CNC Programming
Tribal Knowledge

Mark Terryberry
Applications Engineer
I am a machinist.

Mark Terryberry is an applications engineer for Haas Automation, the largest machine tool builder in the western world. He has managed machine shops for nearly two decades, and holds a degree in Organizational Leadership from Biola University. When he’s not busy generating Oscar buzz for his breakout role in the Haas Tip-of-the-Day video series, you’ll find Mark playing his favorite board game Agricola, or hard at work mentoring a FIRST Robotics Team at one of the local high schools.
I am a machinist.

According to the BLS, CNC Programmer would be more appropriate.
OUR UNSTATED PURPOSE IS TO ELIMINATE TRIBAL KNOWLEDGE
Required Skills of the CNC Programmer

- Machine: 50%
- Tooling: 50%
- CAM: 50%
- Inspection: 50%

“The whole is greater than the sum of its parts”
Essential 9-Lines

Start here. Don’t end here.
Start Simply.
The majority of parts can be machined using only the codes shown on this page.

**MILL, Simple 9-line Program**

<table>
<thead>
<tr>
<th>%</th>
<th>O1234 (MILL EXAMPLE PROGRAM)</th>
<th>Program 'O' number, and comment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M06</td>
<td>Tool Change, to Tool #1</td>
</tr>
<tr>
<td></td>
<td>M03</td>
<td>Start Spindle, Clockwise, at 7,500 RPM</td>
</tr>
<tr>
<td></td>
<td>G54</td>
<td>Use Work Offset G54, Safe Startup Line</td>
</tr>
<tr>
<td></td>
<td>M03</td>
<td>XYZ Positioning</td>
</tr>
<tr>
<td></td>
<td>G43</td>
<td>Use Tool Offset #1, move to Z position, turn on coolant</td>
</tr>
<tr>
<td></td>
<td>G01</td>
<td>Feed the tool, in a straight line, at 5 inches per minute</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Can add more dot-to-dot XY location points here</td>
</tr>
<tr>
<td></td>
<td>G00</td>
<td>Rapid to location.</td>
</tr>
<tr>
<td></td>
<td>Z2.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M30</td>
<td>End program</td>
</tr>
</tbody>
</table>

**Lathe, Simple 9-line Program**

<table>
<thead>
<tr>
<th>%</th>
<th>O1235 (LATHÉ EXAMPLE PROGRAM)</th>
<th>Program 'O' number, and comment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T101</td>
<td>Change to Tool #1, use Offset #1</td>
</tr>
<tr>
<td></td>
<td>G50</td>
<td>Set maximum spindle RPM to 2000</td>
</tr>
<tr>
<td></td>
<td>G54</td>
<td>Start spindle, clockwise, at 1000 RPM</td>
</tr>
<tr>
<td></td>
<td>G97 M03</td>
<td>Use Work Offset G54, Safe Startup Line</td>
</tr>
<tr>
<td></td>
<td>X1 Z1</td>
<td>Position in XZ, turn on coolant</td>
</tr>
<tr>
<td></td>
<td>G01</td>
<td>Feed the tool, in a straight line, at .006 inches per revolution</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Can add more dot-to-dot XZ location points here</td>
</tr>
<tr>
<td></td>
<td>G00</td>
<td>Rapid to location.</td>
</tr>
<tr>
<td></td>
<td>Z2.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>M30</td>
<td>End program</td>
</tr>
</tbody>
</table>

Study the codes shown in the simple programs above.
Once these codes are mastered, move on and study the following:

