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Computer Numerical Control Machines: An Account of Programming Methods and Techniques

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Abstract—*A Computer Numerical Control (CNC) machine tool is basically the same as a conventional machine tool. The functional capabilities of CNC machine tools in terms of machining are also not much different from those of conventional ones. The major difference is in the way in which the machine functions and slide/tool movements are controlled. Thus, this paper is to address this key difference i.e. the programming aspect of CNC machines. This paper primarily provides a discussion on the various methods of programming the CNC machines which also includes the less known method viz. Parametric Programming. This paper also provides a brief on the new standard for the exchange of product data i.e. STEP NC. The paper concludes with a discussion and conclusion.*

Keywords*: Computer Numerical Control; CNC; CAD/CAM, Part Programming; Manual Part Programming; Computer Aided Part Programming; Conversational Programming; CAD/CAM Programming; Parametric Programming; Macro Programming, STEP NC.*

1. INTRODUCTION

In 1952, the first numerically controlled (NC) machine tool was demonstrated at the Massachusetts Institute of Technology (MIT). That event, it is said by some, marked the beginning of the second industrial revolution. In the sixty plus years since, the book on manufacturing technology has been completely rewritten, at least one complete chapter on Computer Numerical Control (CNC) machine tools as an advanced version of Numerical Control (NC) machine tools has almost become a norm in almost all types and levels of books on Manufacturing / Production Technology. The industry has also responded to this call of change and one could easily find use of CNC machines in modern manufacturing-industries. Although, the industry is aware of the importance, potential and capabilities of the CNC machines, the use of CNC machines by the industry is not as much as it could be.

There are two main reasons for lack of use of CNC machines: (1) High Cost of the CNC Machines, and (2) Shortage of skilled operators and programmers. Although cost of CNC machines is continuously coming down with the advancement of technology and with more number of CNC manufacturers in the market, the shortage of Human Resource is a big challenge. This shortage of Human Resource in the field of CNC machines is a direct consequence of the shortage of educators or teachers or trainers who could impart skills in the field of CNC machines. This paper is a small step to develop an awareness and further work in the field of understanding the programming methods and techniques of CNC machines.

This paper mainly focuses on the Programming aspects of the CNC machines. An account of various programming method have been provided and discussed. A lesser known but highly potential and useful method of programming known as Parametric Programming is also discussed. At the end of the paper a concluding discussion has been made and some conclusions have been provided along with the identification of some future research directions.

2. CNC MACHINES: A PROGRAMMING APPROACH

Numerical Control (NC) is a system in which actions are controlled by the direct insertion of numerical data at some point. The system must automatically interpret at least some portion of the data.

CNC is the abbreviation for “Computer Numerical Control”. The idea of Computer Numerical Control is to position a computer right at the machine tool. Thus, CNC machines are those machines which are controlled by numbers while making use of computers for processing the information fed to these machines. The numbers used for controlling these machines are actually alpha-numerals and are popularly known as Codes of CNC Machines e.g. G Codes, M Codes, etc. These codes vary with the number attached to these codes e.g. G00, G01, G02, M01, M02, M03, T01, S2000, X40, Y20, Z30, etc. and each code makes the CNC machine to perform a

specific function. These codes are arranged in a logical sequence depending on the type and sequence of operations to be performed on a job. This logical sequence of CNC codes is known as Programme of Instructions or simply Part Program. These part programs are fed to the Controller which is the brain of the CNC machine, for processing and execution of these instructions. If these part programs are fully developed by the operator or human being, then this method of programming the CNC machines is known as Manual Part Programming. However, this format of programming the CNC machines is tedious and bounded by the limitations of human being, but presently is almost inevitable as CNC machines only understands the language of G and M codes. But, there are other methods of programming the CNC machines, discussed later, which basically helps the human being or operator of these machines to generate the part program in this standard format (ISO 6983 and others).

