3 CNC Milling Programs Using Multi-Axis Movement

Objectives

Students will be able to:

- Prepare programming techniques for Multi-Axis machining operations.
- Arrange and validate CNC Multi-Axis programs.
- Analyze and rewrite CNC Multi-Axis programs.
- Produce and complete projects for Multi-Axis Machining.

Orienting Questions

- ✓ What is the difference between 3rd and 4th axis machining?
- ✓ What is the difference between "A", "B" & "C" axis'?
- ✓ What is the benefit of 4th axis machining?

The **bolded/underlined words are key terms…click on the **blue underlined terms** for more information.

Closed Captions and transcripts are available for all videos in this module. Click the CC button at the bottom right of the play menu to turn on closed captioning in the language of your choice. You may also read a full transcript of this video by clicking on the bottom below the play menu.

INTRODUCTION

Standard CNC Milling Machines produce **"X"**, **"Y"** & **"Z"** movements for basic machining applications. 4th Axis movements can be **Linear interpolation** or **Rotational interpolation**. The linear movements will move along the "X", "Y" and "Z" planes of reference; the 4th axis movements will rotate around the "A", "B" and "C" axis'. **4th Axis** movements are generally referred to as the first **Multi-Axis** movement for CNC machining. Even though "X", "Y' & "Z" are multi in number, they follow the Cartesian Coordinate Word System which are standard movements. The 4th Axis movement is the beginning of many multi-axis machining planes used in the process of stock removal. These "Multi-Axis" movements revolve around a rotational or angular plane not limited to the basic "X", "Y' & "Z" cutting planes or movements.

Click on the highlighted **4th Axis** text to watch video. Video shows a CNC 4th-Axis movement.

3.1 DESCRIPTION OF MULTI-AXIS MOVEMENT

The 4th-Axis movements are rotational movements. They range between **"A"**, **"B"** or **"C"** directions, depending upon their relationship with the "X", "Y' & "Z" planes. (Figure 1.)The **"A"** Axis revolves around the "X" direction of movement. The **"B"** Axis revolves around the "Y" direction of movement and the **"C"** Axis revolves around the "Z" direction of movement. The rotational movement of the "A", "B' & "C" planes are sometimes not always 360 degrees. These rotational movements can be singular movements or they can be combined with the "X", "Y' & "Z" plane movements to create multi-axis geometry. CNC Machining Centers can be set-up to establish an **"A"**, **"B"** or **"C"** directional rotation depending upon user preference using the placement of the rotary fixture coupled with CNC software parameter settings.

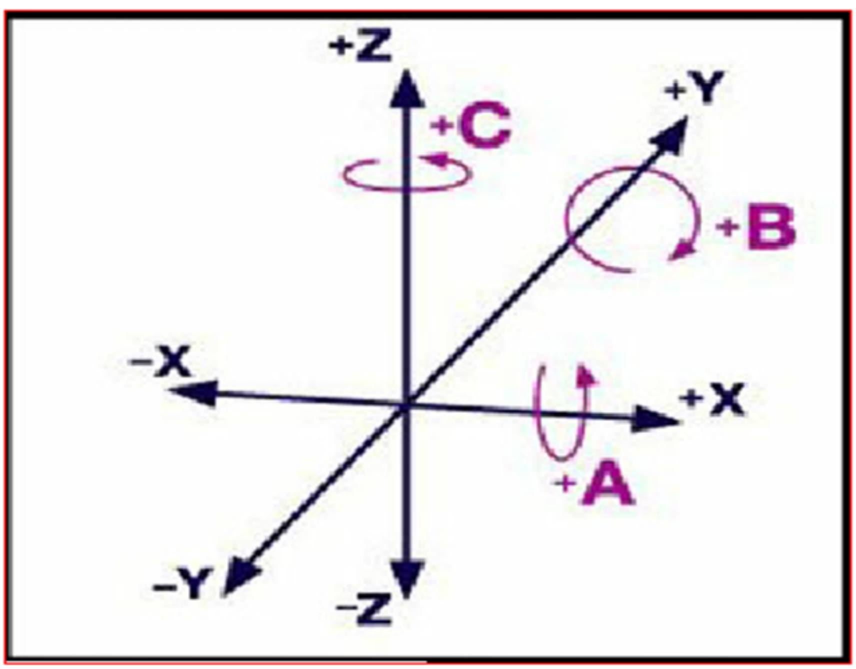


Figure 1. Multi-axis movement

3.1.1 AXIS A

This is an example of an **Axis A** set-up revolving around the "X" direction of movement (Figure 2.). This set-up format would be addressed in a typical CNC program by using the following sequence, **G0 A90**. This programming format would rotate the chuck 90 degrees in a CW direction using a rapid movement.

