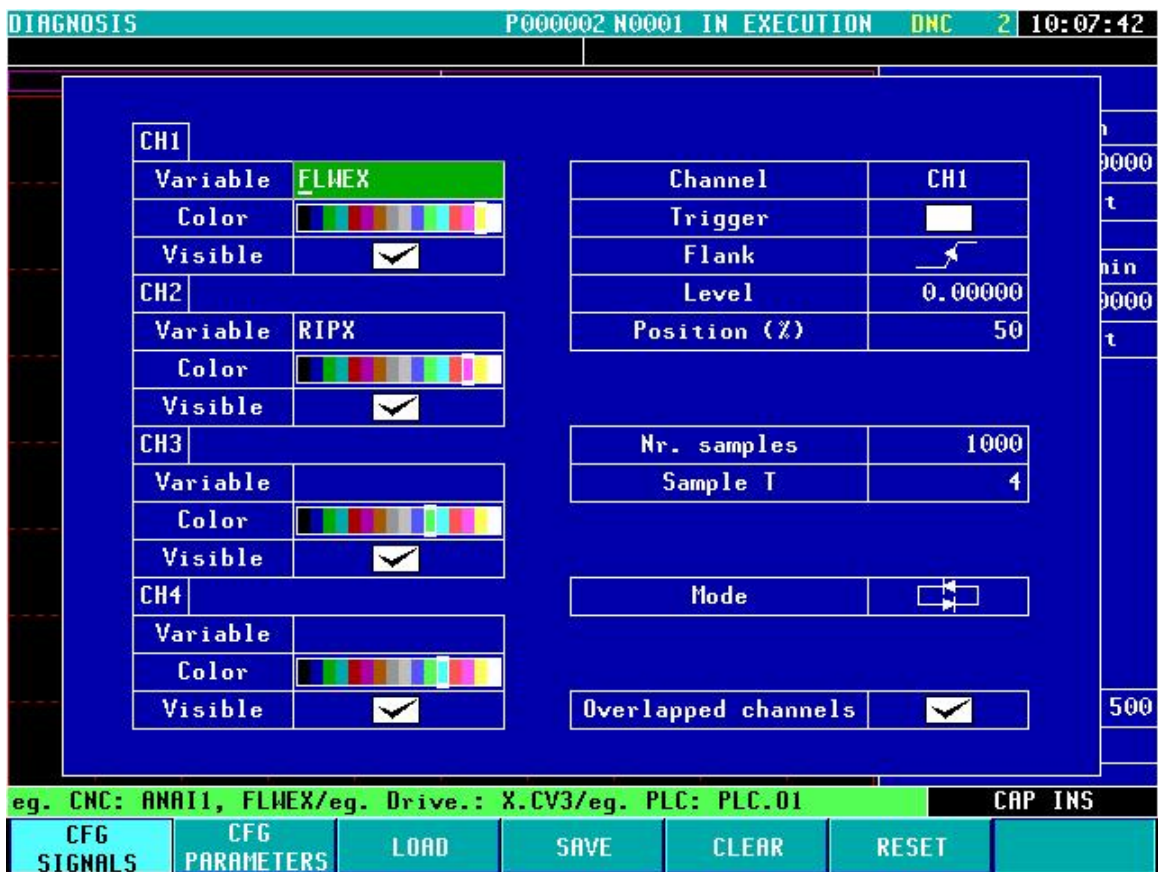
## Using Oscilloscope:

Fagor Oscilloscope is a very powerful tool to adjust the axis behavior. It can be accessed in ISO mode. Following keys direct you to go to oscilloscope menu:

MAIN MENU --- F7(+) --- F5(DIAGNOSIS) --- F4(ADJUSTMENT) --- F2(OSCILLOSCOPE)

Oscilloscope can be accessed even during execution of a program and it can change the axes parameters when they move. So it is possible to adjust the behavior of the axes during movement.

