

Table of Contents

PREFACE	11	Who creates a formula?	29
Prerequisites	11	More about numbers	30
Basic machining practice experience	12	Integers.....	30
Math.....	12	Real numbers.....	30
Motivation.....	12	Decimal format.....	30
Controls covered	12	Fractional format.....	30
Limitations	12	Converting fractional format to decimal format	31
The need for hands-on practice	12	Decimal equivalents for common fractions ...	32
Instruction method	13	Decimal places.....	32
Scope	13	Rounding to a given number of decimal places ..	32
Key Concepts approach.....	13	Measurement systems	33
Lesson structure	14	Saying numeric values out loud in a machine shop	34
Practice makes perfect.....	14	Saying values in the Metric system	35
Key Concepts and lessons	14	Understanding polarity.....	35
Enjoy!	14	Summary of shop math	35
 		Interpreting an engineering drawing	37
GET READY TO LEARN ABOUT CNC TURNING CENTERS	15	Orthographic projection.....	37
 		Line appearance	38
Basic Machining Practices Required for CNC Turning Centers	17	Non-standard views.....	39
Shop Safety	17	Isometric views.....	39
Safety equipment	17	Angular views	40
Safety practices	18	Detail views	40
Handling raw material	19	Section views.....	41
Finished workpiece handling.....	19	Multiple page engineering drawings.....	42
Tightening and loosening fasteners	19	Do you have a sample workpiece?	42
Getting around the shop	20	Drawing scale	42
Behavior	20	Dimensioning.....	43
Turning-center-specific safety practices	20	Measurement systems	44
Shop math	21	Other descriptive notes.....	44
A few suggestions for choosing your calculator ..	21	Title block	44
Keep it simple	21	Revisions.....	44
Watch out for trick functions	21	Introduction to tolerance interpretation	46
Avoid solar powered calculators	22	Who specifies tolerance?	47
Big buttons – big display	22	Dimensional tolerances	48
Be sure it has clear entry button.....	22	Tolerance terminology	49
Calculator basics.....	23	Judging acceptability	50
What is an arithmetic expression?.....	23	What are you shooting for?.....	50
Practice makes perfect	24	Calculating the deviation (adjustment) amount	50
The most basic arithmetic functions	24	Determining the deviation (sizing adjustment) polarity.....	50
Addition.....	24	More on dimensional tolerance specifications	50
Subtraction	25	High/low limits	51
Multiplication	25	Uneven +/-.....	51
Division	25	You may get some help	52
More on the priority of arithmetic operators	25	Implied tolerances.....	52
The use of parentheses in an expression	25	Four conditions of a measured surface.....	52
Does your calculator have parentheses? ...	26	If the surface is not within low and high limits, can the workpiece be saved?.....	52
Does your calculator have one or more memories?.....	26	Tool wear affects acceptability.....	53
What is a formula?	28		

Cutting tool type affects how quickly tool wear affects machined surfaces	53	Summary	96
Dealing with deviations.....	54	What Does A CNC Turning Center Do?	99
Choosing the surface to measure	54	Comparing a CNC turning center to other types of machines	99
More on determining deviation amount ...	55	Machining action of any lathe	101
Setup sizing versus production run sizing.....	55	The importance of basic machining practice to CNC people	102
During setup.....	55	The three general turning applications	103
During production runs.....	56	Shaft work.....	103
Why targeting the mean value may not be best	56	Chucking work.....	104
Geometric (surface relationship) tolerances	57	Bar work.....	105
Measuring devices	60	How a cutting tool works	106
Checking calibration.....	60	External versus internal work	107
Measurement systems affect gauges	60	Roughing versus finishing operations	108
Gauge resolution	61	Roughing	108
Common gauge resolutions in each measurement system	61	How much finishing stock should be left for finishing?	109
Environments for measuring	61	Deterioration of roughing tools	109
Minimizing the impact temperature changes	63	When is finishing done?	110
Measurement types.....	63	Finishing.....	110
Gauge types	65	Some examples of rough and finish turning	111
Fixed gauges.....	66	Machining operations performed by single point cutting tools	114
Go/No-go fixed gauges	66	Components of single point cutting tools.....	116
Fixed gauges with dial displays	67	The holder	116
Importance of the secondary dial.....	71	Right hand versus left hand cutting tools	118
More on needle rotation direction and internal versus external measurements.....	71	The insert	120