The ISO 6983 standard (G-Codes) focuses on programming the path of the cutter centre location (CL) with respect to the machine axes, rather than the machining tasks with respect to the part. The CNC machine tools (or CAM software), no matter how capable they are, can do nothing but ‘‘faithfully’’ follow the G code program. It is impossible to perform neither intelligent-control nor machining optimization. Due to the limitations of these legacy standards known as G-Codes (ISO 6983), new standards for the exchange of product data (STEP), ISO 10303 and ISO 14649 (STEP and STEP NC) have been developed with the aim of next generation of computer numerically controlled (CNC) machines be portable, interoperable and adaptable. Contrary to the current NC programming standard (ISO 6983), ISO 14649 is not a method for part programming and does not normally describe the tool movements for a CNC machine. Instead, it provides an object oriented data model for CNCs with a detailed and structured data interface that incorporates feature-based programming where a range of information is represented such as the features to be machined, tool types used, the operations to perform, and the sequence of operations to follow [1].

A futuristic view of STEP-NC is to support distributed interoperable intelligent manufacturing through global networking with autonomous manufacturing workstations with STEP compliant data interpretation, intelligent part program generation, diagnostics and maintenance, monitoring and job production scheduling [1]. Radical approach of STEP-NC requires a totally new kind of CNC controller. Hence current implementation on existing machine uses ‘plug and play’ method where the final STEP-NC codes have to be converted to the conventional NC codes [2].

3. CNC PROGRAMMING METHODS

The movement of the tool / slides in a CNC Machine could be made by the operator using Jog Buttons or Electronic Hand-Wheel in the same fashion as on the Conventional Machines. This method of imparting movements to the CNC Machines is known as Manual Control and is not a CNC programming method.

The CNC programming methods [3-5, 7] may be broadly classified as follows: Manual Part Programming, Computer Aided Part Programming, Conversational Programming, Programming Using CAD/CAM software, and Parametric Programming.

At present, the programming of CNC is done mostly using commercially available CAD/CAM software and also through menu-driven or feature based conversational programming. But, for simple parts, manual part programming (with or without parametric/macro programming) is also an excellent option.

3.1 Manual Part Programming

Manual Part Programming is also known as Conventional Method of Part Programming and is largely based on ISO 6983 standard (G-Codes) discussed earlier. If this programming is done and fed directly block by block through the console of the machine, it is known as Manual Data Input (MDI). In Manual Part Programming, a complete Part Program is developed and saved as a File (MS – Word File or any other compatible file) which is fed to the CNC machine [3,7,9].

3.2 Computer Aided Part Programming

The Computer-Aided (or Computer-Assisted) Part Programming for CNC machines is done through various Languages developed for this purpose. Many languages have been developed for this purpose but the most widely used are APT and COMPACT II. Although the approach of both APT and COMPACT II is similar but APT is easy to understand and use, and is the Abbreviation of “Automatically Programmed Tool”. APT makes use of simple English like words for instructing the CNC machine to perform various functions.

Although Computer Aided Part Programming is presently not in use as such, APT remains an important language even today in the United States and around the world as most of the CAD/CAM approaches to part programming are based on APT and APT is also important because many of the concepts incorporated into it formed the basis for other subsequently developed systems in interactive graphics.

The following procedure [3] is adopted in Computer Aided Part Programming:

- The programmer identifies the part geometry, cutter motions, feeds, speeds, cutter and other cutting parameters.
- The programmer codes the part geometry, cutter motion, feed etc. as per the format of the programming language and this is the *source* for the programming language.

- The source is then compiled to produce the machine independent list of cutter movements and other machine control information (the cutter location control data file or CL data file).
- The CL data is then processed by post-processor of a specific machine to generate machine control data / part program for the particular machine. The post-processing involves addition of G- Codes, M- Codes and other machine dependent information in the required format.

3.3 Conversational Programming

This type of programming is true to its name in the sense that the software of the Conversational Programming and the operator of the CNC machine are in a sort of conversation with each other. This conversational programming software seeks all the relevant information in a systematic manner about the jobs to be performed on the CNC machine from the operator and based on this information develops a part programme. The information to be provided by the operator to the conversational programming software is about the blank size, blank material, dimensions of the blank, type and sequence of operations to be done, final dimensions of the job, etc.