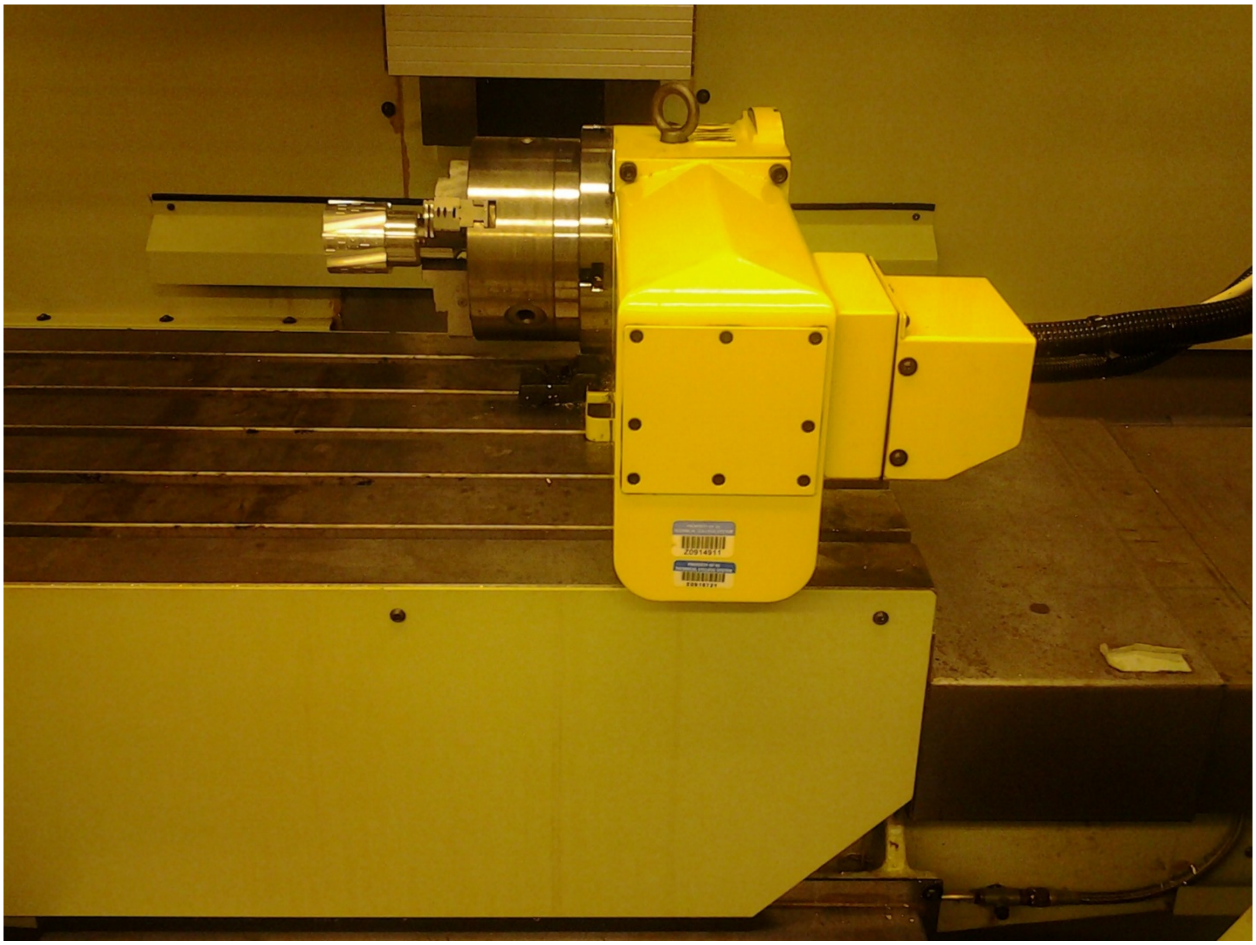


Figure 2. A – Axis Example

3.1.2 AXIS B

This is an example of an **Axis B** revolving around the "Y" direction of movement (Figure 3.). This set-up format would be addressed in a typical CNC program by using the following sequence, **G0 B90**. This programming format would rotate the chuck 90 degrees in a CW direction using a rapid movement.