Variable gauges.....	74	More about the geometry of a single point cutting tool.....	121
Display types	76	Insert shape.....	121
Electronic digital display	76	Lead angle, nose angle, clearance angle.....	121
Dial display	77	Nose radius	122
Dial indicators	79	Rake and relief angle.....	122
Vernier display	81	Other attributes of single point cutting tools ..	122
Display type demonstrations	82	Chip breaker.....	123
Accuracy of the measuring device	82	Clamp screw/pin, clamp, and/or retaining pin	123
Checking calibration.....	82	The difference between indexing and replacing an insert	123
A general suggestion for getting started with any variable gauge	84	Tool life	124
Interpreting (reading) the displayed value of a Vernier micrometer	85	Chatter (vibration)	124
General use of a micrometer that has a clamp and ratchet.....	86	Part finish	124
Steps to reading the displayed value for a micrometer that measures in inches.....	86	Shim	124
Steps to reading the displayed value for a micrometer that measures in millimeters .	88	How carbide inserts are specified	124
Interpreting (reading) the displayed value of a dial caliper.....	91	First letter (shape):.....	125
Steps to reading the displayed value for a micrometer that measures in inches	91	Second letter (relief angle):	125
Steps to reading the displayed value for a micrometer that measures in millimeters .	92	Third letter (tolerances):	125
Interpreting (reading) the displayed value of a Vernier caliper.....	93	Fourth letter (type of insert).....	126
Using a depth gauge	95	First digit (size of insert).....	126
Testing for calibration	96	Second digit (thickness)	126
		Third digit (tool nose radius).....	126
		Understanding wear on single point cutting tools	126
		Introduction to cutting conditions	128

How cutting conditions are recommended.....	128	Cutting conditions for finish facing and turning	149
Spindle speed: Converting from surface feet per minute (sfm) to revolutions per minute (rpm).....	129	Cutting tools used for finish facing and turning	150
Spindle speed: Converting from meters per minute (mpm) to revolutions per minute (rpm)	129	Sizing adjustments needed during the life of the finish facing and turning tool	150
Feedrate: Converting inches per revolution (ipr) to inches per minute (ipm)	129	Finish boring	151
Feedrate: Converting millimeters per revolution (mmpm) to millimeters per minute (mmpm).....	129	About the finishing stock left on faces	152
Getting recommendations for speed and feed	129	Understanding surface finish requirements.....	152
Other cutting conditions related to machining operations	130	Cutting conditions for finish facing and turning	152
Cutting tool materials.....	131	Cutting tools used for finish boring	153
Getting recommendations for cutting conditions	131	Sizing adjustments needed during the life of the finish boring bar	153
The machining process	131	Other common lathe machining operations	153
Rough facing.....	132	Necking (also called grooving)	153
More on depth-of-cut	133	Cutting conditions for necking	154
Roughing facing all external raw material....	133	Parting (also called cut-off)	155
Finishing stock – on diameters and faces.....	134	Threading	155
Cutting conditions for rough facing.....	134	Cutting conditions for threading	156
Cutting tools used for rough facing.....	135	Cutting tools for threading	157
Sizing adjustments needed during the life of the rough facing tool	136	Measuring threads	157
Rough Turning	136	Machining internal threads	158
More about depth-of-cut	137	Sizing adjustments needed during the life of a threading tool.....	158
Finishing stock – on diameters and faces.....	137	Workholding and support devices	158
Cutting conditions for rough turning.....	137	Three jaw chucks	159
Cutting tools used for rough turning.....	138	Top tooling	160
A note about back turning.....	139	Hard jaws.....	160
Sizing adjustments needed during the life of the rough turning tool.....	140	Soft jaws	161
Drilling	140	Programmable and/or manual features of three jaw chucks	162
Cutting conditions for drilling.....	141	Chuck jaws open and close.....	162
Other types of drills.....	141	Chucking pressure	162
Spade drills	141	Chucking direction.....	163
Carbide insert drills	142	Collet chucks.....	163
Sizing adjustments needed during the life of a drill	143	Bar feeding with collet chucks.....	164
Rough boring	143	Work support devices.....	165
More on depth-of-cut	143	Tailstocks	165
