

## Table of Contents

**Preface 7**

- Prerequisites 7
  - Basic machining practice experience 8
- Controls covered 8
- Limitations 8
  - Programming method 8
  - The need for hands-on practice 9
- Instruction method 9
  - Scope 9
  - Key Concepts approach 9
  - Lesson structure 10
  - Practice makes perfect 10
- Key Concepts and lessons 10

**Key concept 1: Know Your Machine From A Programmer's Viewpoint 11****Lesson 1: Machine Configurations 13**

- Vertical machining centers 13
  - C-frame style 14
    - Directions of motion (axes) for a C-frame style vertical machining center 14
    - Axis polarity 15
  - Knee style vertical CNC milling machines 16
  - Bridge-style vertical machining center (also called gantry-style) 17
- Horizontal machining centers 17
  - Directions of motion (axes) for a horizontal machining center 18
  - Axis polarity 19
- Programmable functions of machining centers 20
  - Spindle 20
    - Spindle speed 20
    - Spindle activation and direction 20
    - Spindle range 21
  - Feedrate 21
  - Coolant 22
  - Automatic tool changer 22
  - Measurement system mode (inch or metric) 23
- What else might be programmable? 24
- Key points for Lesson One: 24

**Lesson 2: Visualizing The Execution Of A CNC Program 27**

- Program make-up 28
  - Method of program execution 28
  - An example of program execution 28
    - Manual milling machine procedure: 29
    - CNC program: 29
    - Sequence numbers 30
    - A note about decimal point programming 30
    - A decimal point tip 31
    - Other mistakes of omission 31
    - Modal words 31
    - Initialized words 31
    - Letter O or number zero? 31
    - Word order in a command 32

**Lesson 3: Program Zero And The Rectangular Coordinate System 33**

- Graph analogy 33
  - What about the Z axis? 34
- Understanding polarity 35
- Wisely choosing the program zero point location 37
  - In X and Y 38
  - Reminder about axis movement 39
  - In Z 39
- Absolute versus incremental positioning modes 41
  - A decimal point reminder 42
- How the program zero location is specified in the program 42
- Setup-related tasks for program zero assignment 43

**Lesson 4: Introduction To Programming Words 47**

- Words allowing a decimal point 47
- O 48
- N 48
- G 48
- X 48
- Y 48
- Z 48
- A 48
- B 49
- C 49
  - Note about rotary axis designators and indexer activators 49
- R 49
- I, J, K 50
- Q 50
- P 50
- L 50
- F 50
- S 51
- T 51
- M 51
- D 51
- H 51
- EOB (end of block character) 51
- / (slash code) 52
- G and M codes 52
  - G codes 52
    - G code limitation: 52
    - Option G codes 52
    - What does initialized mean? 52
    - What does modal mean? 53
    - The most popular G codes 53
- Common M codes used on a CNC machining center 55
  - Other M Codes for your machine (found in your machine tool builder's manuals) 55
  - Lesson one – Machine configurations: 56

Lesson two – Visualizing program execution: 56  
 Lesson three – Program zero and the rectangular coordinate system: 56  
 Lesson four – Introduction to CNC words: 56

## Key Concept 2: You Must Prepare To Write Programs 57

Preparation and time 57  
 Preparation and safety 58  
 Typical mistakes 59  
 Syntax mistakes 59  
 Motion mistakes 59  
 Mistakes of omission 59  
 Process mistakes 60

## Lesson 5: Preparation Steps For Programming 61

Prepare the machining process 61  
 Develop the needed cutting conditions 63  
 An example 64  
 Cutting conditions can be subjective 64  
 Do the required math and mark-up the print 65  
 Marking up the print 67  
 Doing the math 68  
 What about milling operations? 69  
 Check the required tooling 70  
 Plan the work holding set-up 71  
 Other documentation needed for the job 72  
 Production run documentation 72  
 Program listing 73  
 Is it all worth it? 73

## Key Concept 3: Understand The Motion Types 75

What is interpolation? 75

## Lesson 6: Programming The Three Most Basic Motion Types 79

Motion commonalities 79  
 Understanding the programmed point of each cutting tool 79

Center drill 80  
 Spot drill (not shown above) 80  
 Drill 80  
 Reamer 80  
 Tap 80  
 Boring bar 81