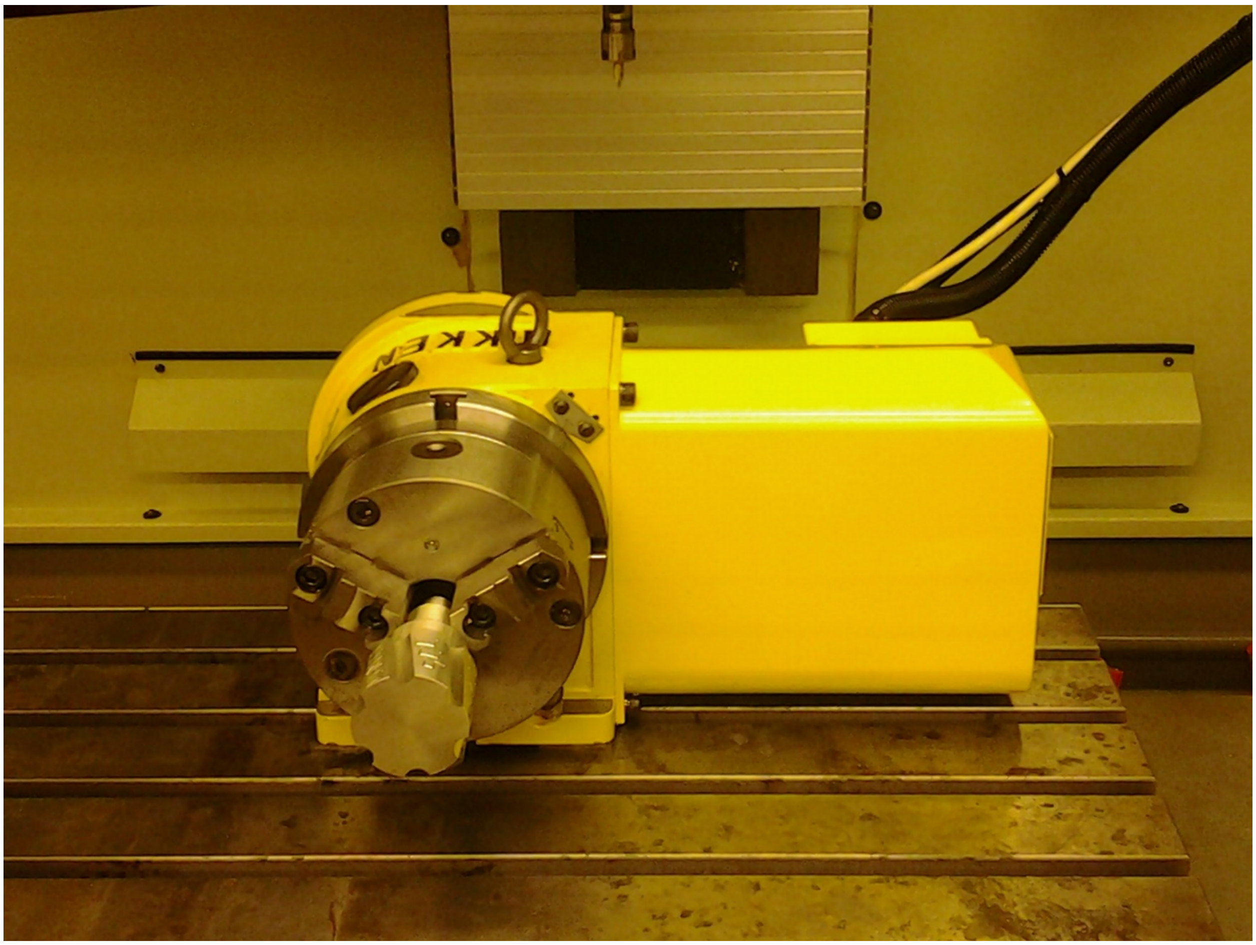


Figure 3. B – Axis Example

3.1.3 AXIS C

This is an example of an **Axis C** revolving around the “Z” direction of movement (Figure 4.). This set-up format would be addressed in a typical CNC program by using the following sequence, **G0 C90**. This programming format would rotate the chuck 90 degrees in a CW direction using a rapid movement.