In following screen it is possible to define signals to be monitored:



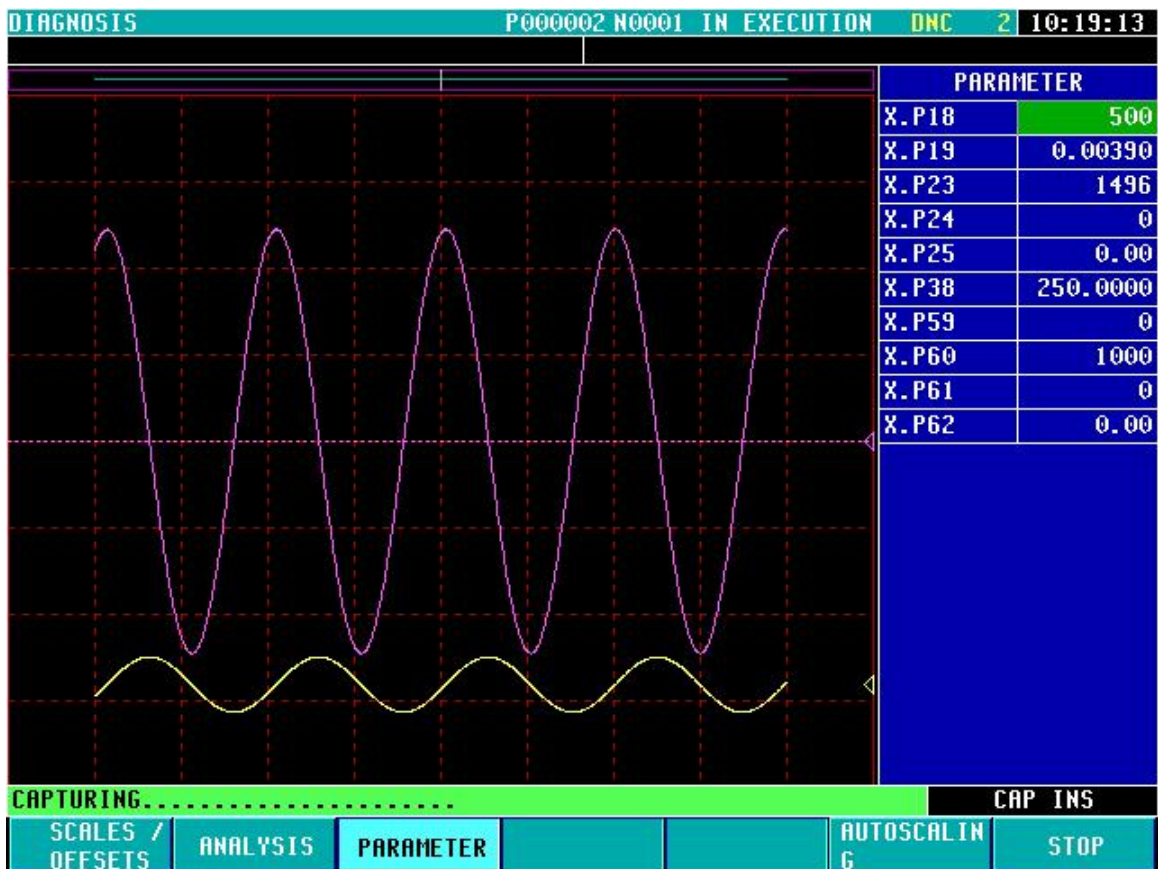
FLWEX is the amount of X-axis following error. All the axes adjustments are about controlling the shape and value of this signal. FLWEX will be changed if there are any changes in Gains.

RIPX is the final command value which is coming from controller to drive. More ACCTIME create smoother shape on RIPX.



For adjusting the X-axis we need to run following program. The following program will move X-axis back and forth. It will be possible adjust steady state and transient behavior of axis by this program.

```
G80
G92 X0
G1 F100
G51 E0.001
N1 X10
X-10
(GOTO N1)
```



## Steady State Adjustments

Steady state mode means acceleration is over and the axis reaches to the requested speed and moving forward. In this case, without Feed Forward, the following Error of an axis will be proportional to Feed Rate of it. It means more feed rate create more following error. In steady state condition, the amount of following error depends on Program Feed Rate, G00FEED(P38) and PROGAIN(P23).

These are the rules:

More G00FEED	→	more following error
More Program Feed-rate	→	more following error
More PROGAIN	→	less following error

### Adjusting G00FEED:

Axis can not move faster than a certain amount. This amount depends on lead-screw pitch, motor maximum rpm and gear ratio.