<table>
<thead>
<tr>
<th>Mill</th>
<th>Lathe</th>
</tr>
</thead>
<tbody>
<tr>
<td>G00 / M01</td>
<td>M00 / M01</td>
</tr>
<tr>
<td>G02 / G03</td>
<td>G02 / G03</td>
</tr>
<tr>
<td>G03</td>
<td>G03</td>
</tr>
<tr>
<td>G04</td>
<td>G04</td>
</tr>
<tr>
<td>G41 / G42 / D</td>
<td>G41 / G42</td>
</tr>
<tr>
<td>G49 / G50</td>
<td>X2 / UW</td>
</tr>
<tr>
<td>G51</td>
<td>G51</td>
</tr>
<tr>
<td>G52 / G53</td>
<td>G52 / G53</td>
</tr>
<tr>
<td>G54</td>
<td>G54</td>
</tr>
<tr>
<td>G55</td>
<td>G55</td>
</tr>
<tr>
<td>G56 / G57</td>
<td>G56 / G57</td>
</tr>
<tr>
<td>G58</td>
<td>G58</td>
</tr>
<tr>
<td>G59</td>
<td>G59</td>
</tr>
<tr>
<td>G60</td>
<td>G60</td>
</tr>
<tr>
<td>G61</td>
<td>G61</td>
</tr>
<tr>
<td>G62</td>
<td>G62</td>
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<tr>
<td>G63</td>
<td>G63</td>
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<tr>
<td>G64</td>
<td>G64</td>
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<tr>
<td>G65</td>
<td>G65</td>
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<tr>
<td>G66</td>
<td>G66</td>
</tr>
<tr>
<td>G67</td>
<td>G67</td>
</tr>
<tr>
<td>G68</td>
<td>G68</td>
</tr>
<tr>
<td>G69</td>
<td>G69</td>
</tr>
<tr>
<td>G70</td>
<td>G70</td>
</tr>
<tr>
<td>G71</td>
<td>G71</td>
</tr>
<tr>
<td>G72</td>
<td>G72</td>
</tr>
<tr>
<td>G73</td>
<td>G73</td>
</tr>
<tr>
<td>G74</td>
<td>G74</td>
</tr>
<tr>
<td>G75</td>
<td>G75</td>
</tr>
<tr>
<td>G76</td>
<td>G76</td>
</tr>
</tbody>
</table>
Start Simply.

The majority of parts can be machined using only the codes shown on this page.

---

**Mill. Simple 9-line Program**

<table>
<thead>
<tr>
<th>%</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>O1234 (MILL EXAMPLE PROGRAM)</strong></td>
<td></td>
</tr>
<tr>
<td>M06</td>
<td>T1</td>
</tr>
<tr>
<td>M03</td>
<td>S7500</td>
</tr>
<tr>
<td>G54</td>
<td>G00</td>
</tr>
<tr>
<td>X0.</td>
<td>Y0.</td>
</tr>
<tr>
<td>G43</td>
<td>H01</td>
</tr>
<tr>
<td>G01</td>
<td>F5.0</td>
</tr>
</tbody>
</table>

**Program 'O' number, and comment**
- Tool Change, to Tool #1
- Start Spindle, Clockwise, at 7,500 RPM
- Use Work Offset G54, Safe Startup Line
- XYZ Positioning
- Use Tool Offset #1, move to Z position, turn on coolant
- Feed the tool, in a straight line, at 5 inches per minute

**Can add more dot-to-dot XY location points here**

**Rapid to location.**

**End program**
Lathe. Simple 9-line Program

% O1235 (LATHE EXAMPLE PROGRAM)  Program 'O' number, and comment
T101  Change to Tool #1, use Offset #1
G50 S2000  Set maximum spindle RPM to 2000
G97 M03 S1000  Start spindle, clockwise, at 1000 RPM
G54 G00 G99 G18  Use Work Offset G54, Safe Startup Line
X3. Z1. M08  Position in XZ, turn on coolant
G01 F.006 Z.1  Feed the tool, in a straight line, at .006 inches per revolution

{ DOT-TO-DOT XZ LOCATIONS }

G00 Z2.0  Can add more dot-to-dot XZ location points here
M30  Rapid to location.

