G-Code

From ShapeOko

Contents

Overview

cvoinescu wrote up the following in a post in the thread Re: MakerCAM - Issues with Circles (Google Chrome, Mac) (http://www.shapeoko.com/forum/viewtopic.php?f=33&t=1536#p12065) :

X, Y, Z, I, J and K are coordinates. They're in millimeters, and it makes no sense to preserve precision beyond one micron. Three decimals are plenty, but if you want four, so be it, as long as your lines are less than 50/70 characters long (so as to comply w/ Grbl's line length limits).

G-code is relatively easy to read. It consists of commands (which start with G, and some with M) followed by parameters. G0 moves as fast as the machine can go and is called "traverse", G1 moves at the speed given by the F parameter and is called "feed", G2 and G3 draw arcs, clockwise and counterclockwise. The expectation is that milling occurs during G1, G2 and G3, but not G0, which is why there's no speed ("feed rate") control for G0. Of the parameters, X, Y and Z are the coordinates to move to (usually absolute, but there's a relative mode too), and, for arcs, I, J and K are the coordinates of the center (usually relative, and K is for modes that are rarely used). If a coordinate does not change during a move, it can be omitted (which is why you see almost no Z parameters). With some commands (G0 to G3 included), you don't need to repeat the command on a new line if it's the same as before: you can supply just the new set of parameters (coordinates, and maybe feed rate), which is why most of your lines are just X, Y, I, J and F. Linear moves would be just X and Y (and/or Z if moving vertically too, and/or F if speed has to change).

G-code is not compiled; the Arduino runs an interpreter which receives it line by line and executes it. It doesn't move right away, then read another line. In order to avoid starting and stopping for each little move, it processes several commands ahead and feeds them into a movement planner, which schedules the moves as fast as it can while making sure that (a) it doesn't exceed the pre-programmed speed, acceleration (and/or jerk) limits of the machine, (b) it doesn't exceed the given feed rates, (c) it keeps the movements coordinated, that is, if several axes move simultaneously, they accelerate and decelerate together so that the resultant movement is a straight line (or an arc), and (d) it can stop at the end of the last command processed so far, while still obeying the same limits. It's fairly tricky to do this, and even trickier to do it on the Arduino Uno, which has only limited processing power. The Uno also generates pulses for every single microstep each motor has to move, each perfectly timed, while also doing what I described above. Be suitably impressed!

You can tell most CAM programs how many decimals to generate. Sometimes that's part of a post-processing step for the G-code. Some G-code senders can do that for you too. Failing that, just read the file and round any number after a letter X, Y, Z, I, J or K to 3-5 decimals (3 should be plenty for mm, 4 should be good for inch coordinates too).

The "AutoCAD to G-code" is what "CAM" is about. You design the part (essentially a shape) in CAD, and then design the manufacturing process for it in CAM. It's not as easy as converting, say, JPG to PNG, which any dumb computer can do. While there are programs that attempt to guess, and maybe even do a good job for simple parts, in most cases you have to tell the CAM program what to do and how to do it for each feature of your part (type of operation, choice of tool, other parameters). The CAM program helps a lot: once you've told it how you'd like it to mill a certain feature, it'll calculate what could be a very complex toolpath for you (the G-code), taking into account the geometry of the part, the geometry of the tool, and the practical limits of your manufacturing process (e.g. you can't mill more than this much material with every pass, you can't plunge more than this much at a time, you have to do a roughing pass stopping slightly short of the final shape followed by a finishing pass with a different tool, and so on). The CAM program will help you visualize the planned movement of the tool and the resulting object. It'll keep track of features and help you optimize the order of operations, and do all sorts of other things to make the process easier. But, ultimately, it's still a blend of design and engineering, with a human involved.

G-code supported by Grbl

In G-code, each "action" (modal group) should be on a separate line.

Grbl accepts coordinates in various forms ("0", "0." and "0.0000" are all ok), but some CNC machines require a decimal point to follow the number, which is why you'll see things like "0." in G-code. Please note that GRBL is limited in how long of a line it will accept. If your job is previewing correctly, but not running properly, check to see that line lengths are w/in its limits (50 for older versions, 70 for 0.8c dev or later) as discussed here (http://www.shapeoko.com/forum/viewtopic.php?f=3&t=1161) .

For further details, please see **G-Code** and Grbl: How it works and other thoughts… (http://onehossshay.wordpress.com/2011/08/21/grbl-how-it-works-and-other-thoughts/) --- includes a list of “currently supported g-code commands and unsupported commands from grbl gcode.c” --- see entries below for more complete G-Code specifications.

Note: The following table currently lists the G-codes which are supported by Grbl. If other codes are added, a column will need to be added which indicates compatibility with Grbl. See the next section which should probably be kept regardless.

