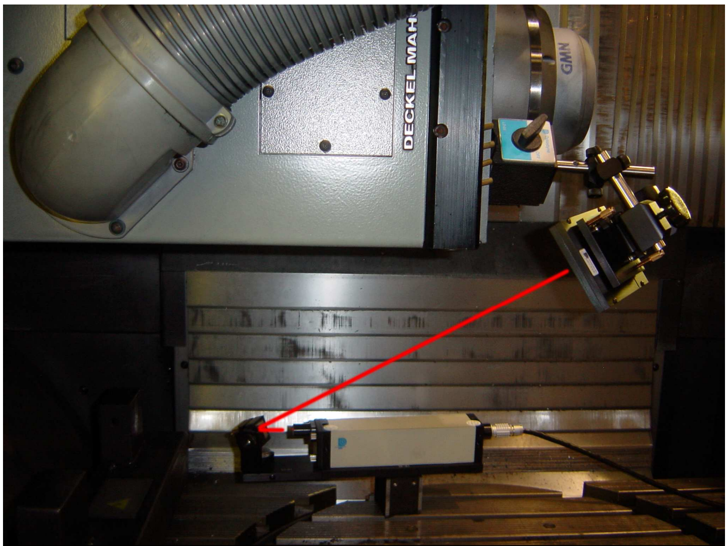
3D volumetric error compensation on Part program or G-code (both linear and circular interpolations)

I. Introduction

For many controllers, only linear pitch errors of each axis can be compensated. The compensation of 3D volumetric positioning errors can be achieved by compensating the part program (G-code). First input the measured 3D volumetric positioning errors of the machine tool, then input the part program to be compensated, a compensated part program or G-code will be generated. Please note the compensation program only reads G0 for positioning, G1 for linear interpolation, G2 (cw) and G3 (ccw) for circular interpolation, G17 (XY-plane), G18 (ZX-plane) and G19 (YZ-plane) for the plane of the circular path and I (center of circular path in X), J (center of circular path in Y), K (center of circular path in Z) and also G90 (absolute program) and G91 (increment program). All other commands are not read or changed. Also, lines in the compensated G-code usually are several times more than the original G-code.

For linear interpolation or circular interpolation, first divide the tool path to many segments. Using the measured 3D volumetric positioning errors, compensate each starting position and ending position of each segment. For higher accuracy or machine with large positioning errors, divide into more segments. To generate the 3D positioning error table with the machine coordinate, input the measurement coordinate (if it is different from the machine coordinate) and the parts coordinate (if it is different from the machine coordinate or the part location changed).



Measurement of the 3D volumetric error by Vector system

II. User inputs

In a popup screen, user input the parameters,

Measurement coordinates:

Xm =
Ym =
Zm = default are all 0,

Part coordinates:

Xp =
Yp =
Zp = default are all 0

Compensation segment length:

D = (same unit as in the G-code, default=10)

Number of digits = default is 3 digits

Cancel [ ], OK [ ]

The default assumes the machine coordinate, the measurement coordinate and the part coordinate are the same. Otherwise, enter the origin of the measurement coordinate and the origin of the part program.

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III. Linear interpolation G1

After read the G0, the next X, Y, and Z are the starting position, Xo, Yo and Zo.
The next G1 or G01, XXe YYe ZZe, where Xe, Ye and Ze are ending position. For G91 increment program, it will be converted to G90 absolute program.
Divide the linear travel from Xo, Yo, and Zo to Xe, Ye and Ze by a number of segments, N, such that each segment length is small than D.

For example
Original G-code:
Previous position Xo Y0 Z0
G1 XXe YYe ZZe

Segmented G-code:
Previous position Xo Yo Zo
G1 XX1 YY1 ZZ1
G1 XX2 YY2 ZZ2
G1 XX3 YY3 ZZ3
…………………
…………………
…………………
G1 XXN YYN ZZN,

Where XN=Xe, YN=Ye, and ZN=Ze.

Similarly, for the next G1 or linear interpolation use the same formula.
If there is a circular interpolation, G2, G3 before the G1, use the ending position as the starting position of the following G1 or linear interpolation.

IV. Circular interpolation G2, G3, G17, G18, G19

After read G2 or G3, Check for G17, G18 or G19. G17 is circular path in XY-plane, G18 is circular path in ZX-plane and G19 is circular path in YZ-plane. The following example is for XY-plane. Similarly for ZX-plane and YZ-plane.
After read the last G1, G2 and G3, the ending position X, Y, and Z is the starting position Xo,Yo and Zo for the next G2 or G3 (G17 means in the XY-plane) XXe YYe IIo JJo where Xe and Ye is the ending position after the circular path and Io and Jo is the distances to the center (Xc, Yc) of the circular arc, where Xc=Xo+Io, Yc=Yo+Jo.