About length-to-diameter ratio	143	The tailstock body	166
Finishing stock – on diameters and faces.....	144	Spindle considerations	166
Cutting conditions for rough boring.....	144	Tailstock quill.....	166
Cutting tools used for rough boring	145	Center	166
Sizing adjustments needed during the life of the rough boring bar	146	Tailstock alignment.....	167
Where we stand in the process.....	146	Steady rests	167
Finish facing and turning	147	Summary of key points.....	168
A reminder about the finishing stock left on faces	147	Conclusion to Key Concept Number One	168
Understanding surface finish requirements.....	148	 	
		KNOW YOUR MACHINE FROM AN OPERATOR'S VIEWPOINT	171
		The need for hands-on experience	171
		General Flow of the CNC Process	173
		Companies that use CNC turning centers	173
		What will you be doing?.....	174

Flow of the CNC process	174	Program Display Pages.....	200
Study the workpiece engineering drawing	175	Offset Display Pages.....	201
Decision is made as to which CNC machine to use	175	Graph Display Pages.....	202
.....	175	Other Display Screen Modes.....	202
The machining process is developed	175	The Keyboard	202
Tooling is ordered and checked	175	Letter Keys	203
The program is developed	175	Slash Key (/).....	203
Setup and production run documentation is made	175	Number Keys.....	203
.....	175	Decimal Point Key	203
Program is loaded into the CNC control's memory	175	CAN Key.....	203
.....	175	EOB Key.....	203
The setup is made.....	176	Input Key	203
The program is cautiously verified (still	176	Cursor Control Keys.....	203
considered part of setup)	176	Program Editing Keys	203
Production is run.....	176	Reset Key.....	203
Corrected version of the program is stored for	176	The Machine Panel.....	204
future use.....	176	Power Buttons	204
Machine Configurations	179	MODE Switch	204
Types of CNC turning centers	179	CYCLE START Button.....	204
Universal style slant bed turning center	179	FEED HOLD Button	205
Directions of motion (axes) for a universal style	180	FEEDRATE OVERRIDE Switch	205
slant bed turning center	180	RAPID OVERRIDE Switch	205
X is specified in diameter	181	EMERGENCY STOP Button.....	205
Live tooling for a universal style slant bed	181	Conditional Switches.....	206
turning center	181	DRY RUN On/Off Switch	206
Other types of CNC turning centers.....	182	SINGLE BLOCK On/Off Switch.....	206
Chucking style slant bed turning center	183	BLOCK DELETE On/Off Switch (also called	206
Twin spindle horizontal bed turning centers	183	optional block skip)	206
Sub-spindle style turning centers	184	OPTIONAL STOP On/Off Switch.....	206
Vertical single spindle turning centers.....	185	Buttons and Switches for Manual Functions	206
Twin spindle vertical turning centers.....	186	Axis Jogging Controls (continuous jog) ...	206
Gang style turning centers.....	186	Axis Jogging Controls (incremental jog) ...	207
Swiss-type CNC turning centers (also called	187	Hand wheel Controls.....	207
sliding headstock turning centers).....	187	Spindle Control.....	207
Programmable functions of turning centers	188	Turret Index Control.....	207
Spindle	188	Indicator Lights and Meters	207
Spindle speed.....	188	Spindle RPM and Horsepower Meters.....	207
Spindle activation and direction	188	Axis Drive-Motor Horsepower Meter	208
Spindle range	189	Cycle Indicator Lights	208
Feedrate.....	189	Reference Position Indicator Lights	208
Turret indexing (tool changing)	190	Optional Stop Indicator Light	208
Turret station and offset selection	191	Other Buttons and Switches on the Machine	208
Coolant.....	192	Panel	208
Other possible programmable functions	192	Other Operation Panels on your Turning Center	208
Tailstock	192	208
Programmable steady rest.....	192	More About the Mode Switch	208
Bar feeders and chuck activation.....	192	The Manual Mode Switch Positions.....	208
Part catcher.....	192	MDI Mode Switch Position.....	209
Tool touch off probe	193	Commanding an MDI Reference Return	209
Key points for Lesson Four:	193	The Complete Procedure to Execute an MDI	210
Buttons And Switches on the Operation Panels	197	Command.....	210
The Most Important Operation Panels	197	Commanding an MDI Turret Index	210
Control Panel Functions.....	198	Commanding Spindle Activation with MDI ..	210
Display Screen Function Keys.....	199	Other Times when MDI is used	211
		Commanding Motion with MDI	211
		EDIT Mode Switch Position	211

To Make a Program in Memory the Active Program (to call up a program)	212	To Save Programs to an External Device	223