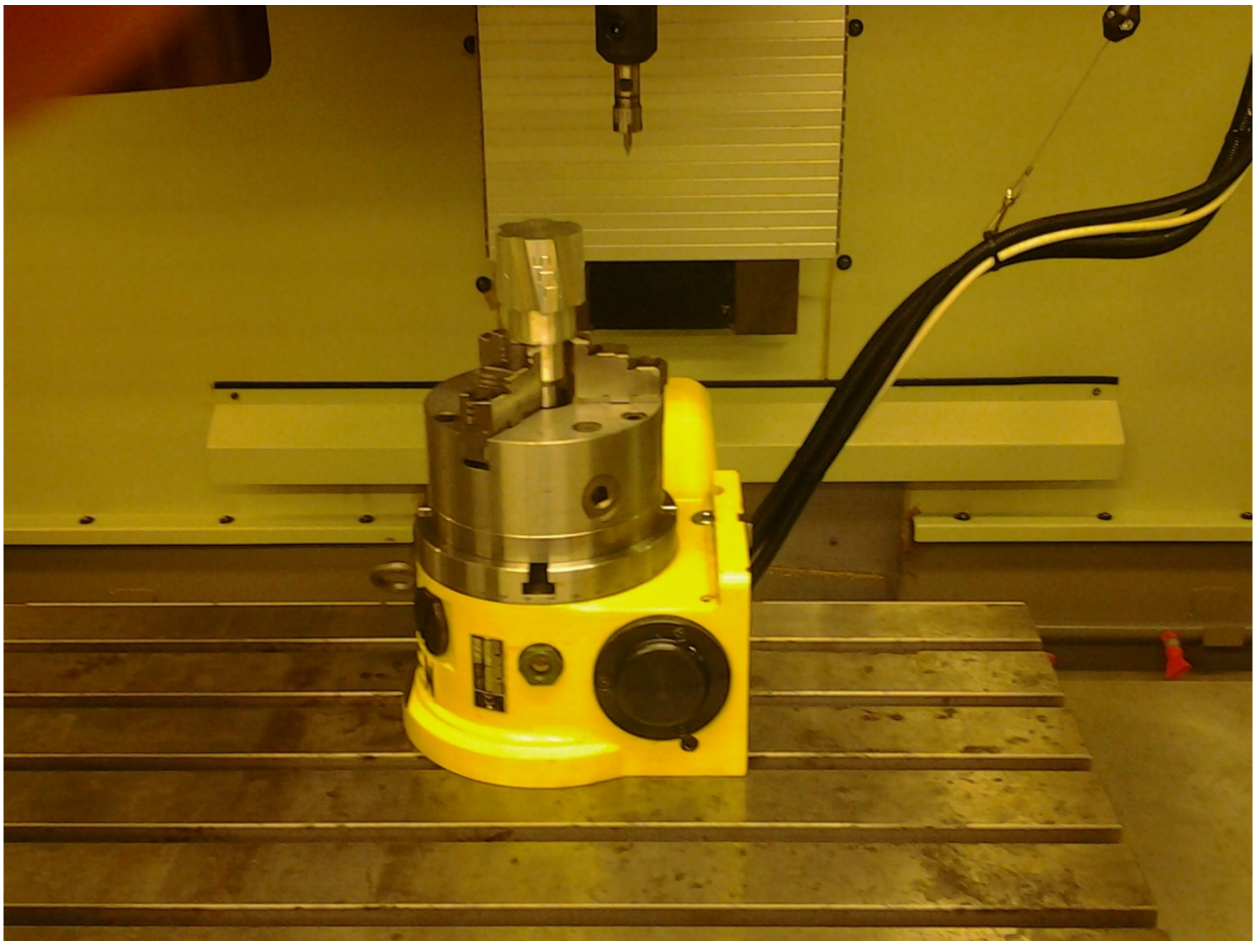


Figure 4. C – Axis Example

ACTIVITY #1

Match the following terms and definitions listed below.

1. A Axis	_______	A. Revolves around "Z" Direction of Movement
2. B Axis	_______	B. Standard Milling Movements
3. C Axis	_______	C. Linear Interpolation
4. G01	_______	D. Clockwise Circular Interpolation
5. G02	_______	E. Counter-Clockwise Circular Interpolation
6. G03	_______	F. Revolves around "X" Direction of Movement
7. "R"	_______	G. Incremental Radial Values
8. "I' & "J"	_______	H. Known as the first Multi-Axis movement
9. "X", "Y", "Z"	_______	I. Revolves around "Y" Direction of Movement
10. 4th Axis	_______	J. Absolute Radial Value

Activity #1 Answers

1. F
2. I
3. A
4. C
5. D
6. E
7. J
8. G
9. B
10. H

3.2 MULTI-AXIS MODES

The 4th Axis movement can be divided into three different modes of movement. The simplest mode of movement is known as the **Indexer Mode**, this particular movement is a rotational interpolation involving the "A", "B" or "C" axis depending upon the position of the 4th axis attachment. This is a basic rotation of the part by calling a certain degree of movement; these movements can be either absolute or incremental in value and do not require a feed calculation, because the rotation is a rapid move. The next mode is the **Single – Axis Mode**; this movement can be rotational or linear in direction, but is limited to moving only one axis at a time. Both the rotational and linear movements require a feed rate. The linear movements require a standard feed rate such as F5.0; this would simply be 5 inches of travel per minute. The rotational travel requires a calculation involving the diameter of the part. It will be necessary to calculate a feed rate to compensate for traveling around the circumference of the part. Feed rate moves with the 4th axis can be G1 (linear) moves, but the distance traveled are in degrees and the feed rates are in degrees per minute instead of inches per minute. The last mode of movement is known as the **Multi – Axis Mode**; this mode of movement involves rotary and linear movement occurring at the same time. These moves are programmed as standard linear moves, but calculating the combined inch/degree feed rate is a little more complex to calculate. All programming examples for 4th axis machining operations will be using position "A" (Figure 2.).