With conversational programming, the program is created at the CNC machine tool itself. Generally speaking, the conversational program is created using graphic and menu-driven functions while making use of macros which are simple part-programs available in the memory of the controller. The programmer will be able to visually check whether various inputs are correct as the program is created. When finished, most conversational controls will even show the programmer a tool path plot of what will happen during the machining cycle.

This is the easiest way to develop a part program and is widely used in the industry. But, this type of programming is limited to manufacturing components or jobs with relatively simple parts geometry. The software for conversational programming is generally provided by the manufacturer of the machine which is appropriate to the machine's capabilities.

3.4 Programming Using CAD/CAM software

This programming is done using commercially available CAD/CAM software which could be used to programme a variety of CNC machines. Some manufacturers provide their own versions of CAD/CAM software for programming but their applicability is generally limited to a particular machine. These CAD/CAM software are generally provided with the drawing tools as well as tools to generate the part program from the drawing of the job to be manufactured. The drawing of the jobs to be manufactured can be drawn in 2D or 3D directly using the drawing tools of these CAD/CAM software or the drawings can be supplied in a compatible format to these software. Once the drawing of the job to be manufactured is ready with these software, it seeks some relevant information in a similar fashion as the software of conversational programming. After seeking the relevant information, these CAD/CAM software are capable to generate Part Programs for a particular type of machine. These CAD/CAM software generate part programs only for those machines or controllers which are listed in their database. From the utility point, the difference in the software of conversational programming and CAD/CAM software is of the versatility. The CAD/CAM software are much more versatile and equipped with more sophisticated tools than software for conversational programming.

Some of the CAD/CAM packages that have the NC code generation capabilities are MasterCAM, CATIA, Pro/ ENGINEER, Pro/ Toolmaker, Siemens NX, DELCAM, EdgeCAM, Work NC, GibbsCAM, etc. Although, the procedure of generating codes for manufacturing a component on CNC machine varies from one CAD/CAM software to another CAD/CAM software, there are following three basic steps that are performed on almost all of them. First, the programmer must give some general information. Second, work piece geometry must be defined and trimmed to match the work-piece shape. Third, the machining operations must be defined.

3.5 Parametric Programming

Parametric programming is programming the CNC machines making use of the capabilities of the controller in making arithmetic calculations, feeding formulae, storing and assigning values to the system variables as well as Local and Common variables, etc. These CNC controller variables are just like algebra variables that can be used along with G-code. They can be assigned values, and when you refer to them, they give back the last value they were assigned.

Parametric programming is also known as Macro Programming. Macros are simple part-programs which reside in the memory of the controller and are called using a specific code for that macro. All sort of canned cycles are basically Macros.

Parametric programming can be compared to any computer programming language like BASIC, C Language, and PASCAL. However, this programming language is available right in the CNC controller and can be accessed at G code level, which means that it can be combined with manual programming techniques of CNC machines [6]. As it is like any computer language and thus also possesses Computer-related features like variables, arithmetic, logic statements, and looping. Like computer programming languages, parametric programming also comes in several versions. The most popular is Custom Macro B (used by Fanuc and Fanuc-compatible controls). Others include User Task (from Okuma), Q Routine (from Sodick), and Advanced Programming Language [APL] (from G& L).

In addition to computer related features, Parametric programming could also be used for extensive CNC related features which are more commonly related to the utilities such

as part counters, tool life managers, etc. and driving accessory devices such as probes, in-process and post process gauging systems, etc. [4-5, 8].

4. DISCUSSION AND CONCLUSION

This paper is to explore the most lacking aspect in the realm of CNC machines i.e. how to program the CNC machines for actual production. To answer this query, various programming methods have been discussed in this paper. A lesser known but highly potential and useful method of programming known as Parametric Programming is also examined. However, there is a need for more and more work in the field of programming the CNC machines and to explore the various methods of programming for generating efficient and sophisticated part programs with ease and flexibility. Further researches needs to be carried out for the practical implementation of new standards for the exchange of product data (STEP), ISO 10303 and ISO 14649 (STEP and STEP NC) in order to truly develop the computer numerically controlled (CNC) machines to be portable, interoperable, adaptable and supportive to feature-based programming.

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