Numerical Control Programming: An Exciting Entry Point to Manufacturing Engineering Education

Peter S. Rourke
Wentworth Institute of Technology

Abstract
The irony of the manufacturing profession today is that even though there is increasing need for skilled manufacturing technologists and engineers, fewer high school seniors are selecting manufacturing as a career. A large part of the problem stems from the perception of what is actually involved. Machine control is often visualized to be "turning handles" (often greasy dirty ones at that). In reality though, this is simply not the case as it is primarily direct interaction with computer numerical control (CNC), or even computer aided manufacturing (CAM) software and machine simulators. Indeed, most equipment in an advanced machine laboratory does not have any actual handles at all, only virtual ones.

This paper discusses how the exciting world of advanced manufacturing machine control can be introduced when algebra topics are being studied at high school. While teaching the basics of the Cartesian coordinate system a few simple numerical control machine codes are also explained. This enables students to compose the code required to complete simple movements of a cutter and understand concepts of computer related manufacturing. Free, easy to use simulation software allows the students to test their code.

This approach has been used in a technology course during the past 2 years at Arlington High School in the Boston area, with the cooperation of a local undergraduate technical institution (Wentworth Institute of Technology). Enrollment in the course doubled in the second year, resulting in having to turn away interested students. The present digital generation of students quickly learns computer application skills. As these students begin to appreciate how these skills can be used to control advanced manufacturing systems, it is hoped that they will become interested in investigating a manufacturing engineering or related degree.

Section One: The Need for Manufacturing Education
As some high volume production jobs leave for foreign factories the perception is that manufacturing careers that accompany them here in the US are going right with them. This is far from the truth. It is frequently only the highly repetitive, low skill jobs that are associated with the high volume output that goes. What remains here is the required high level of manufacturing knowledge needed to bring the next generation of products to the line. Often left out of the discussion is the need for increased education in manufacturing to insure we keep this capability. Following are some quotes taken from the Bureau of Labor Statistics Overview of the 2008-18 Projections, Production Heading:

From the Significant Points section:
Job opportunities are expected to be good in the manufacturing sector, particularly in growing, high-technology industries. (1)

From the Nature of the Work section:
(1) Changes in technology have transformed the manufacturing and assembly process. Modern manufacturing systems use robots, computers, programmable motion control devices, and various sensing technologies. These systems change the way in which goods are made and affect the jobs of

those who make them. The more advanced assemblers must be able to work with these new technologies and use them to produce goods. (1)

Finally, from the Job Outlook section:
(1) Some employers report difficulty finding qualified applicants looking for manufacturing employment. Many job openings will result from the need to replace workers leaving or retiring from this large occupational group (1)

There are currently efforts to overcome the problem of lack of manufacturing education. A notable example is the Society of Manufacturing Engineers (SME) initiative: *Manufacturing is Cool* (2). This is a large scale effort by a leading professional group to attract young people into the field. Through interactive links, classroom activities, and various other internet based tools K-12 teachers can bring the world of manufacturing into their curriculum in an interesting and innovative way. SME is active at all levels of education, from primary through graduate work. Scholarships, local chapters and student groups at technical colleges and universities are used as outreach. Their web page describes their education foundation: *The SME Education Foundation is committed to inspiring, supporting and preparing the next generation of manufacturing engineers and technologists in the advancement of manufacturing education. Created by the Society of Manufacturing Engineers in 1979, the SME Education Foundation has provided more than $29 million since 1980 in grants, scholarships and awards through its partnerships with corporations, organizations, foundations, and individual donors.* (3)

SME also recognizes the need for growth in the manufacturing sector of our economy. A recent SME press release states:

The Bureau of Labor Statistics predicts that employers will be seeking 17,000 industrial and manufacturing engineers, 14,000 mechanical engineers, 14,000 engineering technicians, and 273,000 metal and plastic production workers every year until 2012. These numbers indicate that young people need to learn more about these highly-skilled jobs and realize how necessary math and science have become for a secure future. (4)