G-code	Meaning	Notes
G0/G00	Rapid positioning	Switch to rapid linear motion mode (seek). Used to get the tool somewhere quickly without cutting --- moves the machine as quickly as possible along each axis --- an axis which needs less movement will finish before the others, so one cannot count on the movement being a straight line.
G1/G01	Linear interpolation	Switch to linear motion at the current feed rate. Used to cut a straight line --- the interpreter will determine the acceleration needed along each axis to ensure direct movement from the original to the destination point at no more than the current Feed rate (F see below).
G2/G02	Circular interpolation,	Switch to clockwise arc mode. The interpreter will cut an arc or circle from the current position to the destination using the specified radius (R) or center (IJK

	clockwise	location) at the current Feed rate (F see below).
G3/G03	Circular interpolation, counterclockwise	Switch to anti-clockwise arc mode. Corollary to G02 above.
G4/G04	Dwell (pause)	This should probably be calculated to be only one or two spindle rotations for best efficiency.
G10 (v0.8 or later)	Set Work Coordinate Origin (and resultant Offsets)	Coordinate system origin setting. This setting is persistent and expects the user to follow good practices and not manually move the machine, instead only using jogging commands via the interface or a pendant which works through the control system. Example given is G10 L20 P1 X0 Y0 Z0 (which is the equivalent of G92 X0 Y0 Z0)[1] (https://github.com/grbl/grbl/issues/155) --- see Re: Move after Homing to a position (http://www.shapeoko.com/forum/viewtopic.php?f=3&t=2409&p=18585#p18258) for a discussion of this.
G17	Select the XY plane (for arcs)	
G18	Select the XZ plane (for arcs)	
G19	Select the YZ plane (for arcs)	
G20	After this, units will be in inches	Best practice: do this at the start of a program and nowhere else. The usual minimum increment in G20 is one ten-thousandth of an inch (0.0001").
G21	After this, units will be in mm	Best practice: do this at the start of a program and nowhere else. The usual minimum increment in G21 (one thousandth of a millimeter, .001 mm, that is, one micrometre).
G28 (v0.8 or later)	Go to Pre-Defined Position	Takes an argument of an X Y Z coordinate for the intermediate point that the tool tip will pass through on its way home to machine zero. v0.7 “Incorrectly performed the homing cycle”[2] (https://github.com/grbl/grbl/wiki)
G28.1 (v0.8 or later)	Set Pre-Defined Position	Takes X Y Z addresses which define the intermediate point that the tool tip will pass through on its way home to part zero, not machine zero.
G30 (v0.8 or later)	Go to Pre-Defined Position (Return to secondary home position)	Takes a P address specifying which machine zero point is desired, if the machine has several secondary points (P1 to P4). Takes X Y Z addresses which define the intermediate point that the tool tip will pass through on its way home to machine zero. v0.7 “Incorrectly performed the homing cycle”[3] (https://github.com/grbl/grbl/wiki)
G30.1 (v0.8 or later)	Set Pre-Defined Position	
G53	Absolute mode override	Move in Machine Coordinates
G54--	Work	Fixture offset 1--6. CF G10 and G92.[4]

G59 (v0.8 or later)	Coordinate Systems	(http://www.shapeoko.com/forum/viewtopic.php?f=3&t=2409&p=18585#p18258)
G80	Motion mode cancel	Canned cycle
G90	Switch to absolute distance mode	Coordinates are now relative to the origin of the currently active coordinate system, as opposed to the current position. G0 X-10 Y5 will move to the position 10 units to the left and 5 above the origin X0,Y0. C.F. G91 below.
G91	Switch to incremental distance mode	Coordinates are now relative to the current position, with no consideration for machine origin. G0 X-10 Y5 will move to the position 10 units to the left and 5 above the current position. C.F. G90 above.
G92	Coordinate offset. Change the current coordinates without moving	e.g. "G92 x0 y0 z0" makes the current position a temporary home position. The intent is to allow one to re-use code (say for a part when doing multiples) which has a given origin. The temporary origin can then be cleared and the actual machine origin, set via G10 restored by the command below.[5] (http://www.shapeoko.com/forum/viewtopic.php?f=3&t=2409&p=18585#p18258)
G92.1 (v0.8 or later)	Clear (temporary) Coordinate System Offsets	Previously set by G92 (see above).
G93	Set inverse time feed rate mode	An F word is interpreted to mean that the move should be completed in (one divided by the F number) minutes. For example, if F is 2, the move should be completed in half a minute
G94	Set units per minute feed rate mode	An F Word is interpreted to mean the controlled point should move at a certain number of units (or degrees) per minute

