Table of Contents

Preface 9

Prerequisites 9 Basic machining practice experience 9 Controls covered 10 Limitations 10 Programming method 10 The need for hands -on practice 10 Instruction method 11 Scope 11 Key Concepts approach 11 Lesson structure 12 Practice makes perfect 12 Key Concepts and lessons 12 Enjoy! 12

Key Concept 1: Know Your Machine From A Programmer's Viewpoint 13

Lesson 1: Machine Configurations 15

Types of CNC turning centers 15 Universal style slant bed turning center 15 Directions of motion (axes) for a universal style slant bed turning center 16 Live tooling for a universal style slant bed turning center 17 Other types of CNC turning centers 19 Chucking style slant bed turning center 19 Twin spindle horizontal bed turning centers 20 Sub-spindle style turning centers 21 Vertical single spindle turning centers 22 Twin spindle vertical turning centers 23 Gang style turning centers 23 Swiss-type CNC turning centers (also called sliding headstock turning centers) 24 Programmable functions of turning centers 24 Spindle 24 Spindle speed 24 Spindle activation and direction 25 Spindle range 25 Feedrate 26 Turret indexing (tool changing) 27 Turret station and offset selection 28 Coolant 28 Other possible programmable functions 28 Tailstock 28 Programmable steady rest 29 Bar feeders and chuck activation 29 Part catcher 29 Tool touch off probe 29 Automatic tool changing systems 30 Exceptions to X axis 30 A quick fix 30 Gang style turning centers with cutting tools on both sides of the spindle centerline 30 Center cutting axis 31 What else might be programmable? 31

Key points for Lesson One: 31 Lesson 2: Understanding Turning Center Speeds and Feeds 33 The machining operation to be performed 33 The material to be machined 33 The material of the cutting tool's cutting edge 33 The two ways to select spindle speed 34 When to use constant surface speed mode 35 When to use rpm mode 36 How fast will the spindle be running when constant surface speed is used? 37 How fast can the spindle rotate? 37 How to specify a maximum speed for the constant surface speed mode 38 A potential limitation of constant surface speed 38 The two ways to specify feedrate 39 When to use the feed per revolution mode 39 When to use the feed per minute feedrate mode 40 An example of speed and feed usage 40 Key points for Lesson Two: 41 Lesson 3: Visualizing The Execution Of A CNC Program 43 Program make-up 44 Method of program execution 44 An example of program execution 44 The CNC program to machine the 2.875 diameter 45 Sequence numbers 46 A note about decimal point programming 46 A decimal point tip 47 Other mistakes of omission 47 Modal words 47 Initialized words 47 Letter O or number zero? 47 Word order in a command 48 Key points for Lesson Three: 48 Lesson 4: Program Zero And The Rectangular **Coordinate System 49** Graph analogy 49 More about polarity 50 Wisely choosing the program zero point location 51 In X 51 In Z 51 Absolute versus incremental positioning movements 56 Another way to specify absolute and incremental positioning 56 A decimal point reminder 57 Key points for Lesson Four: 58 Lesson 5: Introduction To Programming Words 61 Words allowing a decimal point 61 O 62 N 62 G 62

X 62 Y 62 Z 62 U 63 W 63 C 63 R 63 I & K 63 F 63 E 63 S 64 T 64 M 64 P 64 Q 64 L 64 EOB (end of block character) 65 / (slash code) 65 G and M codes 65 G codes 65 G code limitation: 65 Option G codes 65 What does initialized mean? 66 What does modal mean? 66 The most popular G codes 66 Common M codes used on a CNC turning center 67 Key points for Lesson Five: 68 Key points: Key Concept one, Know your machine from a programmer's viewpoint 69

Key Concept 2: You Must Prepare To Write Programs 71

Preparation and time 71 Preparation and safety 72 Typical mistakes 73 Syntax mistakes 73 Motion mistakes 73 Mistakes of omission 73 Process mistakes 74

Lesson 6: Preparation Steps For Programming 75

Prepare the machining process 75 Develop the needed cutting conditions 77 An example 78 Roughing tools 78 Drilling 79 Finishing tools 79 Chasing threads 79 Cutting conditions can be subjective 79 Do the required math and mark-up the print 80 Other ways to come up with coordinates 83 Marking up the print 83 Doing the math 84 Check the required tooling 86 Plan the work holding set-up 87 Other documentation needed for the job 88 Production run documentation 89