%  End program
Study the codes shown in the simple programs above. Once these codes are mastered, move on and study the following:

<table>
<thead>
<tr>
<th>Mill</th>
<th>Lathe</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>M00 / M01</td>
<td>M00 / M01</td>
<td>Program / Optional Stop</td>
</tr>
<tr>
<td>G53</td>
<td>G53</td>
<td>Non-Modal Machine Position</td>
</tr>
<tr>
<td>G02 / G03</td>
<td>G02 / G03</td>
<td>Arcs, right and left</td>
</tr>
<tr>
<td>G83</td>
<td>G83</td>
<td>Peck Drilling Cycle</td>
</tr>
<tr>
<td>G84</td>
<td>G84</td>
<td>Tapping Cycle, right-hand taps</td>
</tr>
<tr>
<td>G41 / G42 / D</td>
<td>G41 / G42</td>
<td>Cutter Compensation</td>
</tr>
<tr>
<td>G90 / G91</td>
<td>XZ / UW</td>
<td>Absolute vs Incremental</td>
</tr>
<tr>
<td>G94 / G95</td>
<td>G98 / G99</td>
<td>Feed per Minute / Revolution</td>
</tr>
<tr>
<td></td>
<td>G96 / G97</td>
<td>Constant Surface Speed On / Off</td>
</tr>
<tr>
<td></td>
<td>G70</td>
<td>Finish Turning Cycle</td>
</tr>
<tr>
<td></td>
<td>G71</td>
<td>Rough Turning Cycle</td>
</tr>
<tr>
<td></td>
<td>G76</td>
<td>Threading Cycle</td>
</tr>
</tbody>
</table>

Do a Google search for: "Graphing Coordinate Pairs"
How much of my career has been spent hand-writing code?

- Job-Shop
  - Lathe
    - About 2-weeks
  - Mill
    - About 2-weeks

- Production Shop
  - Castings

- Captive Shop
  - Molds
  - Dies
How often would I hand-edit code?

- **Job-Shop**
  - Low-volume
    - Slim to none
  - Higher volume
    - Sub-programs for running multiple parts
    - Edits for streamlining, efficiency
“GIVE ME SIX HOURS TO CHOP DOWN A TREE AND I WILL SPEND THE FIRST FOUR SHARPENING THE AXE.”
Expand your worldview
Required Skills of the CNC Programmer

“The whole is greater than the sum of its parts”
I’ve learned that..

Most indexable tooling screws are **not** Torx like we might think
I’ve learned that

Most indexable tooling screws are **not** Torx like we might think

- **T10** is not the same as **T10P** or **IP10**
  - T10 is a standard Torx
  - T10p and IP10 wrenches are for the much stronger Torx Plus
  - If your wrench is loose, check to make sure it is a Torx ‘PLUS’ before you cam-out the screw
I’ve learned that..

Most indexable tooling screws are not Torx like we might think

- T10 is not the same as T10P or IP10
  - T10 is a standard Torx
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  - If your wrench is loose, check to make sure it is a Torx ‘PLUS’ before you cam-out the screw

T10  T10P  IP10
[Red X]  [Green Check]  [Green Check]
I’ve learned that..

Most indexable tooling screws are not Torx like we might think

- T10 is not the same as T10P or IP10
  - T10 is a standard Torx
  - T10p and IP10 wrenches are for the much stronger Torx Plus
  - If your wrench is loose, check to make sure it is a Torx ‘PLUS’ before you cam-out the screw
Mitee-bite fixture plate for client to run on their VF2. 140 finished parts per run bringing their cycle time from 108 seconds to 14 seconds per part.
I’ve learned that..

Most indexable tooling screws are **not** Torx like we might think

- **T10 is not the same as T10P or IP10**
  - T10 is a standard Torx
  - T10P and **IP10** wrenches are for the much stronger Torx Plus
  - If your wrench is loose, check to make sure it is a Torx ‘PLUS’ before you cam-out the screw
  - Torx Plus Socket Cap Screws exist for production tooling applications (Mitee Bite upgrades..)
  - You can replace hardware in your fixtures with Torx Plus Cap Screws
“EVERYONE YOU WILL EVER MEET KNOWS SOMETHING YOU DON’T.” – BILL NYE
How to Square and Indicate a Vise on Your CNC Mill
How to Manually Pick Up a Bore or a Hole with an Indicator
I’ve learned that..