Doug Mitchell, development engineer at Ford Motor Company Design and a member of the Rapid Technologies & Additive Manufacturing Community (RTAM) of SME is concerned about the future. (4)

"Not enough engineers are being trained in the U.S. That's one reason work is being outsourced," he says. (4)

And he believes that this shortage may have something to do with the perception that "manufacturing engineering is not considered a glamorous profession like law or medicine." (4)

Section Two: A Classroom Introduction to Manufacturing Engineering
Frequently the first exposure a young student gets to a manufacturing facility is in high school, where they see a very old, very large, and very dirty engine lathe or vertical milling machine. Right away many of them turn away from the field. If the initial student exposure is a field trip to an actual factory the equipment is most usually even larger, greasier, and accompanied by a high level of hydraulic noise. This can truly be frightening. It would be understandable if the young high school student thought that perhaps if Dante were alive today there would be a whole new level in his Inferno.

Approaching the student on their own ground, through a computer interface is a far kinder and gentler approach. The setting could even be in a geometry class that is introducing the topic of Cartesian coordinates. The only essentials in the instruction are a PC and machine code path verification software. This paper uses pictures of outcomes from a proprietary part verify package from Light Machines Company, distributed by Intellitek Inc.(5) as verification software. Freeware packages are available on the internet.

The following is a limited introduction to the Word-Address system. While not intended as a complete tutorial, enough material is provided such that the reader can follow the commands in the simple program shown in Figure 1. (The conference does provide a workshop for attendees to actually complete the example part) The code conforms to the industry standard RS274D (6).

N: line numbers
G: move code
- 00: rapid traverse (full open throttle of the axis position motors)
- 01: linear interpolation at a controlled feed rate
- 02: circular interpolation, clockwise
- 03 circular interpolation, counter-clockwise

M: miscellaneous codes: M30 is used to stop the program instructions.

With a quick, perhaps 1 hour, introduction to coding and machine requirements students are able to program tool paths for a milling machine. Figure one is the first assignment: complete a part program to machine your initials. Arcs are a bit more difficult as they combine both absolute and relative coordinate systems. Each student is given a block of wood (4.0,3.5,1.5). The programming origin is located at the lower left corner, putting the part in the first quadrant. The top surface is Z0.0. All cuts into the wood then require a negative value on the Z axis.

Other coding commands necessary to program an actual part are excluded, as they are not needed here. This is simply a basic exercise to pique the student's interest in the area. It is also a terrific example of how topics and tools introduced in the math class are applied in a technology field.