Divide the circular path from Xo, and Yo to Xe, and Ye by a number of segments N, such that the length of each segment is less than D.
Original G-code:

Previous position Xo Y0
G3 XXe YYe IXc JYc

Segmented G-code:
Previous position Xo Yo
G3 XX1 YY1 II1 JJ1
G3 XX2 YY2 II2 JJ2
G3 XX3 YY3 II3 JJ3
…………………
…………………
…………………
G3 XXN YYN IIN JJN

Where XN=Xe, and YN=Ye,

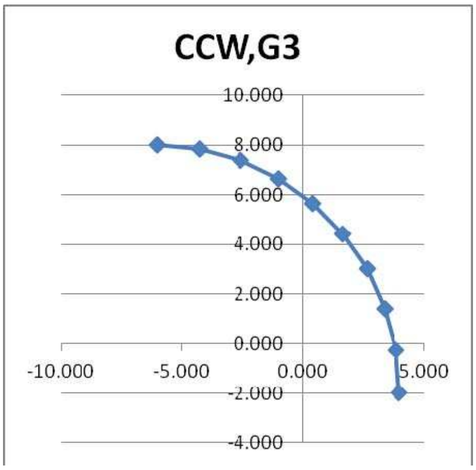
Similarly for G2 (cw direction), use negative increment angles. For G18 (ZX-plane) replace X by Z, Y by X, I by K and J by I. For G19 (YZ-plane), replace X by Y, Y by Z I by J and J by K.

Example:

Original G-code:
Previous position Xo = 4.000 Yo = -2.000
G17
G3 X-6.000 Y8.000 I-10.000 J0

Segmented G-code:
Previous position Xo = 4.000 Yo = -2.000
G3 X3.848 Y-0.264 I-10.000 J0.000
G3 X3.397 Y1.420 I-9.848 J-1.736
G3 X2.660 Y3.000 I-9.397 J-3.420
G3 X1.660 Y4.428 I-8.660 J-5.000
G3 X0.428 Y5.660 I-7.660 J-6.428
G3 X-1.000 Y6.660 I-6.428 J-7.660

G3 X-2.580 Y7.397 I-5.000 J-8.660
G3 X-4.264 Y7.848 I-3.420 J-9.397
G3 X-6.000 Y8.000 I-1.736 J-9.848

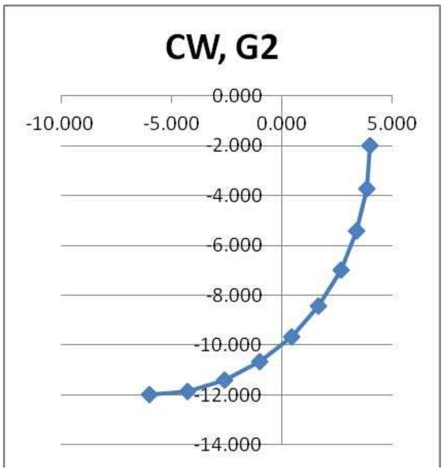


Original G-code:

Previous position Xo = 4.000 Yo = -2.000
G17
G2 X-6.000 Y-12.000 I-10.000 J0

Segmented G-code:

Previous position Xo = 4.000 Yo = -2.000
G2 X3.848 Y-3.736 I-10 J0
G2 X3.397 Y-5.420 I-9.848 J1.736
G2 X2.660 Y-7.000 I-9.396 J3.420
G2 X1.660 Y-8.428 I-8.660 J5
G2 X0.428 Y-9.660 I-7.660 J6.427
G2 X-1.000 Y-10.660 I-6.427 J7.660
G2 X-2.580 Y-11.397 I-5 J8.660
G2 X-4.264 Y-11.848 I-3.420 J9.396
G2 X-6.000 Y-12.000 I-1.736 J9.848



After a segmented G-code is generated, compensate each X, Y, and Z coordinates by using the measured 3D volumetric error table.

V. To generate a compensated G-code
First measure the 3D volumetric positioning errors of a CNC machining center by sequential step diagonal displacement measurement. Next enter the measured 4 sequential diagonal displacement files to calculate the 3D volumetric positioning errors.