3.2.1 INDEXER MODE

The following programming example **O5123** (Figure 5.) is for drilling 8 holes located .5 in from the left and right edge of the part equally spaced around the cylinder .1 deep using a G81 Drilling Cycle.

```
Start:                          Continue:
O5123;                          N66 M11;
N5 G17 G20 G40 G80 G90;         N70 A180.0;
N10 M6 T01;                     N71 M10;
N15 G0 G54 X0.5 Y0.0 A0.0;      N75 G81 X0.5 Z-.2 F2.0;
N20 G0 G43 H1 Z1.0;             N80 X1.35;
N25 M3 S1000;                   N85 G80;
N30 G0 Z.1;                     N86 M11;
N35 G81 X0.5 Z-.2 R.1 F2.0;     N90 A270.0;
N40 X1.35;                          M10;
N45 G80;                        N95 G81 X0.5 Z-.2 F2.0;
N45 M11;                        N100 X1.35;
N50 A90.0;                      N105 G0 G80 Z1.0;
N51 M10;                             M11;
N55 G81 X0.5 Z-.2 F2.0;         N110 G92 A0.0;
N60 X1.35;                      N115 G91 G28 Y0.0 Z0.0 A0.0;
N65 G80;                        N120 M30
                                End
```

Figure 5. Program Example

ACTIVITY #2

Using the program example from Figure 5. fill in the blanks on the following program O5124, drilling 3 holes .25 deep equally spaced around a cylinder. The holes will be located X1.00 from the left edge of the part.

O5124;

N5 G17 G20 G40 G80 G90;

N10 M6 T01;

N15 G0 ______ ______ ______ ______;

N20 G0 ______ ______ Z1.0;

N25 M3 S1000;

N30 G0 Z.1

N35 _______ _______ ______ F2.0

N40 ______

N45 ______

N50 _______ _______ ______ F2.0

N55 ______

N60 ______

N65 _______ _______ ______ F2.0

N70 ______ _______ ______

N75 ______ _______ ______ ______ ______

N80 ______ _______

N85 M30

ANSWERS TO ACTIVITY #2

```
O5124;

N5 G17 G20 G40 G80 G90;

N10 M6 T01;

N15 G0 G54 X1.00 Y0.0 A0.0;

N20 G0 G43 H1 Z1.0;

N25 M3 S1000;

N30 G0 Z.1;

N35 G81 Z-.25 R.100 F2.0;

N40 G80

N45 A120.0;

N50 G81 Z-.25 R.100 F2.0;

N55 G80;

N60 A240.0;

N65 G81 Z-.25 R.100 F2.0;

N70 G0 G80 Z1.0;

N75 G91 G28 A0.0 Y0.0 Z0.0;

N80 G92 A0.0;

N75 M30;
```

PHYSICAL LAB FOR ACTIVITY #2

Introduction: When Activity #2 has been completed and approved; the next process will be setting up and programming the CNC mill to machine the actual part according to the specifications that were listed.

Materials and methods: The material will be a 2” diameter by 4” long aluminum bar stock being held in a 4^{th} Axis drive.

Requirements for successful lab completion: This lab will require all safety procedures to be followed to complete the manufactured part. WPC and offset set-ups including proper programming format, graphic evaluation coupled with first piece single-block application. The final machined part will match the program specifications.

3.2.2 SINGLE AXIS MODE

The single axis mode involves an actual cutting or removing of stock requiring a feed rate, unlike the indexer mode. Feed rates for linear movements for "X", "Y" & "Z" require only standard **IPM** calculations. 4th axis movements will require a calculation involving the outside diameter of the stock being machined. Feed rate moves on the rotary fourth axis with G1 (linear) moves are just like any other axis, except the distance traveled is in degrees and feed rates are in **Degrees per Minute**. The following feed rate calculation example (Figure 6.) would be as follows to cut a 1" square outline 0.01" deep in the surface of a 2" diameter cylinder, cutting at 12.0 inches per minute. The following program **O5124** (Figure 7.) would machine the 1.00 x 1.00 square involving the "X" and "A" travel movements.

Feed rate is 12.0 x 114.6/2.0 = 687.6 deg/min.