For example

Pitch = 0.2"

Gear ratio = 1/2

Motor maximum rpm = 2000

$G00FEED < 0.2 \times \frac{1}{2} \times 2000 = 200\text{ipm}$

For having G00FEED, controller must send maximum voltage to the servo-drive. It could be 9.9V=9900mV. If we want to restrict this speed to something less we can either decrease the MAXVOLT (P37) and the G00FEED (P38) parameters.

### Adjusting PROGAIN:

A proper starting point for calculating PROGAIN is having 0.1" following error with 100ipm program feed-rate. So we need to run a program which moves the axis back and forth. The program must move the axis in a wide interval that allows it to reach to steady state speed. The following error can be monitored by the oscilloscope. This formula can be used for having 0.1" of following error in 100ipm speed.

$PROGAIN = (1000\text{mm}/\text{min} \times \text{MAXVOLT}(\text{mv})) / (G00FEED * 25.4)$

In this case:

$PROGAIN = (1000\text{mm} \times 9500) / (200 * 25.4) = 1870$

By increasing the PROGAIN, it may possible to have less following error. If we use  $PROGAIN = 1870 \times 2 = 3740$  the following error will be decreased from 0.1" to 0.05". But increasing following error may cause instability or oscillation. In some cases because of machine's mechanics it may not let us to have even 0.1" following error so we may use less PROGAIN.

Another reason which may restrict us to have more PROGAIN is poor velocity loop. It means the servodrive is not adjusted correctly. The servodrive has to be adjusted to have better response. If you are using FAGOR servodrive systems the velocity loop parameters (SPn) must be adjusted to have better performance. Increasing SP1 and/or Decreasing SP2 will improve the behavior of the servodrive. It means servodrive responds faster to controller commands.

The Procedure for adjusting SP1 is increasing it gradually so we will here noise at a certain value then we have to put 50% of that amount for SP1.

The Procedure for adjusting SP2 is decreasing it gradually so we will here noise at a certain value then we have to put double of that amount for SP2.

One of the other reasons that we need more PROGAIN is having more accuracy in positioning. An axis will be considered as a **positioned axis** if its following error is less than a window which is defined in INPOSW (P019). Having less INPOSW may need more PROGAIN.

## Transient State Adjustments

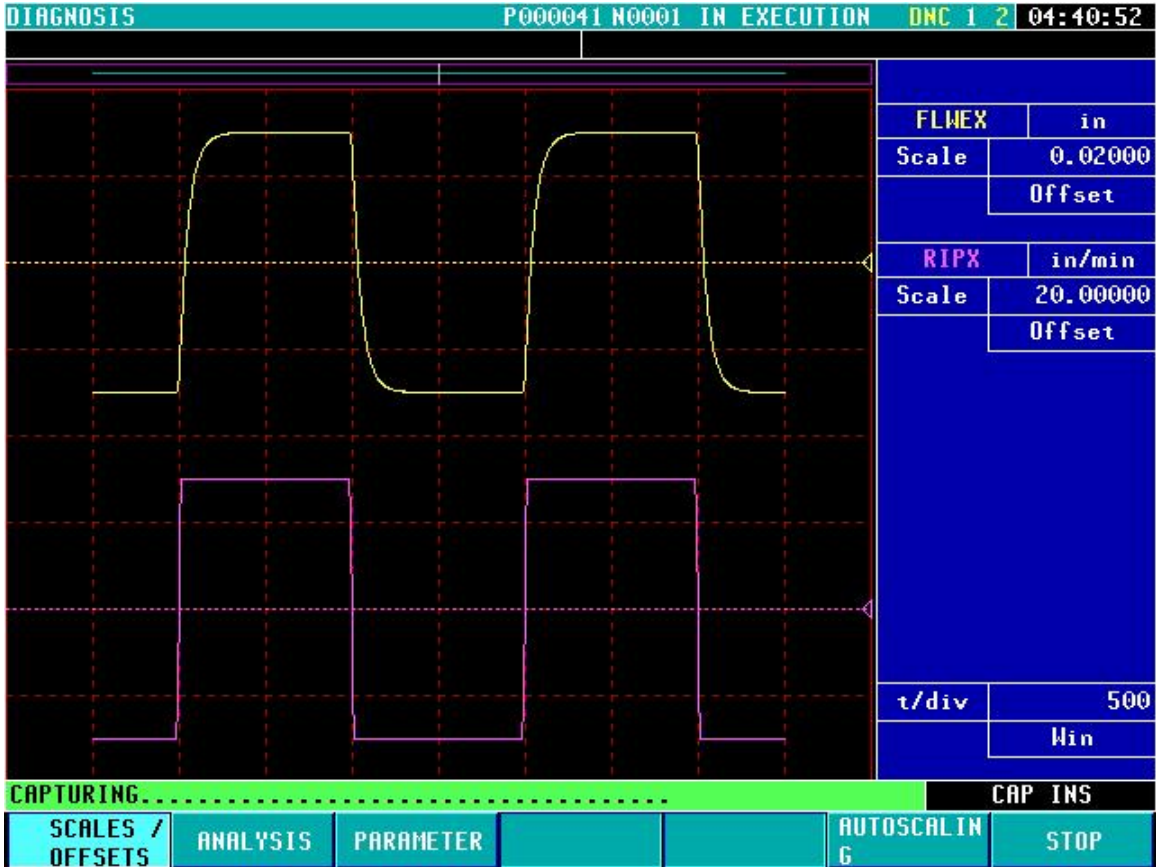
Moving an axis from one point to the other needs Acceleration at the beginning and Deceleration at the end. The amount of acceleration or deceleration time depends on the weight of the axis and how fast it is moving. Heavier or faster axis needs longer acceleration/deceleration time.