The measured 3D volumetric positioning errors are shown below.

x-axis

target,n	dxx	dxy	dxz
0.0	0.0	0.0	0.0
48.0	-0.0009479	-0.0015643	-0.0031717
96.0	-0.0038110	-0.0034922	-0.0040282
144.0	-0.0064295	-0.0060658	-0.0047497
192.0	-0.0074602	-0.0071584	-0.0059618
240.0	-0.0083099	-0.0088231	-0.0067169
288.0	-0.010453	-0.0098209	-0.0062623
336.0	-0.011624	-0.0082648	-0.0052214
384.0	-0.013692	-0.0061277	-0.0031075
432.0	-0.0144781	-0.003230	-0.0028492
480.0	-0.0142820	0.0	0.0

y-axis

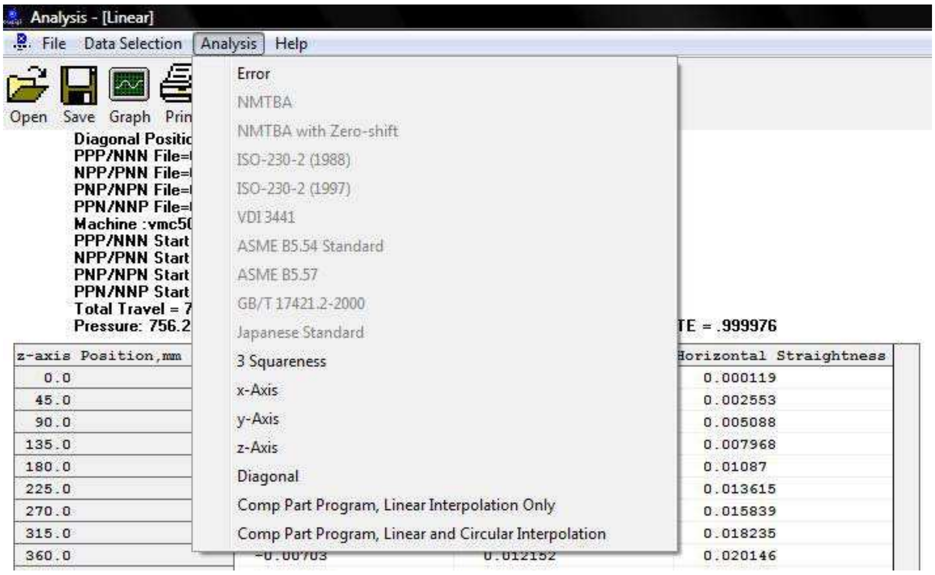
target,n	dyx	dyy	dyz
0.0	0.0	0.0	0.0
33.0	-0.0010738	-0.0039176	-0.0012255
66.0	0.0000804	-0.0042665	-0.0016438
99.0	0.0005462	-0.0072451	-0.0022323
132.0	0.0020470	-0.0088609	-0.0008964
165.0	0.0033270	-0.0094763	0.0000568
198.0	0.0043364	-0.0087056	-0.0002838
231.0	0.0066423	-0.0068262	0.0000806
264.0	0.0087687	-0.0071640	0.0006363
297.0	0.0100242	-0.0083214	0.0015772
330.0	0.0083370	-0.009819	0.0

z-axis

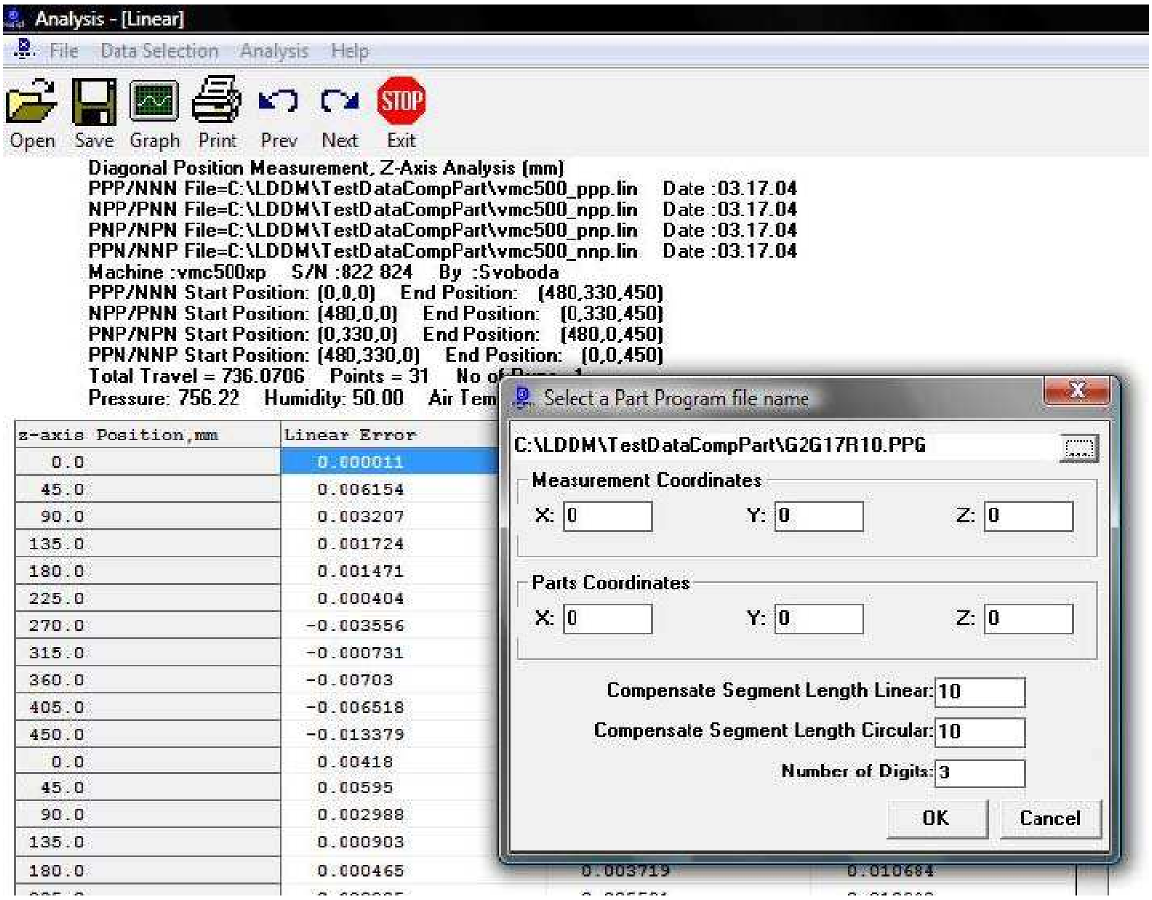
target,n	dzx	dzy	dzz
0.0	0.0	0.0	0.0
45.0	0.0018057	0.0024344	0.0061428
90.0	0.0031612	0.0049691	0.0031962
135.0	0.004779	0.0078495	0.0017127
180.0	0.0061315	0.0107512	0.00146
225.0	0.0077631	0.0134967	0.0003928
270.0	0.0088113	0.0157202	-0.0035672
315.0	0.0106522	0.0181167	-0.0007415
360.0	0.0121948	0.0200268	-0.0070404
405.0	0.0140105	0.0220084	-0.0065292
450.0	0.0154910	0.023681	-0.01339