A 1" distance around a 2" diameter cylinder is 1.0 x 114.6/2.0 = 57.3°

Figure 6. Feed rate

```
O5124;
N5 G17 G20 G40 G80 G90;
N10 M6 T01;
N15 G0 G54 X.425 Y0.0 A0.0;
N20 G0 G43 H1 Z1.0;
N25 M3 S1000;
N30 G0 Z.1;
N35 G1 Z-.010 F5.0;          Feeds "Z" Travel .010 into Part
N40 G1 X1.425 F12.0;         Move "X" Across Bottom of Square
N45 G1 A57.3 F687.6;         Move "A" up Right Side of Square
N50 G1 X.425 F12.0;          Move "X" Across Top of Square
N55 G1 A0.0 F687.6;          Move "A" Down Left Side of Square
N60 G0 Z1.0;
N65 G0 G91 G28 Y0.0 Z0.0 A0.0;
N70 G92 A0.0
N75 M30;
```

Figure 7. X & A travel movements

ACTIVITY #3

Using the formula from (Figure 6.) and program example from (Figure 7.), fill in the blanks on the following program O5125 (Figure 8.), machine a 1.5" square outline 0.02" deep in the surface of a 3" diameter cylinder, cutting at 8.0 inches per minute. Begin the outline 1.00 in from left edge of part.

O5125;

N5 G17 G20 G40 G80 G90;

N10 M6 T01;

N15 G0 G54 ______ ______ ______;

N20 G0 ______ ______ Z1.0;

N25 M3 S1000;

N30 G0 Z.1

N35 ______ ______ ______;

N40 ______ ______ ______;

N45 ______ ______ ______;

N50 ______ ______ ______;

N55 ______ ______ ______;

N60 ______ ______;

N65 G0 G91 G28 ______ ______ ______;

N70 G92 A0.0

N75 M30;

Figure 8. Combining formula and program

ANSWERS TO ACTIVITY #3

Feed rate is 8.0 x 114.6/3.0 = 305.6 deg/min.

A 1.5" distance around a 3" diameter cylinder is 1.5 x 114.6/3.0 = 57.3°

Formula Calculation

```
O5125;
N5 G17 G20 G40 G80 G90;
N10 M6 T01;
N15 G0 G54 X1.00 Y0.0 A0.0;
N20 G0 G43 H1 Z1.0;
N25 M3 S1000;
N30 G0 Z.1
N35 G1 Z-.020 F5.0;
N40 G1 X2.5 F12.0;
N45 G1 A57.3 F305.6;
N50 G1 X1.0 F12.0;
N55 G1 A0.0 F305.6;
N60 G0 Z1.0;
N65 G0 G91 G28 Y0.0 Z0.0 A0.0;
N70 G92 A0.0
N70 M30;
```

PHYSICAL LAB FOR ACTIVITY #3

Introduction: When Activity #3 has been completed and approved; the next process will be setting up and programming the CNC mill to machine the actual part according to the specifications that were listed.

Materials and methods: The material will be a 3" diameter by 5" long aluminum bar stock being held in a 4th Axis drive.

Requirements for successful lab completion: This lab will require all safety procedures to be followed to complete the manufactured part. WPC and offset set-ups including proper programming format, graphic evaluation coupled with first piece single-block application. The final machined part will match the program specifications.

3.2.3 MULTI-AXIS MODE

Multi-Axis movements are a combination of linear axis and rotary axis movement occurring at the same time. These linear movements will be "X", "Y" or "Z" directional movements and the rotational movements will be "A", "B" or "C" depending upon the placement of the 4th Axis attachment. The following examples will be using position "A" (Figure 2.) so the linear movements will be "X" movements and the rotational movements will be "A". Multi-Axis program movements will require 3 codes, a linear movement, an angular movement and a feed rate. The following program **O5126** (Figure 9.) will be for machining a 1" wide, 1" high diamond on a 2" diameter cylinder.

```
O5126;
N5 G17 G20 G40 G80 G90;
N10 M6 T01;
N15 G0 G54 X.925 Y0.0 A0.0;
N20 G0 G43 H1 Z1.0;
N25 M3 S1000;
N30 G0 Z.1;
N35 G1 Z-.010 F5.0;                 Feeds "Z" Travel .010 into Part
N40 G1 X1.425 A-28.65 F486.3        Move "X" and "A"
N45 G1 X.925 A-57.3 F486.3;         Move "X" and "A"
N50 G1 X.475 A-28.65 F486.3;        Move "X" and "A"
N55 G1 X.925 A0.0 F486.3;           Move "X" and "A"
N60 G0 Z1.0;
N65 G0 G91 G28 Y0.0 Z0.0 A0.0;
N70 G92 A0.0
N75 M30;
```

Figure 9. 4th axis Multi-axis mode

ACTIVITY #4

Using the formula from (Figure 6.) and program example from (Figure 9.), fill in the blanks on the following program O5126 (Figure 10.), machine a 2” wide, 2” high diamond on a 3” diameter cylinder 0.02" deep using incremental movements, cutting at 8.0 inches per minute. Begin the outline 2.00 in from left edge of part at top of diamond according to Print O5126 (Figure 11.).