F-code	Meaning	Notes
F	Defines feed rate	Unit used is that set by G20 or G21 (see above)

M-code	Meaning	Notes
M0 (v0.8 or later)	Program Pause and End	Stop
M2 (v0.8 or later)	Program Pause and End	End
M3	Spindle direction	Clockwise
M4	Spindle direction	Counterclockwise
M5 (v0.8 or later)	Spindle Control	Stop spindle rotation
M8 (v0.8 or later)	Coolant Control	Flood coolant on
M9 (v0.8 or later)	Coolant Control	All coolant off
M30 (v0.8 or later)	Program Pause and End	End and rewind

G-code *Not* supported by Grbl

Please note that unsupported G-code may cause Grbl to behave oddly, for example drifting into a corner.

G-code	Meaning	Notes
G40	Tool radius comp off	
G49	Tool offset comp cancel	

List of all G-codes[6] (http://www.buildlog.net/cnc_laser/cnc/gcode_comment.html)

See also G-Code and M-Code Grand Master List (http://softsolder.com/2013/03/14/g-code-and-m-code-grand-master-list/) .

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G00 ( G00:Rapid positioning )
G01 ( G01:Linear interpolation )
G02 ( G02:CW circular/helical interpolation )
G03 ( G03:CCW circular/helical interpolation )
G04 ( G04:Dwell )
G05 ( G05:Spline definition )
G06 ( G06:Spline interpolation )
G07 ( G07:Imaginary axis designation )
G08 ( G08:Radius mode )
G09 ( G09:Exact stop check )
G10 ( G10:Program parameter input )
G11 ( G11:Program parameter input cancel )
G12 ( G12:Circle Cutting CW )
G13 ( G13:Circle Cutting CCW )
G14 ( G13:Polar coordinate programming, absolute )
G15 ( G15:Polar coordinate programming, relative )
G16 ( G16:Definition of pole point in polar system )
G17 ( G17:X-Y plane selection )
G18 ( G18:X-Z plane selection )
G19 ( G19:Y-Z plane selection )
G20 ( G20:Inch system selection )
G21 ( G21:Milimeter system selection )
G28 ( G28:Return to home )
G30 ( G30:Return to secondard home )
G31 ( G31:Skip function  )
G32 ( G32:Thread cutting )
G33 ( G33:Constant pitch threading )
G34 ( G34:Variable pitch threading )
G40 ( G40:Tool radius comp off )
G41 ( G41:Tool radius compensation left )
G42 ( G42:Tool radius compensation right )
G43 ( G43:Tool offset compensation positive )
G44 ( G44:Tool offset compensation negative )
G45 ( G45:Tool offset compensation negative )
G46 ( G46:Axis offset single decrease )
G47 ( G47:Axis offset double increase )
G48 ( G48:Axis offset double decrease )
G49 ( G49:Tool offset comp cancel )
G50 ( G50:Scaling OFF )
G61 ( G61:Exact stop mode )
G63 ( G63:Tapping mode )
G64 ( G64:Constant velocity mode )
G65 ( G65:Custom macro simple call )
G66 ( G66:Custom macro modal call )
G67 ( G67:Custom macro modal call cancel )
G68 ( G68:Coordinate system rotation ON )
G69 ( G69:Coordinate system rotation OFF )
G70 ( G70:Enter inch mode )
G73 ( G73:High speed drilling canned cycle )
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G74 ( G74:Left hand tapping canned cycle )
G76 ( G76:Fine boring canned cycle )
G80 ( G80:Cancel canned cycle )
G81 ( G81:Drilling to final depth canned cycle )
G82 ( G82:Drilling to final depth canned cycle )
G83 ( G83:Deep hole drilling canned cycle )
G84 ( G84:Tapping or thread cutting with balanced chuck canned cycle )
G85 ( G85:Reaming canned cycle )
G86 ( G86:boring canned cycle )
G87 ( G87:Reaming with measuring stop canned cycle )
G88 ( G88:Boring with spindle stop canned cycle )
G89 ( G89:Boring with intermediate stop canned cycle )
G90 ( G90:Absolute prog )
G91 ( G91:Incremental programming )
G92 ( G92:Reposition current point - can be used to zero machine )
G94 ( G94:Inch per minute )
G95 ( G95:Per revolution feed )
G98 ( G98:Set Initial Plane default )