Decreasing acc/dec time will create more impact on axis mechanics and may create vibration. On the other hand more acc/dec time makes axis more sluggish.

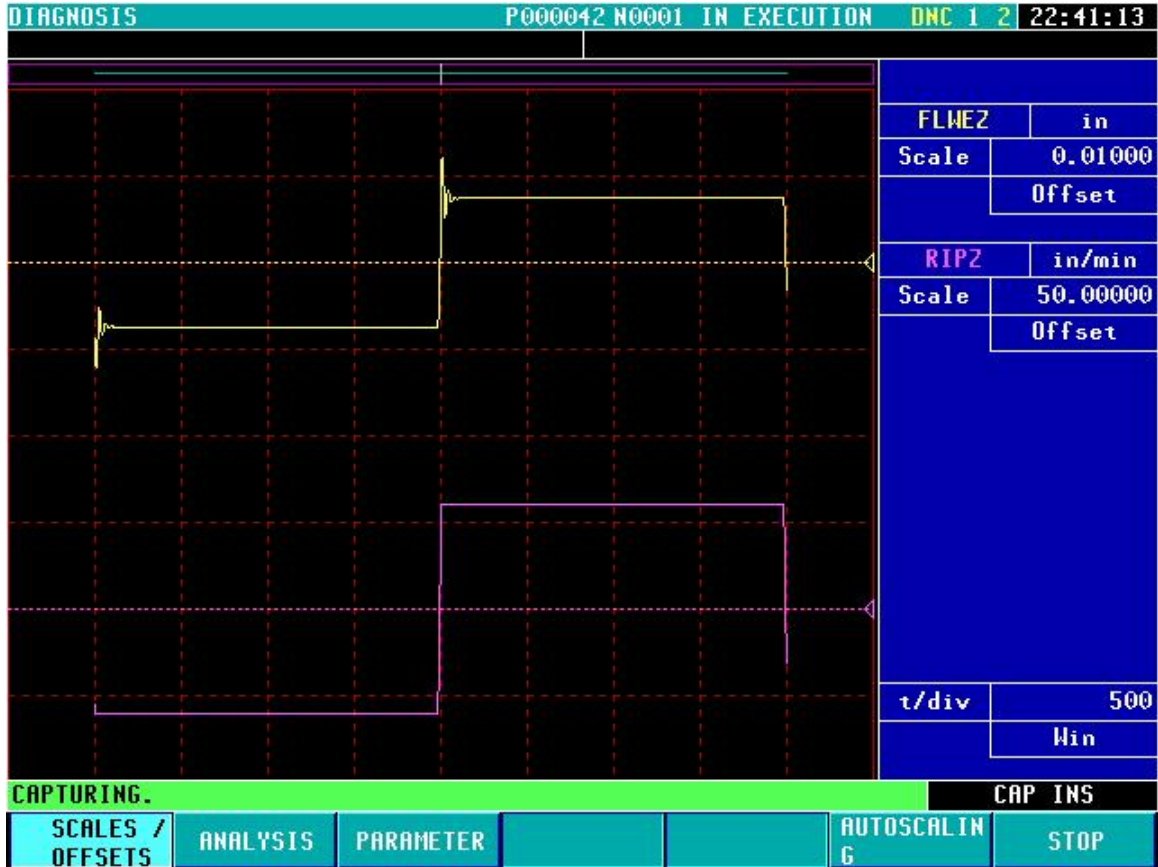
There is a parameter for each axis which defines the amount of acc/dec time. It is ACCTIME (P18). The proper value of ACCTIME will be a compromise between make the axis livelier and having less vibration.