O5126;

N5 G17 G20 G40 G80 G90;

N10 M6 T01;

N15 G0 G54 ______ ______ ______;

N20 G0 ______ ______ Z1.0;

N25 M3 S1000;

N30 G0 Z.1

N35 G1 ______ ______ ______;

N40 G1 ______ ______ ______;

N45 G1 ______ ______ ______;

N50 G1 ______ ______ ______;

N55 G1 ______ ______ ______;

N60 ______ ______;

N65 G0 G91 G28 ______ ______ ______;

N70 G92 A0.0;

N75 M30;

Figure 10. 4th axis Multi-axis mode

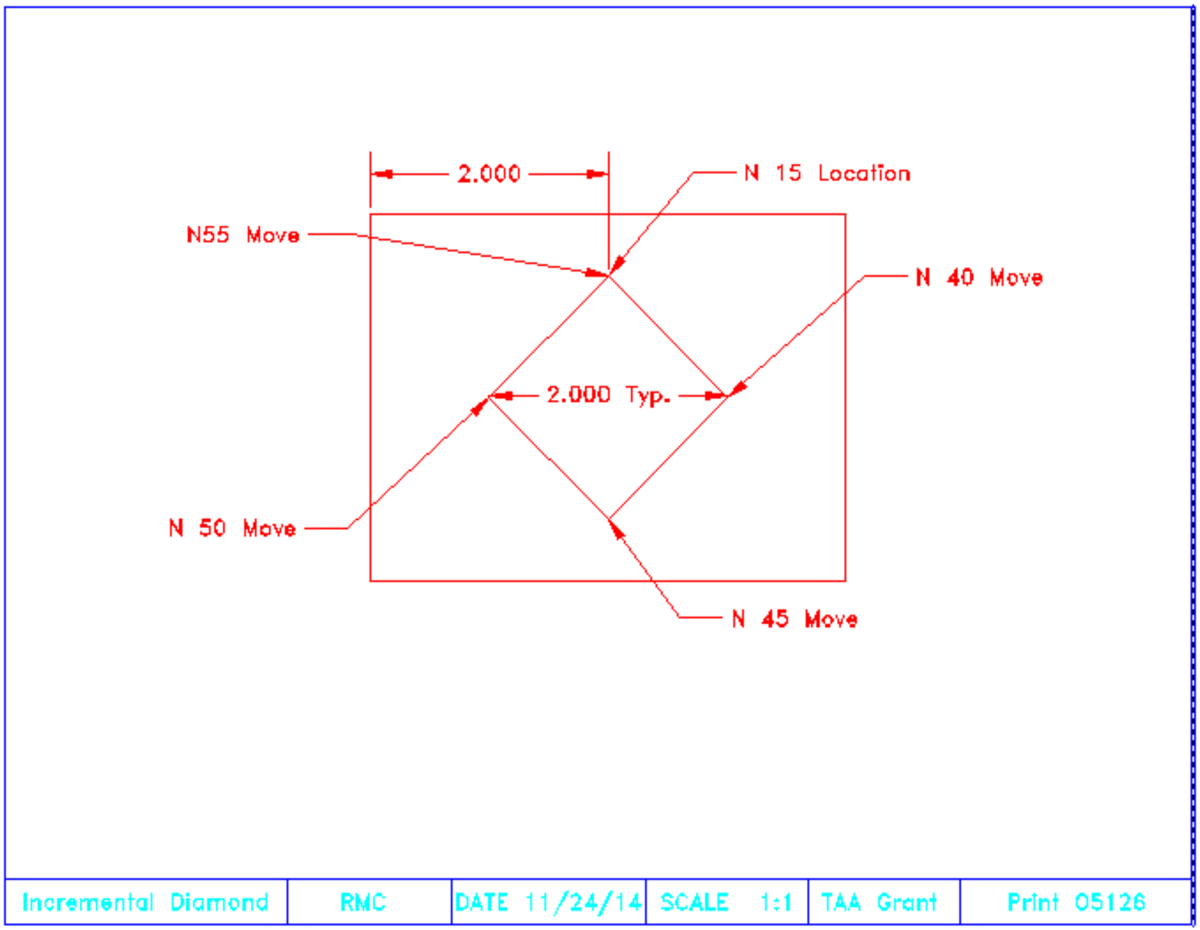


Figure 11. 4th axis Multi-axis mode

ANSWERS TO ACTIVITY #4

O5126;