To Enter a New Program	212	To Use Background Edit.....	223
What if I Make a Mistake when Typing?	212	Setup Procedures	223
Program Operation Mode	212	To Mount Jaws	223
To Run the Active Program from the Beginning	213	To Measure and Enter Program zero Assignment Values	223
Important Operation Procedures.....	217	For the X-Axis Geometry Offset.....	223
Develop Your Own Operation Handbooks	217	For the Z-Axis Geometry Offset.....	224
Manual Procedures:	217	To Measure and Enter the Work Shift Value	224
MDI Procedures.....	217	Program Running Procedures.....	224
Program Manipulation Procedures.....	217	To Run the Program (in normal production - no verification techniques).....	224
Setup Procedures	218	To Rerun Tools.....	225
Program Running Procedures	218	To Do a Free-Flowing Dry Run	225
Blank Procedure Form.....	218	To Do a Normal Air Cutting Run	225
Sample Operation Handbook (for a machine with a FANUC OiF control)	219	To Run the First Workpiece	225
Manual Procedures	219	To Cancel the Cycle.....	226
To Power-Up the Machine	219	To Clear an Alarm	226
To Do a Reference Return (send each axis to its reference position).....	219		
To Index the Turret.....	219	KNOW THE COMPENSATION TYPES	229
To Start the Spindle.....	219	Introduction To Compensation	231
To Jog the Axes (using continuous jog)	219	What is compensation and why is it needed?	231
To Jog the Axes (using incremental jog).....	219	Tolerance review	232
To Use the Hand Wheel.....	220	What if a Measured Attribute is not On-Size (not acceptable)?	232
To Set Axis Displays	220	The Target Value	232
Origin.....	220	One More Consideration – Tool Wear	233
Preset	220	Do You Really Want to Target the Mean Value?	233
To Enter Wear Offsets.....	220	The Initial Setting for Compensation.....	234
+INPUT (Modifies current offset value) ..	220	When is Trial Machining Required?.....	234
INPUT (Overwrites current offset value)..	220	What happens as tools begin to wear?	234
MDI Procedures.....	220	Never make sizing adjustments by changing the CNC program!	235
To Execute an MDI Command	220	Understanding Offsets	235
Program Manipulation Procedures.....	221	Offset Organization	236
To Get Ready to Edit Programs	221	Offset Pages on the Display Screen	236
To Show a Directory of Programs.....	221	How Offsets are Instated.....	238
To Call up a Program from within the CNC Memory (make it the active program)	221	Key points for Lesson Seven:	238
Method 1: (from the program page, assumes you know the program number)	221	Geometry Offsets and Assigning Program Zero.....	241
Method 2: (from the directory/folder page)	221	How is the program zero point determined?241	
To Load a Program	221	In X.....	241
To Delete a Program.....	222	In Z.....	241
To Search within a Program	222	Determining the Geometry Offset Values	243
Search with Cursor Keys	222	Understanding Program zero Assignment Values	244
Find the Next Word Occurrence Using Only the Letter Address.....	222	What is the Reference Position?	244
Find the Next Word Occurrence Using the Whole Word	222	Program zero Assignment Values.....	245
To Alter, Insert, & Delete	222	The Relative Position Display Page.....	246
Alter.....	222	Other Kinds of Cutting Tools	247
Insert	222	Other Considerations that Affect Program Zero Assignment Values	248
Delete	222		

How Accurate are the Program Zero Assignment Values?	249	Tool #1: Rough Face and Turn Tool.....	280
Understanding Geometry Offsets	249	Tool #2: Finish Face and Turn Tool.....	280
How Geometry Offsets are Instated	251	Tool #3: 3.0-mm (or 0.125-in) Wide Grooving Tool	280
Three Common Ways to Assign Program zero	251	A Reminder About Up-Coming Jobs.....	280
Using a Tool Touch-Off Probe (1st choice)	252	A Reminder About Target Values.....	281
Stylus Use.....	253	Tool Nose Radius Compensation.....	285
How it Works	256	Why Tool Nose Radius Compensation is Required	285
What About the Wear Offset for a Cutting Tool that has been Probed?.....	256	+The Size of the Deviation	287
A Note about Tool Pressure.....	256	Keeping the Cutting-Edge Flush with the Work Surface	287
Determining and Entering the Work Shift Value	257	When to use Tool Nose Radius Compensation	288
A Note about the Polarity of the Work Shift Value	259	Tool Nose Radius Compensation from a Setup Person's Viewpoint	288
Using Geometry Offsets with Work Shift to Assign Program Zero (2nd choice)	259	If You Forget to Enter Tool Nose Radius Compensation Values	290