More ACCTIME may increase the Cycle Time of the execution of a program too. Therefore G00FEED is not the only factor which can tell us how fast a machine could be. Large ACCTIME can decrease the machining speed drastically.

Following Diagram shows a proper behavior of an axis moving back and forth. It doesn't have any overshoot and it doesn't oscillate either. Each step of changing the direction of the axis command (RIPX) will be followed by its real movement.



Following Diagram shows an improper behavior of an axis moving back and forth. It has overshoot and moves jerky. It may be because of large PROGAIN or improper mechanics behavior for example the motor belt adjustment or ballscrew problem.



## Ballbar Test and Adjustments

One of the major tests is roundness and circularity of machining a circle. We are looking for an accurate circle which has same radius everywhere. If there is any improper adjustment on axes gains the circle's shape may become an ellipse or even a peanut shape. So Ballbar test is a tool to make sure that the axes are adjusted correctly or not. It can also show the potential backlash problems too. The Ballbar screen can be accessed by pressing following keys:

MAIN MENU --- F7(+)  
--- F5(DIAGNOSIS)  
--- F4(ADJUSTMENT)  
--- F1(BALLBAR TEST)

Following program must be executed to have the circular test on XY axes. It is going to run a 2" diameter circle.

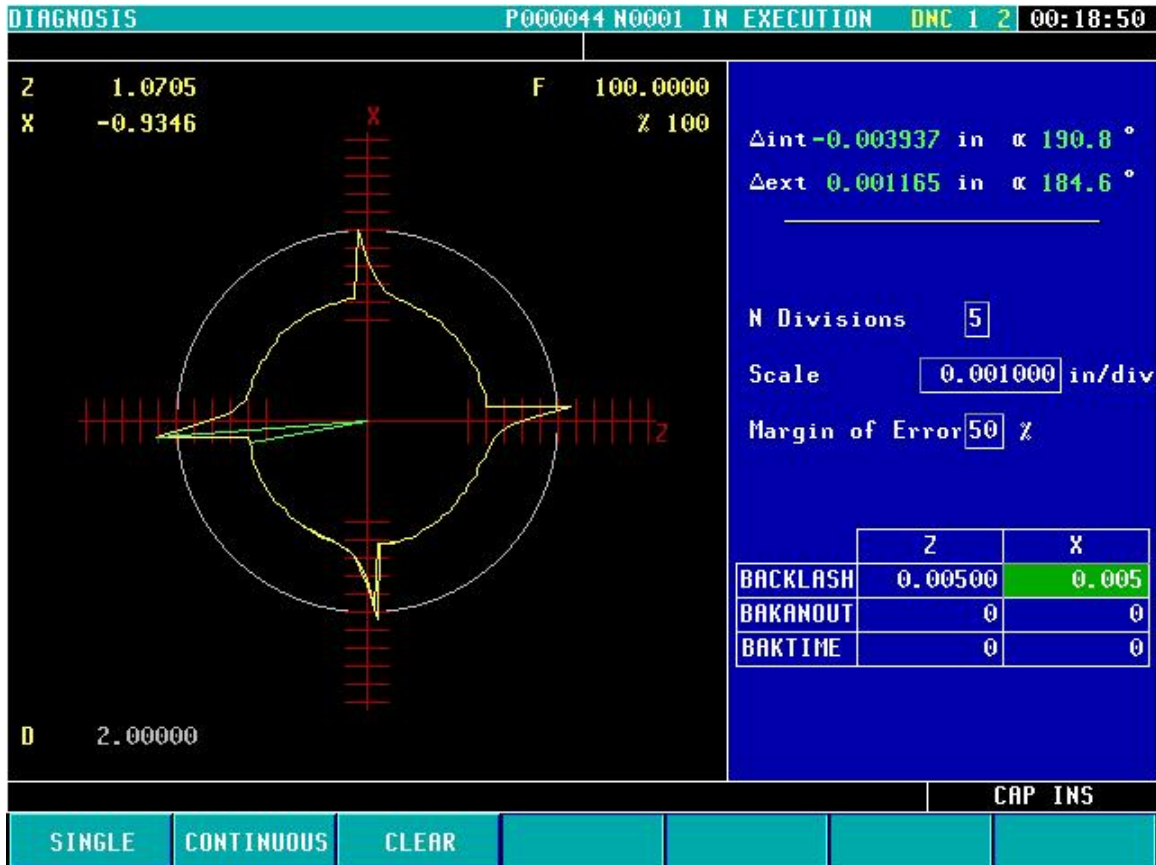
```
G80  
G17  
G92 X0  
G1 F100 X0  
G51 E0.001  
N1 G2 I-1  
(GOTO N1)
```