Program listing 89 Is it all worth it? 89 Key points for Lesson Six: 89 **Key Concept 3: Understand The Motion** Types 93 What is interpolation? 93 Lesson 7: Programming The Three Most Basic Motion Types 97 Motion commonalties 97 Understanding the programmed point of each cutting tool 97 G00 Rapid motion (also called positioning) 101 What is a safe approach distance? 102 What about feed-off distance? 103 G01 linear interpolation (straight line motion) 104 Using G01 for a fast feed approach 106 G02 and G03 Circular motion commands 107 Specifying a circular motion with the radius word 107 Circular motion with directional vectors (I and K) 109 What's wrong with this picture? 110 Key points for Lesson Six: 113 Key Concept 4: Know The Compensation Types 115 More on interpreting tolerances 115 What if a measured dimension is not on-size (not acceptable)? 116 The target value 117 Another consideration - tool wear 117 Do you really want to target the mean value? 118 Lesson 8: Introduction To Compensation 119 What is compensation and why is it needed? 119 The initial setting for compensation 120 When is trial machining required? 120 What happens as tools begin to wear? 121 What do you shoot for? 121 Why do programmers have to know this? 121 Understanding offsets 121 Offset organization 122 Offset pages on the display screen 122 Key points for Lesson Eight: 124 Lesson 9: Geomety Offsets And Wear Offsets 125 Review of reasons for using geometry offsets to assign program zero 125 How geometry offsets work 125 The total program zero assignment value 126 Warning about the machine lock feature: 127 Minimizing program zero assignment effort from job to iob 127 So when do you clear geometry offsets? 129 Wear offsets 129 Which dimension do you choose for sizing? 130 How wear offsets are programmed 130 What about wear offset cancellation? 131 Secondary wear offset applications 131 Flip jobs 132

Two or more critical diameters 132 Unwanted taper 132 Grooving into different areas of the workpiece 132 Key points for Lesson Nine: 132

Lesson 10: Tool Nose Radius Compensation 137

Keeping the cutting edge flush with the work surface at all times 139

When to use tool nose radius compensation 140 Steps to programming tool nose radius compensation 140

Instating tool nose radius compensation 140 Programming motion commands to machine the workpiece 141

Canceling tool nose radius compensation 142 An example program 142

Tool nose radius compensation from a setup person's point of view 143

What if my machine does not have geometry offsets? 145

What if I forget to enter tool nose radius compensation values? 145

What if I enter tool nose radius compensation values into wear offsets? 145

What if I enter tool nose radius compensation values into both the geometry and wear offsets? 145

Programming tool nose radius compensation value entries 145

Another example program showing tool nose radius compensation 145

Key points for Lesson Ten: 147

Key Concept 5: You Must Provide Structure To Your CNC Programs 149

Lesson 11: Introduction To Program Structure 151

Objectives of your program structure 151 Reasons for structuring programs with a strict and consistent format 151 Familiarization 151 Consistency 152 Re-running tools in the program 152 Efficiency limitations 154 Machine variations that affect program structure 155 M code differences 155 G code numbering differences 156 Turret variations 157 How do you determine a safe yet efficient index position? 157 What if my machine doesn't have geometry offsets? 158 A few spindle concerns 159 Spindle limiting 159 Choosing the appropriate spindle range 160 Which direction do you run the spindle? 160 How do you check what each tool has done? 160 Safety commands 160

How to use our given formats 161 Key points for Lesson Eleven: 162

Lesson 12: Four Types Of Program Format 163

Format for assigning program zero with geometry offsets 164

Format for assigning program zero in the program with G50 165

A reminder about the program's starting point and tool change position 165

Program startup format (assigning program zero in the program) 165

Tool ending format (assigning program zero in the program) 166

Tool startup format (assigning program zero in the program) 167

Program ending format (assigning program zero in the program) 167

Understanding the formats 167

G Words 167

M Words 168

Other M Words Related to Turning Centers 168 Other Words In The Format 169

Example programs showing format for turning centers 169

Where are the restart commands? 171 Example program when assigning program zero in the program 171

Where are the restart commands? 172

Suggestions for cycle time improvements. 173 Combine M codes in motion commands 173 Minimize spindle dead time 173

Efficiently programming spindle range changes 176 Minimize spindle reversals 177

Key points for Lesson Twelve: 178

Key Concept 6: Special Features That Help With Programming 181

Control series differences 182

Lesson 13: One-Pass Canned Cycles 183 Cycle consistencies 183 G90 - One pass turning and boring cycle 184 G92 - One pass threading cycle 185 G94 - One pass facing command 186 Example of G90 and G94 186 Example of G92 command 187 Key points for Lesson Thirteen: 188

Lesson 14: G71 And G70 – Rough Turning And Boring Followed By Finishing 189

G71 - Rough turning and boring 189 The two phases of G71 190 Understanding G71 command words 192 P word 192 U word 192 U word 192 W word 192 D word 192 F word 193 What about finishing? 193 Example showing G71 for rough turning and G70 for finish turning 193 Using G71 for rough boring 195 Limitations of the G71 command 197 Different format for some controls (with two-line multiple repetitive cycle) 198 Key points for Lesson Fourteen: 198