M01 ( M01:Optional Stop )
M02 ( M02:End of program..no rewind )
M03 ( M03:Spindle On )
M04 ( M04:Spindle CCW )
M05 ( M05:Spindle Stop )
M06 ( M06:Tool change )
M07 ( M07: Coolant On )
M08 ( M08:Flood coolant on )
M09 ( M09:Mist Coolant Device Off )
M10 ( M10:(Mach) Digital Pin Off )
M11 ( M10:(Mach) Digital Pin On )
M20 ( M20:(RepRap) List SD Card )
M21 ( M21:(RepRap) Init SD Card )
M22 ( M20:(RepRap) Release SD Card )
M23 ( M22:(RepRap) Select SD File )
M24 ( M24:(RepRap) Start/Resume SD Print )
M25 ( M25:(RepRap) Pause SD Print )
M26 ( M26:enable automatic b-axis clamping  )
M27 ( M27:disable automatic b-axis clamping )
M27 ( M27:disable automatic b-axis clamping )
M28 ( M28:(RepRap) Start SD Write )
M29 ( M29:(RepRap) Stop SD Write )
M30 ( M30:End program...rewind stop )
M42 ( M42:(RepRap) Set output pin )
M47 ( M47:Repeat program from first line )
M48 ( M48:enable speed and feed overrides )
M49 ( M49:Disable speed and feed overrides )
M50 ( M50:(EMC2) Feed Control Override )
M51 ( M51:(EMC2) Spindle Speed Override Control )
M52 ( M52:(EMC2) Adaptive Feed Control )
M53 ( M53:(EMC2) Feed stop control )
M60 ( M60:pallet shuttle and program stop )
M61 ( M61:(EMC2) Set current tool number )
M62 ( M62:(EMC2) turn on digital output synched with motion )
M63 ( M63:(EMC2) Turn off digital output synched with motion )
M64 ( M64:(EMC2) Turn on digital output immediately )
M65 ( M65:(EMC2) Turn off digital output immediately )
M66 ( M66:(EMC2) Input control )
M80 ( M80:(RepRap) Turn on P/S )
M81 ( M81:(RepRap) Turn off P/S )
M82 ( M82:(RepRap) Set E codes Absolute (default) )
M83 ( M83:(RepRap) Set E codes relative while in Absolute Coordinates (G90) mode )
M84 ( M84:(RepRap) Disable steppers until next move )
M85 ( M85:(RepRap) Set inactivity shutdown timer )
M95 ( M95:?? )
M98 ( M98:Call subroutine )
M99 ( M99:Return from subroutine )
M104 ( M104: (RepRap) Set Extruder Target Temp )
M105 ( M105:(RepRap) Read current Temp )
M106 ( M106:(RepRap) Fan On )
M107 ( M107:(RepRap) Fan off )
M109 ( M109:(RepRap) Wait for extruder current temp to reach target temp. )
M114 ( M114:(RepRap) Display current position )
M115 ( M115:(RepRap) Capabilities string )
M140 ( M140:(RepRap) Set bed target temp )
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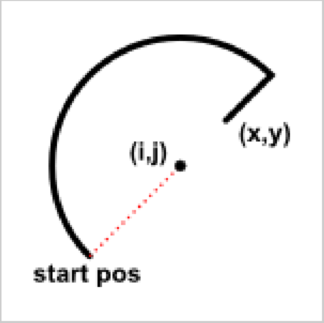
M190 ( M190:(RepRap) Wait for bed current temp to reach target temp )
M201 ( M201:(RepRap)  Set max acceleration in units/s^2 for print moves (M201 X1000 Y1000) )
M202 ( M202:(RepRap)  Set max acceleration in units/s^2 for travel moves (M202 X1000 Y1000) )
F ( F:Feedrate: )
H ( H:Tool length offset index: )
I ( I:X axis offset for arcs: )
J ( J:Y axis offset for arcs: )
K ( K:Z axis offset for arcs: )
O ( O:Subroutine label number: )
P ( P:Line Number: )
Q ( Q:Repititions of subroutine call: )
R ( R:Arc radius: )
S ( S:Spindle Speed: )
T ( T:Tool Number: )
# ( #: Variable Assignment:# )
% ( %: Start or end of program )
```

G-code examples

G2 - clockwise arc

```
G2 Xx Yy Ii Jj
```



Notes:

- I and J are relative to the current position, but X and Y may not be (depends which of G90 or G91 modes is selected)
- If (i,j) isn't half way along a straight line from the start position to (x,y), the move will still begin with an arc of a circle (not an ellipse), and it will be followed by a straight line move to (x,y)

References

- G-Code Commenter (http://www.buildlog.net/cnc_laser/cnc/gcode_comment.html)
- grbl wiki (https://github.com/grbl/grbl/wiki)
- The NIST RS274/NGC Interpreter (http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.15.7813)
- LinuxCNC G Codes (http://www.linuxcnc.org/docs/2.5/html/gcode/gcode.html)
- GCODE Introduction for Programmers (http://cncutil.org/gcode-introduction.html)

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