Following Screen will show the axes' gains are not set correctly. Not Having Same Following Errors for same feedrates is the cause.



Circular test will show all the mechanical problems when the machine is using Scales for feedbacks. In this case the reversal spikes on circle's quadrants will show you the rigidity of Ballscrew's trans-bearings. The quadrants may be smoothed by applying BAKANOUT and BAKTIME. BAKANOUT is the amount of backlash excess voltage (mV) which will be applied in BAKTIME (ms) to move the motors faster during axis direction change.



## Zero Following Error

Using Fagor SERCOS technology will allow us to remove following error and make it almost zero. For this purpose we need to set FFGAIN (P25) = 100. FFGAIN is Feed-Forward Gain and can remove the following error during steady state movement. If it is not applied the following error of axis will be changed by changing the feedrate. Faster feedrate creates more following error and for example the circles' radius will be changed. Here is the example that how the shape of a circle can be destroyed when the feedrate is changed during machining. If we had Zero following error this would not happen.

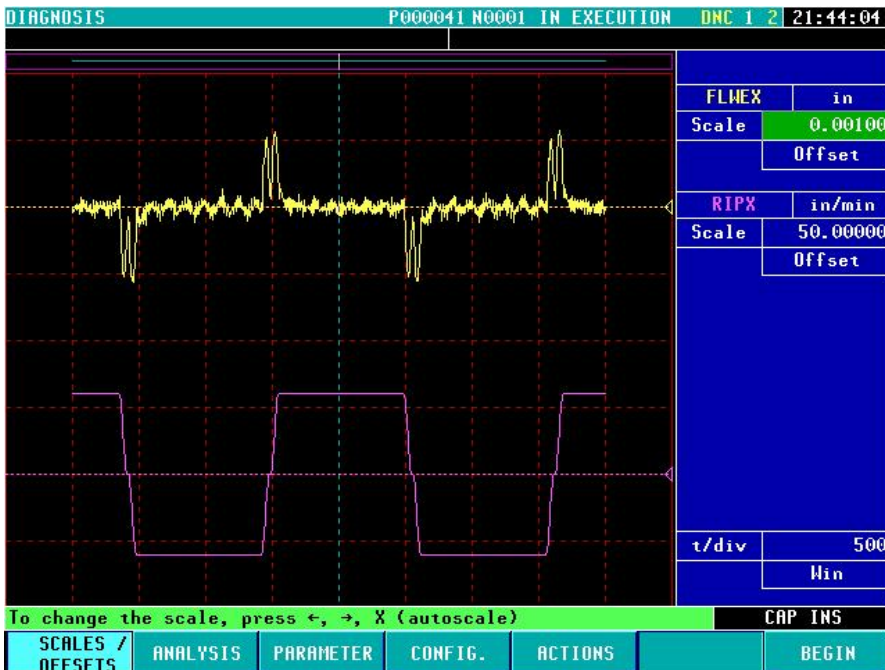
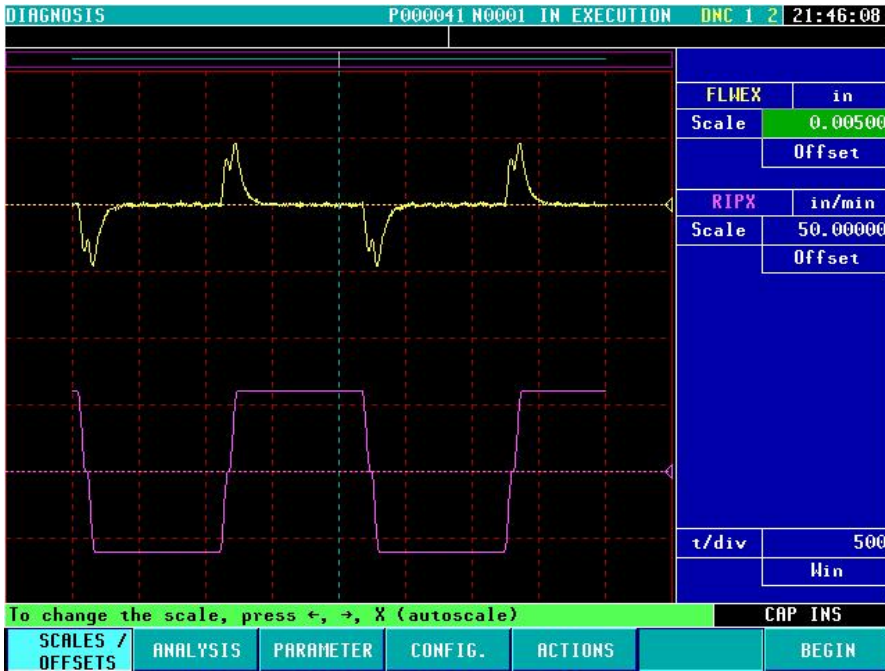