One of the best ways to keep a tool straight and secure in an ER Collet, is to keep those Collets Clean and Dry.
ER Collet Essentials. Do You Know?
Mill Soft Jaws: The Proper Way to Make and Use Them
Required Skills of the CNC Programmer

“The whole is greater than the sum of its parts”

- Machine: 50%
- Tooling: 50%
- CAM: 50%
- Inspection: 50%
- 10%
Tapping Essentials
I’ve learned that..

A Center Drill is the same thing as a Combination Drill

- Yes, they can be used for 60° Live Centers, but also can be used for:
  - 90° Metric FHMS
  - 82° Standard FHMS
  - 60° Countersinks

- Hand programmers would need to carefully calculate the countersink diameter sizes
- CAM programmers simply select the tool from the library

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Table 6. American National Standard Combined Drills and Countersinks — Plain and Bell Types ANSI/ASME B94.11M-1993
I’ve learned that..

On a standard 118° twist drill, the drill tip is

.3 x diameter

• This is something hand-programmers need to consider
• If you rely on your CAM system, it’s a simple click “Drill Tip Through Bottom”
I’ve learned that..

Subtracting the pitch (lead) of a cut tap, from it’s Major Diameter, will give you the needed Tap Drill Size (at approximately 77% Thread Percentage)
Subtracting the pitch (lead) of a cut tap, from its Major Diameter, will give you the needed Tap Drill Size (at approximately 77% Thread Percentage).

**Major Ø - Pitch = Tap Drill size**

(77% Thread %)

- **M8 x 1.25 Tap**
  - Pitch is 1.25
  - $8.0 - 1.25 = 6.75\text{mm}
  - Tap Drill

- **1/2-13 Tap**
  - Pitch is $1/13 = .077''$
  - $.500 - .077 = .423''
  - Tap Drill
I’ve learned that..

When using an indicator on a Horizontal Mill or Lathe, watch out for indicator droop.
I’ve learned that..

When using an indicator on a Horizontal Mill or Lathe, watch out for indicator droop

- You may end up with Indicator Droop of 0.002" - 0.005"
- Try using a Co-axial indicator in these situations for more accurate results
I’ve learned that..

You never, ever, ever grab stringy chips with your hands

• This is probably the one bit of Tribal Knowledge that is told to every new machinist. By everyone they meet. Every time they are seen cleaning out a lathe. Forever
I’ve learned that..

Oil Resistant does not necessarily mean Slip Resistant

• More important than having Steel Toe shoes in the shop, is having Slip Resistant shoes

• Oil Resistant means that oil won’t damage the shoe
• Slip Resistant is what we are looking for

Slip Resistant
Yes
I’ve learned that...

Oil Resistant does not necessarily mean Slip Resistant

- More important than having Steel Toe shoes in the shop, is having Slip Resistant shoes
- Oil Resistant means that oil won’t damage the shoe
- Slip Resistant is what we are looking for
I’ve learned that..

Silly Putty is great for checking engraving
I’ve learned that..

Lathe Chucks need to be greased every day

Total Grip Force of the Three Jaws at Maximum Pressure

<table>
<thead>
<tr>
<th>(kgf)</th>
<th>lbf</th>
</tr>
</thead>
<tbody>
<tr>
<td>(18144)</td>
<td>40000</td>
</tr>
<tr>
<td>(15876)</td>
<td>35000</td>
</tr>
<tr>
<td>(13608)</td>
<td>30000</td>
</tr>
<tr>
<td>(11338)</td>
<td>25000</td>
</tr>
<tr>
<td>(9070)</td>
<td>20000</td>
</tr>
<tr>
<td>(6803)</td>
<td>15000</td>
</tr>
<tr>
<td>(4535)</td>
<td>10000</td>
</tr>
<tr>
<td>(2268)</td>
<td>5000</td>
</tr>
</tbody>
</table>

Lubricate the chuck once a day
I’ve learned that..