N5 G17 G20 G40 G80 G90;

N10 M6 T01;

N15 G0 G54 X2.00 Y0.0 A0.0;

N20 G0 G43 H1 Z1.0;

N25 M3 S1000;

N30 G0 Z.100

N35 G1 G91 Z-.120 F5.0;

N40 G1 X1.00 A38.2 F305.6;

N45 G1 X-1.00 A38.2 F305.6;

N50 G1 X-1.00 A-38.2 F305.6;

N55 G1 X1.00 A-38.2 F305.6;

N60 G0 Z.120;

N65 G0 G91 G28 Y0.0 Z0.0 A0.0;

N70 G92 A0.0;

N75 M30;

PHYSICAL LAB FOR ACTIVITY #4

Introduction: When Activity #4 has been completed and approved; the next process will be setting up and programming the CNC mill to machine the actual part according to the specifications that were listed.

Materials and methods: The material will be a 3" diameter by 5" long aluminum bar stock being held in a 4th Axis drive.

Requirements for successful lab completion: This lab will require all safety procedures to be followed to complete the manufactured part. WPC and offset set-ups including proper programming format, graphic evaluation coupled with first piece single-block application. The final machined part will match the program specifications.

MAJORC ONCEPT S

KEY CONCEPTS

- 4th Axis movements can be "Linear Interpolation" or "Rotational Interpolation". Linear Interpolations consist of X, Y, Z movements. Rotational Interpolations are A, B, C movements.
- 4th Axis movements can be "A", "B" or "C" directional references. The A, B, C directional movement is determined by the relationship between X,Y, Z, and the rotational position.
- 4th Axis movements may be Indexer Mode, Single-Axis Mode, or Multi-Axis Mode. The simplest mode of movement is the Indexer Mode. Single-Axis Mode can be either rotation or linear but only one axis at a time can move. Multi-Axis is the most complex mode because it involves both rotational and linear movement at the same time.

KEYTERMS

"X", "Y", "Z": Basic Linear references in the Cartesian Coordinate Word System.

"A", "B", "C": Basic Rotational references for multi-axis movements.

4th Axis: First reference to multi-axis movement.

Indexer Mode: 4th axis movement requiring a degree of rotation.

Single – Axis Mode: Involves a linear or rotational movement moving one axis at a time.

Multi – Axis Mode: Involves a linear and rotational movement moving at the same time.

IPM: Inches per Minute feed rates for standard linear movements.

Degrees per Minute: The required feed rate calculation for traveling around 4th axis circumferences.

DISCUSSION PROMPTS

EXPLAIN THE DIFFERENCES BETWEEN "A", "B", AND "C" AXIS SET-UP.

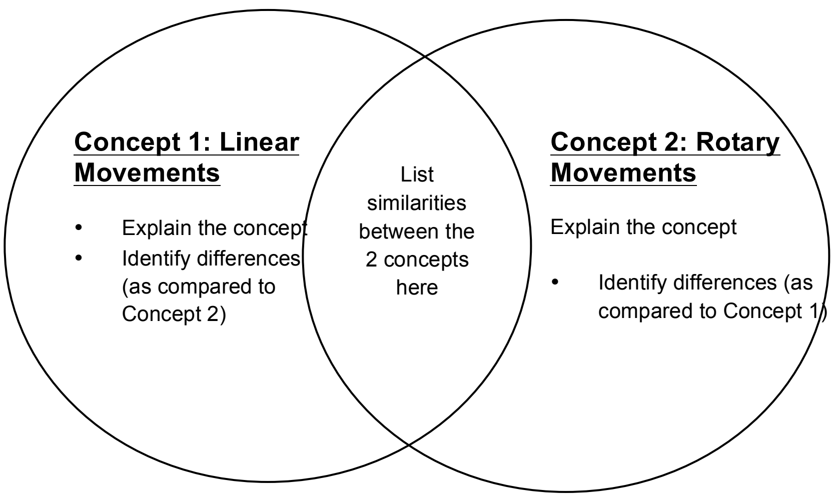
In Module 3, we discussed 4th axis set-up, what 4th axis position would benefit certain machining practices?

EXPLAIN THE DIFFERENCE BETWEEN LINEAR AND ROTATIONAL FEED RATE.

In Module 3, we discussed feed rate differences of linear and rotational movements, explain the calculations and how why they differ in value.

CRITICAL THINKING

	Concept #1 Single – Axis Movement	Concept #2 Multi – Axis Movement
Define or explain each concept		
Explain how the concepts are similar		
Explain how each concept is different with respect to specific attributes		



- Explain Linear and Rotary movements for 4th Axis machining.

ATTRIBUTION TABLE

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