The Measure Function	260	Conclusion to Key Concept Number Three:	290
Using Geometry Offsets Without Work Shift to Assign Program zero (3rd choice)	262		
What if a Machine Does Not Have the Measure Function?	263	MASTER TASKS TO RUN A CNC TURNING CENTER	293
Wear Offsets	267	Tasks Required to Setup a CNC Turning center.....	295
Review of the T-Word	268	A CNC job from start to finish	295
About Wear Offset Cancellation	268	Setup documentation	297
How to Enter Wear Offsets	268	Tear down the previous setup and put everything away.....	298
Which is Better, [INPUT] or [+INPUT]?	270	Gather the components needed to make the setup	298
What if my Machine Does Not Have a [+INPUT] Soft Key?	270	Make the workholding setup	298
Sizing in a Tool After it has Just Been Placed in the Turret	271	How to mount jaws in the correct serrations	298
Sizing in a New Cutting Tool with Trial Machining	272	The diameter at which to mount jaws	299
Causes for the Initial Deviation	272	Using a long boring bar	299
Dealing with Deviations Caused by Tool Wear	273	Actually mounting jaws.....	299
After a Dull tool is Replaced	274	A note about soft jaws	300
If the Machine has a Tool Touch-Off Probe	274	Machining soft jaws during setup.....	300
Consistently Replacing Inserts	275	Other devices related to work holding setup	302
Consistently Indexing Inserts	275	Assemble cutting tools.....	302
Minimizing the Need for Trial Machining	276	A reminder about mounting inserts.....	303
Going from Job to Job	276	Load cutting tools into the turret and adjust coolant nozzles.....	303
When do you Clear Wear Offsets?	277	Assign program zero for each new tool	303
A More Complex Example	277	Enter tool nose radius compensation values (if the programmer uses this feature).....	303
Running the First Workpiece – One Tool at a Time	278	Load the CNC program/s.....	304
Tool #1: Rough Face and Turn Tool	278	The physical tasks related to setup are now completed	304
Tool #2: Finish Face and Turn Tool	278	Verify the correctness of a new or modified program	304
Tool #3: 3.0-mm (0.125-in) Grooving Tool... ..	279	Verify the correctness of the setup	305
What About the Z Position of the Groove?	279	A tip that will save a crash some day	305
Completing the Production Run	280	Dry running our example program	305

What if you do find a problem?	306	Clean and de-burr the just-completed workpiece	326
Canceling the CNC cycle	306	Perform specified measurements	328
To cancel the cycle	307	Which takes longer, the CNC cycle or the off-line tasks an operator must perform?.....	328
Rerunning a tool in the program	307	Make offset adjustments to maintain size for critical dimensions (sizing)	328
When do you want the machine to stop?	308	Replace worn tools	329
Procedure to restart the program from the beginning of a specific cutting tool	308	Clean the machine	329
Cautiously run the first workpiece	309	Preventive maintenance	329
The most dangerous time	309	Machine warm-ups.....	330
Making sure the first workpiece is a good one	310	Anything else you'll be expected to do?	330
Machining the first workpiece in our example job	310	Key points for Lesson Twelve:	330
Tool one:.....	310	Answers to Exercises	
Tool two	311	Exercise 1: Basic Machining Practices	333
Tool three	311	Exercise 2: What Does a CNC Turning center Do?	333
Tool four	311	Exercise 3: General Flow of the CNC Process	333
Tool five	312	Exercise 4: Machine Configurations	334
Move through the program one tool at a time	312	Exercise 5: Buttons and Switches on the Control Panels	334
Upcoming jobs.....	313	Exercise 6: The Key Operation Procedures	335
A note about our example job	313	Exercise 7: Introduction to Compensation	335
First workpiece inspection	313	Exercise 8: Workpiece coordinate system offsets and Assigning Program Zero	335
Program optimizing.....	313	Exercise 9: Tool Length Compensation	336
Saving corrected version of the program.....	313	Exercise 10: Cutter Radius Compensation	337
Verifying a Job that Contains Mistakes	314	Exercise 11: Tasks Required to Setup a CNC Turning center	337
Dry Run to Check for Setup Mistakes.....	318	Exercise 12: Tasks Related to Completing a Production Run	338
Cautiously Running the First Workpiece	319		
Tasks Required to Complete a Production Run	323		
Production run documentation	324		
A note to programmers:.....	324		
Remove the previous workpiece.....	325		
Load the next workpiece	326		
Activate the cycle	326		
Monitor the cycle	326		
		Index: 341	