When the axis direction is going to be changed, FFGAIN = 100 can not remove transient following error. For removing Following Error during ACCTIME we need to apply Derivative Gain or DERGAIN (P24). The way that DERGAIN may be applied depends on ACFGAIN (P46). ACFGAIN status indicates whether or not the value assigned to DERGAIN (P24) is applied onto the variation of programmed feedrate (AC-Forward). If it is NO it means DERGAIN works on variation of following error and otherwise it is applied on variation of programmed feedrate that due to ACC/DEC. In above diagram each division is 0.001".

Following Diagram shows a proper setting in Gains. Each Division is less than 0.0001”.



It is crucial to set the DERGAIN to a proper value. It improves the response of the system in acceleration changes. It minimizes the following error when starting up, braking and when changing movement direction. Following diagrams will show proper and improper setting on DERGAIN. FFGAIN is 100% and it removes steady state following error. Having proper DERGAIN and ACFGAIN = YES will allow to minimize the transient following error.



## Second set of gains

Each Axis can have two set of gains.

P18 = ACCTIME	P59 = ACCTIME2
P23 = PROGAIN	P60 = PROGAIN2
P24 = DERGAIN	P61 = DERGAIN2
P25 = FFGAIN	P62 = FFGAIN2

Sometimes in Manual or Handwheel mode machine can not work with FFGAIN = 100%. It may need much higher value for ACCTIME. Higher value for ACCTIME is not good in Manual/Handwheel mode because when operator releases the JOG buttons or stops rotating the Handwheel the machine will not stop fast. It moves slowly and stops farther. The Axis may have jerky movement when you want to apply less ACCTIME in MANUAL/HANDWHEEL mode. But in EXECUTION mode Axes will stop in the right place which has been programmed. So we may be able to put FFGAIN2 = 100 during execution.

The second set of gains can be activated via PLC. ACTGAIN2 is the mnemonic which is used for this purpose. ACTGAIN2 is going to activate all second set of gains for all axes. Before using ACTGAIN2 all the second set of gains of all axes must be adjusted. The PLC could be like below.

```
      INCYCLE
AND   (AUTOMAT OR MDI)
AND   NOT MANUAL
AND   NOT ZERO
= ACTGAIN2
```

## Corner accuracy in contours

Following G-Codes would be used for controlling the accuracy of vertices on each programmed point:

### G07 (square corner)

When working in G07 (square corner) the CNC does not start executing the following program block until the position programmed in the current block has been reached. The CNC considers that the programmed position has been reached when the axis is within the "INPOSW" (in-position zone or dead band) from the programmed position. The theoretical and real profile coincide, obtaining square corners.