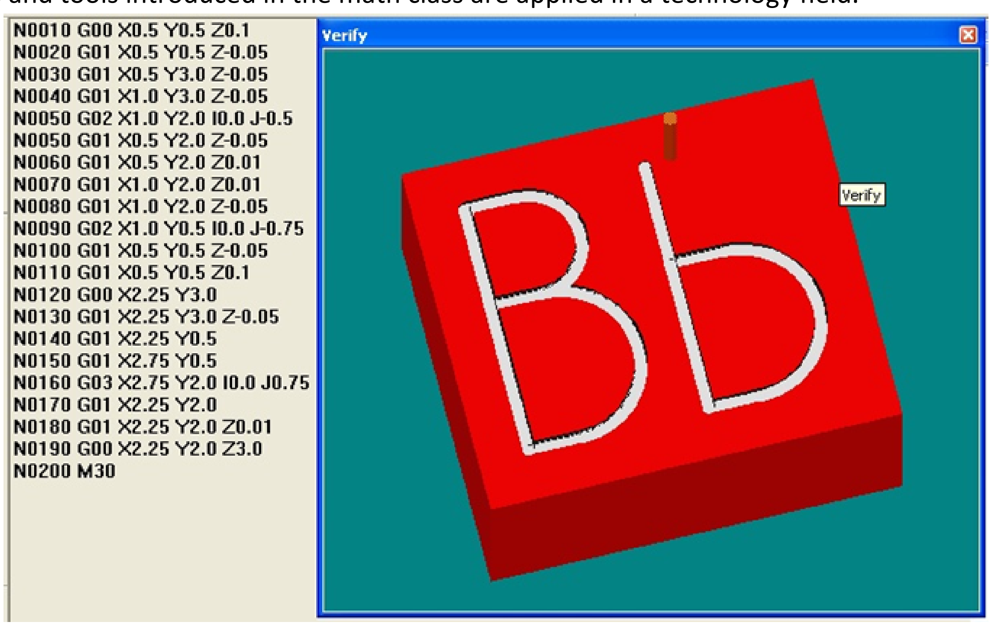

Figure 1: Code for initials and verified tool path

Line N0010 positions the cutting tool 0.1” above the part in a rapid traverse (G00) move. The tool moves straight down into the part in the next line, N0020, at a controlled freed rate: G01. Generally by the third or fourth line of code students understand the process, and begin their own coding. Arcs are programmed by using an X,Y endpoint, with the center of the arc described as a relative distance on the I and J axes. G02 is used for clockwise rotation, G03 for counter-clockwise. Line N0050 in figure one is an example, cutting the upper arc on the capital B. When the program coding is complete the verification software will display the cutter moving along the path. Figure 1 shows the completed tool path takenm from the software.

If it is possible to cut the part on a small gantry or similar, inexpensive CNC machine tool, it will add to the overall experience. If one is not available, this type of activity may become an outreach opportunity to an engineering institute willing to share their equipment. Figure 2 shows a completed block cut on a 3-D Techno-Isel gantry.

Figure 2: Photo of actual block

Students are encouraged to increase their skills by trying more challenging and complex designs such as the examples shown in Figures 3 and 4.

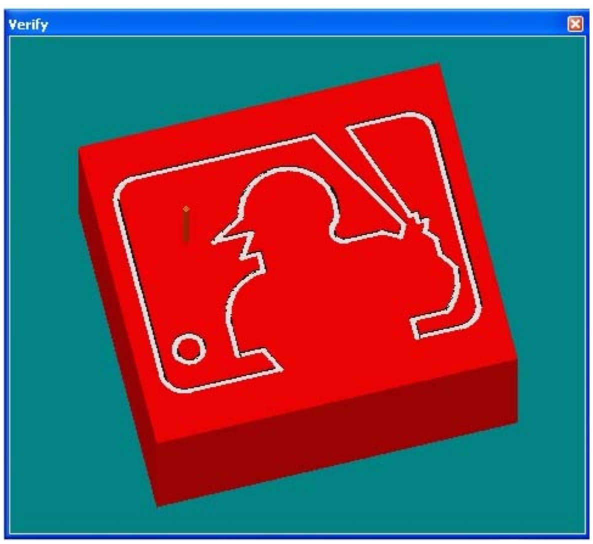

Figure 3: A verified design

Figure 4: The completed design

It is hoped that after the student has successfully completed a machine programming exercise the exposure to the actual manufacturing equipment will not be nearly as overwhelming. Confidence in knowing how it operates, and how to control it should lead to a less intimidating first encounter, and improve the willingness to explore the manufacturing as a career choice.

Section Three: Initial Trials

This approach of introducing manufacturing technology to students is currently being run cooperatively with a technology institute and high school, both located in the Boston metropolitan area. Initial interest in the approach increased enrollments two fold from the first to second years of the trial. In the first year, the programming methodology was explained and demonstrated during a field trip from the high school to the technology institute's lab. The demand was such that the following year engineering faculty was brought into the high school for a guest lecture presentation. Selected student projects were then run during the subsequent laboratory visit. Further expansion of the project into math classrooms as well as technology courses is being explored, along with an on-line preparation presentation.

Bibliography

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