What about milling cutters? 81

G00 – Rapid motion (also called positioning) 82  
 How many axes can be included in a rapid motion command? 83

About the dog-leg motion... 83

When do you use rapid motion? 84

What is a safe approach distance? 84

G01 – Linear interpolation (straight-line motion) 85

Using G01 for a fast-feed approach 86

A milling example 87

Drill holes with G01? 87

G02 and G03 – Circular interpolation (circular motion) 88

Which positions to program 88

Specifying arc size with the R word 88

The R word is not modal 90

Circular motion with directional vectors (I, J, and K) 91

Arc limitations 92

Full circle in one command 93

Planning your own tool paths 95

## Key Concept 4: Know The Compensation Types 97

### Lesson 7: Introduction To Compensation 99

What is compensation and why is it needed? 99

More on tolerances 100

The initial setting for compensation 100

When is trial machining required? 100

What happens as tools begin to wear? 101

What do you shoot for? 101

Why do programmers have to know this? 101

Understanding offsets 101

Offset organization 102

Offsets related to cutting tools 102

Offsets related to program zero assignment 103

How offsets are instated 103

### Lesson 8: Tool Length Compensation 105

The reasons why tool length compensation is needed 105

No two tools will have exactly the same length 105

A given tool's length will vary from one time it is assembled to the next 106

Tool data is entered separately from the program 106

Sizing and trial machining must often be done 106

What about interference and reach? 106

Programming tool length compensation 106

Choosing the offset number to be used with each tool 106

An example program 107

The setup person's responsibilities with tool length compensation 108

Typical mistakes with tool length compensation 109

Forgetting to instate tool length compensation 109

Forgetting to enter the tool length compensation value 109

Mismatching offsets 109

### Lesson 9: Cutter Radius Compensation 113

Will you need to learn this feature? 113

Reasons why cutter radius compensation is required 113

Calculations are simplified for manual programmers 113

Do you have a CAM system? 115

Range of cutter sizes 115

Do you use sharpened (re-ground) cutters? 116

Trial machining and sizing 117

Rough and finish milling with the same set of coordinates 117	T word brings a tool to the ready station, M06 commands the tool change 152
Do you have a CAM system? 118	Do you have a double-arm tool changer? 152
How cutter radius compensation works 118	T word does everything 154
Steps to programming cutter radius compensation 119	Tool change at beginning or end? 155
Step one: Instate cutter radius compensation 119	Does the machine even have an automatic tool changer? 155
The XY motion to the prior position 119	Understanding the G28 command 155
The Z motion/s to the Z axis work surface 121	What about G53? 156
The command instating cutter radius compensation that positions the cutting tool to the first surface to mill 121	A possible problem with initialized modes 157
The offset used with cutter radius compensation 122	How to use our given formats 157
The motion to the first work surface 123	<b>Lesson 12: Four Types Of Program Format 159</b>
Step two: Program the tool path to be machined 124	Format for vertical machining centers 159
Step three: Cancel cutter radius compensation 126	A note about documentation 162
What if I have more than one contour to mill? 127	Example program for vertical machining centers 163
Examples 128	A few questions about the program: 164
What if I use a computer aided manufacturing (CAM) system to prepare programs? 130	More on the optional stop word (M01) 164
The setup person's responsibilities with cutter radius compensation 130	Where is the restart command for each tool? 164
Rough and finish milling with the same set of tool path coordinates 131	What if my machine doesn't have fixture offsets? 165
A warning 132	Format for horizontal machining centers 167
<b>Lesson 10: Fixture Offsets 137</b>	<b>Key Concept 6: Special Features That Help With Programming 173</b>
Do you need to learn about fixture offsets? 137	<b>Lesson 13: Hole-Machining Canned Cycles 175</b>
Assigning multiple program zero points 138	Canned cycle commonalities 176
Programming with multiple program zero points 140	Description of each canned cycle 176
The potential trade-off with this method 141	G80 – Cancel the canned cycle mode 176
Reminder about tool length compensation values 141	G81 –Standard drilling cycle 176
Shifting the point of reference for fixture offset entries 142	G73 – Chip-breaking peck drilling cycle 176
Programming fixture offset entries 144	G83 – Deep-hole drilling cycle (full retract between pecks) 176
Some other applications for the common fixture offset 145	G84 – Right-hand tapping cycle 177
Allowing for variations in pallet changers 145	Feedrate for tapping 178
Allowing for variations after a mishap 145	Tapping can be a little scary 178
Differences in spindle gap from one machine to another 145	Coolant for tapping? 178
To enhance safety during dry-runs 145	When to tap 179
<b>Key Concept 5: You Must Provide Structure To Your CNC Programs 147</b>	G74 – Left-hand tapping cycle 179
<b>Lesson 11: Introduction To Program Structure 149</b>	G82 – Counter-boring cycle 179
Objectives of your chosen program structure 149	G89 – Counter-boring cycle for a boring bar 179
Reasons for structuring programs with a strict and consistent format 149	G86 – Standard boring cycle (leaves drag line witness mark) 180
Familiarization 149	Controlling move-over at hole-bottom 180
Consistency 150	A tip for boring bar tip pointing 181
Re-running tools in the program 150	G85 – Reaming cycle (most programmers use G81 for reaming) 182
Efficiency limitations 151	G87 and G88 – Manual cycles (not recommended) 182
Machine variations that affect program structure 151	Words used in canned cycles 182
M code differences 151	A simple example 183
Automatic tool changer variations 152	Understanding G98 and G99 185
	Canned cycles and the Z axis 187
	Extended example showing canned cycle usage 189
	Using canned cycles in the incremental positioning mode 193
	<b>Lesson 14: Working With Subprograms 199</b>