Function G07 is modal and incompatible with G05, G50 and G51. On power-up, after executing M02, M30 or after EMERGENCY or RESET, the CNC assumes code G05 or G07 depending on how the general machine parameter "ICORNER" is set.

### G05 (round corner)

When working in G05 (round corner), the CNC starts executing the following block of the program as soon as the theoretical interpolation of the current block has concluded. It does not wait for the axes to physically reach the programmed position. The distance prior to the programmed position where the CNC starts executing the next block depends on the actual axis feedrate. Via this function round corners can be obtained. The difference between the theoretical and real profiles depends on the **programmed feedrate** value "F". The higher the feedrate, the greater the difference between both profiles. Function G05 is modal and incompatible with G07, G50 and G51.

### Controlled round corner (G50)

When working in G50 (controlled round corner); once the theoretical interpolation of the current block has concluded, the CNC waits for the axis to enter the area defined by machine parameter "INPOSW2" and it then starts executing the following block of the program. Function G50 assures that the difference between the theoretical and actual paths stays smaller than what was set by machine parameter "INPOSW2". One may need tighter accuracy so the parameter may have smaller number than INPOSW.

### Look-ahead (G51)

Programs consisting of very small movement blocks (CAM, digitizing, etc.) tend to run very slowly. With look-ahead, high speed machining is possible for this type of programs. The look-ahead function analyzes in advance the path to be machined (up to 75 blocks) in order to calculate the maximum feedrate for each section of the path. This function provides smoother and faster machining in programs with very small movements, even in the order of microns.

It is recommended to have the CPU-TURBO option when using the look-ahead function. When operating with "Look-Ahead", it is a good idea to adjust the axes so their following error (lag) is as small as possible because the contouring error will be at least equal to the minimum following error.

The programming format is:

G51 [A] E

E is Maximum contouring error. The lower this parameter value is, the lower the machining feedrate will be.

A (0-255) is optional and it defines the percentage of acceleration to be applied. When not programmed or programmed with a "0" value, the CNC assumes the acceleration value set by machine parameter for each axis.

#### G51 Considerations for the execution

When calculating the feedrate, the CNC takes the following into account:

- The programmed feedrate.
- The curvature and the corners.
- The maximum feedrate of the axes.
- The maximum accelerations.
- The jerk.

If any of the circumstances listed below occurs while executing with Look-Ahead, the CNC slows down to "0" at the previous block and it recovers the machining conditions for Look-Ahead in the next motion block.

- Motionless block.
- Execution of auxiliary functions (M, S, T).
- Single block execution mode.
- MDI mode.
- Tool inspection mode.

If a Cycle Stop, Feed-Hold, etc. occurs while executing in Look-Ahead mode, the machine may not stop at the current block, several additional blocks will be necessary to stop with the permitted deceleration.

Function G51 is modal and incompatible with G05, G07 and G50. Should any of them be programmed, function G51 will be canceled and the new one will be selected. Function G51 must be programmed alone in a block and there must be no more information in that block.

## Look ahead and router machines

Router machines are high speed and not rigid enough to have Zero Following Error with low ACC/DEC of axes and obviously large ACC/DEC values are not acceptable in JOG mode. In a non-rigid machine having Zero Following Error with small ACC/DEC may create jerky movement.

For maintaining of the accuracy of contours in fast speeds each axis must work with **ZERO Following Error**. Otherwise high speeds create high following errors which for example will decrease the radius of small circles.

Example: Applying second set of gains which create Zero Following Error only in EXE mode.

PLC:

INCYCLE AND (AUTOMAT OR MDI) = ACTGAIN2

G00SPEED = 3600ipm

First Set of Gains in Manual Mode:

ACCTIME=500, PROGAIN=100, DERGAIN = 0, FFGAIN = 0

Second Set of Gains in EXE Mode

ACCTIME2=1500, PROGAIN2=100, DERGAIN2 = 800, FFGAIN2 = 100

Higher ACC/DEC time may increase the Cycle Time which in this case is less than 10%.