Note1, meaning of the values:
In this example if is consider a vertical Z axis machining center we will have:
X-axis : in the first column the nominal target position, in the second column dxx or the error measured along the movement axis (linear position error), in the third column dxy the lateral deviation (horizontal straightness) and in the fourth column dxz the vertical deviation or vertical straightness.
Y-axis: the linear position error dyy is now in the third column, while dyx and dyz are respectively the horizontal and vertical straightness.
Z-axis: The linear position error dzz is now in the last column , while dzx and dzy are the horizontal straightness.
Note2, straightness and squareness:
We can note that the straightness dxy, dxz e dyz starts from zero and come back to zero at the end point, it is adjusted straightness; while the straightness dyx, dzx e dzy are not coming back to zero because they shows the squareness error.

Click on "Analysis" and "Comp Part Program, Linear and Circular Interpolation" as shown below.



A screen will be popup to enter the G-code filename, coordinates, segment lengths and number of digits as below.



Click on OK, a compensated G-code will be generated in a file with the same name as the G-code, but with an extension .VCM. On the left is the uncompensated input G-code and on the right is the compensated G-code.

Linear Interpolation

Input G-code:	Output G-code:
%	%
(LINEAR)	(LINEAR)
G54	G54
G90	G90
G01 F3000	G01 F3000
X0.Y0.Z0.	X0.Y0.Z0.
M00	M00
X100.Y70.Z80.	X100.001Y70.004Z80.002
Z240.	Z240.007
X350.	X350.004
Y245.	Y245.
X450.Y315.Z360.	X449.993Y314.991Z360.008
Z0.Y0.X0.	Z0.Y0.X0.
M30	M30
%	%

Circular interpolation

Input G-code:	Output G-code:
(G2 Test Circular contour, R=10)	(G2 Test Circular contour, R=10)
G54 G90 G01 F3000	G54 G90 G01 F3000
X4.000 Y-2.000	X4. Y-2.
G17	G17
G2 X-6.000 Y-12.000 I-10.000 J0	G2 X3.848 Y-3.737 I-10. J0.
G1 X0 Y0	G2 X3.397 Y-5.421 I-9.848 J1.736
M30	G2 X2.66 Y-7.001 I-9.397 J3.42
	G2 X1.66 Y-8.429 I-8.66 J5.
	G2 X0.428 Y-9.662 I-7.66 J6.428
	G2 X-1. Y-10.662 I-6.428 J7.66
	G2 X-2.58 Y-11.398 I-5. J8.66
	G2 X-4.264 Y-11.85 I-3.42 J9.397
	G2 X-6. Y-12.002 I-1.736 J9.848
	G1 X-3. Y-6.001
	G1 X0. Y0.
	M30