Quality starts with the Programmer
Required Skills of the CNC Programmer

- Machine: 50%
- Tooling: 50%
- CAM: 50%
- Inspection: 50%

“The whole is greater than the sum of its parts”
I’ve learned that..

If we want repeatable parts, we should always locate off of your Datums

Figure 8-13
I’ve learned that..

You should always locate off of your Datums
Mill Soft Jaws: The Proper Way to Make and Use Them
I’ve learned that..

Your Print dictates your tooling
Required Skills of the CNC Programmer

- Machine: 50%
- Tooling: 50%
- CAM: 50%
- Inspection: 50%

“The whole is greater than the sum of its parts”
I’ve learned that..

If the blocks can’t be ‘wrung’, there is something wrong

- They are called JO Blocks, named after Carl Edvard Johansson (1864-1943)
I’ve learned that..

If the blocks can’t be ‘wrung’, there is something wrong

• They are called JO Blocks, named after Carl Edvard Johansson (1864-1943)
  
  o The first CEJ gauge block set in America was told to Henry M. Leland at Cadillac Automobile Co. around 1908
  o In 1923 Carl and his crew went to work for Henry Ford
  o Ford bought the whole company
I’ve learned that..
I’ve learned that..

TSC and Probing change the way I program a part
Probing
I’ve learned that..

When running someone else’s program, I always check two things:

• Or Feedrates on Taps, and
• Our Retracts on Lathe Boring Bars
I’ve learned that..

Automation is the key to ‘Scale’

- In a perfect world, we:
  - Never have to hand-edit a program, and
  - Can increase production just by adding another machine
Autodesk University 2019

- MFG324069 – Fusion 360 and Haas Automation – Machine Like a Pro
“YOU’LL BE PAID IN THE FUTURE BASED ON HOW WELL YOU WORK WITH ROBOTS” – KEVIN KELLY
Where do I fit in?

<table>
<thead>
<tr>
<th>Generation</th>
<th>Born</th>
<th>Age today</th>
<th>Workforce %</th>
<th>Workforce millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silent/Greatest Generation</td>
<td>1928 - 1945</td>
<td>75 - 92</td>
<td>2%</td>
<td>3</td>
</tr>
<tr>
<td>Boomers</td>
<td>1946 - 1964</td>
<td>56 - 74</td>
<td>25%</td>
<td>41</td>
</tr>
<tr>
<td>Gen X</td>
<td>1965 - 1980</td>
<td>40 - 55</td>
<td>33%</td>
<td>53</td>
</tr>
<tr>
<td>Gen Y (Millennials)</td>
<td>1981 - 1996</td>
<td>24 - 39</td>
<td>35%</td>
<td>56</td>
</tr>
<tr>
<td>Gen Z (Post-Millenials)</td>
<td>1997 - 2019</td>
<td>1 - 23</td>
<td>6%</td>
<td>9</td>
</tr>
</tbody>
</table>
25
Boomers
10,000 plus Baby Boomers are retiring each day

33
Gen X
Gen X'ers were only the majority of the workforce for 3 short years before Gen Y took the mantle out outnumbered them

35
Gen Y
Millenials
Millenials now make up the primary age group in the workforce

6
Gen Z
Post-Millenials
This group is the future

Who is in the workforce?
Millennials became the largest generation in the labor force in 2016

U.S. labor force, in millions


PEW RESEARCH CENTER
Age by Gender for Machinists

Dataset: ACS PUMS 5-year Estimate
Source: Census Bureau
There is a lot to being a CNC Programmer

If you knew everything we mentioned today, congratulations. You've won a button!
“EVERYONE YOU WILL EVER MEET KNOWS SOMETHING YOU DON’T.” — BILL NYE
“DON’T ASSUME THAT BECAUSE YOU KNOW SOMETHING, THEY KNOW IT TOO”
TOD@HAASCNC.COM
“EVERYONE YOU WILL EVER MEET KNOWS SOMETHING YOU DON’T.” – BILL NYE