The difference between main- and sub- programs 199	Plane selection commands (G17, G18, and G19) 229
Loading multiple programs 201	Inch/metric mode selection G20 and G21 230
Words used with subprograms 201	Secondary reference position, G30 231
Nesting subprograms 202	Scaling commands, G50 and G51 231
Machining multiple identical pockets 202	G50.1 and G51.1 - Mirror image commands 231
Understanding G52 – temporary shift of program zero 204	Applications for mirror image 231
Multiple hole-machining operations on a series of holes 204	The two ways to activate mirror image 232
Do you want to include all of the hole-locations in the subprogram? 206	Motion relative to zero return position, G53 233
Rough and finish contour milling 207	Single direction positioning mode, G60 233
Two utility applications for subprograms 208	Coordinate rotation G68 and G69 234
Control programs 208	<b>Lesson 16: Programming Rotary Devices 239</b>
A trick to get more fixture offsets 209	The difference between an indexer and a rotary axis 239
What is parametric programming (custom macro B)? 211	A note to horizontal machining center programmers 239
Part families 211	Benefits of rotary devices 240
User defined canned cycles 211	Indexers 240
Utilities 211	Programming indexer rotation 240
Complex motions and shapes 211	90 degree and 45 degree indexers 240
Driving accessory devices 212	Five degree indexers 241
<b>Lesson 15: Other Special Programming Features 215</b>	One degree indexer 241
Block delete (also called optional block skip) 215	Rotary axes 241
Applications for block delete 216	How to program a rotary axis departure 242
Another optional stop 216	Comparison to other axes 242
Trial machining 216	Zero return position 242
Trial boring 217	Polarity 243
Sequence number (N word) techniques) 219	Designation of program zero 244
Eliminating sequence numbers 219	Absolute positioning mode 244
Using special sequence numbers in program restart commands 219	Incremental positioning mode 247
Using sequence numbers as statement labels 220	Clamping the rotary axis for machining after rotation 249
Using block delete to exit a series of commands 220	Rapid and straight line motion 249
Using statement labels to change machining order 221	Canned cycle usage 250
Other G codes of interest 222	Approaching rotary device applications 250
Thread milling, G02 & G03 222	Program zero point selection 250
G04 - Dwell command 224	Assigning one program zero point per side 252
G09 and G61 - Exact stop check 225	Using one central program zero point 252
G10 - Offset setting by programmed command 226	Example program using rotary device 254
Applications for G10 226	<b>Practice exercises and programming activities 261</b>
Polar coordinates (G15 and G16) 228	<b>Programming Activities 293</b>
	<b>Answers to Exercises 333</b>
	<b>Answers to programming activities 343</b>
	Index 357