Lesson 15: G72-G75 – Other Multiple Repetitive Cycles 201

G72 - Rough facing 201 Different format for two-command multiple repetitive cylces 203 G73 - pattern repeating 203 D word 204 I word 204 K word 204 Example of G73 pattern repeating 205 Can you use G73 for castings and forgings? 206 Different format for two-command multiple repetitive cycles 207 G74 - peck drilling 207 What if I must clear chips between pecks? 208 Different format for two-command multiple repetitive cycles 209 G75 - grooving cycle 209 Key points for Lesson Fifteen: 210 Lesson 16: G76 Threading Command 211 X word 211 Z word 212 What is thread chamfering? 212 K word 212 D word 212 A word 213 F word and E word 213 I word 213 Q word 214 Example program for threading 214 Other tips on threading 215 When possible, thread in the lowest spindle range 215 Thread in the rpm mode (G97) 215 Watch out for maximum allowable feedrate 215 Thread with thread chamfering turned off 215 Finish the thread before removing workpiece 216 Right hand threads versus left hand threads 216 Offsetting for threading tools 216 Start the tool far enough away from the thread being machined 216 Minimum depth-of-cut, final pass depth, and number of spring passes 216 Disabled or modified control functions during threading 216 Tapered threads 217 Multiple start threads 218 Different format for two-command multiple repetitive cycles 220

What about tapping? 220 Tap in the rpm mode 220 Tap in the low range 220 Use G32 as the motion command for tapping 221 Use a tension/compression tap holder 221 Keep the approach position 0.2 inch from the Z surface to tap 221 Key points for Lesson Sixteen: 222 Lesson 17: G76 Working With Subprograms 223 The difference between main- and sub- programs 223 Loading multiple programs 223 Words used with subprograms 224 A quick example 224 Nesting subprograms 226 Applications for subprograms 226 Repeated machining operations 226 Control programs 226 Utility applications 227 Example for repeating machining operations multiple identical grooves 227 Example for control program applications - flip iobs 229 Example for utility applications - bar feeder activation 230 Special notes about M99 232 Ending a main program with M99 232 Changing the order of program execution with M99 232 What is parametric programming (custom macro B)? 235 Part families 235 User defined canned cycles 236 Utilities 236 Complex motions and shapes 237 Key points for Lesson Seventeen: 238 Lesson 18: Other Special Programming Features 239 Block delete (also called optional block skip) 239 Applications for block delete 240 Another optional stop 240 Trial machining 240 Warning about block delete applications 242 Sequence number (N word) techniques) 242 Eliminating sequence numbers 242 Using special sequence numbers in program restart commands 242 Documenting your programs with messages in parentheses 244 General information about the job 244 **Tool information 245** At every program stop 245 To document anything out of the ordinary 245 For changes made after a dispute 246 Automatic corner rounding and chamfering 246 Other G codes of interest 248 G04 - Dwell command 248

Other G codes 249 Key points for Lesson Eighteen: 250 Lesson 19: Special Machine Types And Accessories251 Work holding and work support devices 251 Work holding devices 251 Three jaw chucks 252 Programmable features of three jaw chucks 254 Collet chucks 255 Work support devices 257 Tailstocks 257 The tailstock body 257 Tailstock quill 258 Tailstock center 258 Tailstock alignment problems 258 Programming considerations 258 Steady rests 259 Bar feeders 260 How a bar feeder works 260

Styles of bar feeders 260 How to program for bar feeders 261 Determining how much to feed the bar 261 The steps to bar feeding 262 The redundancy of bar feed programming 264 When to program the bar feed 264

Workholding considerations 260

Ending a bar feed program 264 An example bar feeding program 265

Part catchers 267

Live tooling 267

Features of live tooling turning centers (also called mill/turn machines) 267

Rotating tools 267 Special tool holders 267 Precise control of main spindle rotation 268 Only one way to specify speed and feedrate 268 Hole machining canned cycles 268 Polar coordinate interpolation 268 Selecting the main spindle mode 269 Programming an indexer 269 Example program for an indexer 270 Programming a rotary axis (C axis) 272 Angular values 272 Zero return position 272 Rapid versus straight line motion 272 Program zero assignment 272 Absolute versus incremental 273 Canned cycles for hole machining 274 How do you specify the machining direction? 274 Canned cycle types 274 Words used in canned cycles 275 Understanding polar coordinate interpolation 276 Other machine types 280 Twin spindle turning centers 281 Sub-spindle turning centers 281 Swiss-type turning centers (also called s liding headstock turning centers) 281 Practice exercises 283 **Programming Activities319** Answers to Exercises 367

Answers to programming activities 376