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Development of the interface between CAD and waterjet NC systems

Sivayasivan Sambandan
New Jersey Institute of Technology

DEVELOPMENT OF THE INTERFACE BETWEEN CAD AND WATERJET NC SYSTEMS

by
Sivayasivan Sambandan

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by

Sivayasivan Sambandan

Dr Ernest S. Geskin, Thesis Advisor

Associate Professor of Mechanical Engineering

Department of Mechanical Engineering, NJIT

Dr Avraham Harnoy, Committee member

Associate Professor of Mechanical Engineering

Department of Mechanical Engineering, NJIT

Dr Z. Ji , Committee member

Assistant Professor of Mechanical Engineering

Department of Mechanical Engineering, NJIT

BIOGRAPHICAL SKETCH

Author: Sivayasivan Sambandan

Degree: Master of Science in Mechanical Engineering

Date: October, 1992

Undergraduate and Graduate Education:

- Master of Science in Mechanical Engineering, New Jersey Institute of Technology, Newark, NJ, 1992

- Bachelor of Engineering in Mechanical Engineering, Government College of Technology, Coimbatore,India,1989

Major: Mechanical Engineering

ABSTRACT
Development of the Interface Between CAD and
Waterjet NC Systems

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Sivayasivan Sambandan

There has been a continuous need in the present to develop softwares that provide interface between cutting machines and computer control. There involves a number of complex stages from the birth of an algorithm, to develop such software, till the end where it successfully gets tested and implemented. Cutting Path Simulation (CPS) is a partially developed software designed to model 2-d and 3-d objects and down load them to water jet cutting machine. Additional menus were created in the software to perform specific functions. Bugs that existed in the previously done work were removed. Investigation was conducted on the feasibility and accuracy of down loading G&M code file to the water jet cutting machine. Future work on this can be carried out in trying to provide more features to 3-d modeling, testing and implementing the software to the cutting machine.

ACKNOWLEDGEMENT

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CHAPTER 1

INTRODUCTION - WATER JET CUTTING

1.1 What is water jet cutting ?

In the simplest terms water jet cutting is a cutting performed using a jet of water flowing at a high velocity through a nozzle. Water is pressurized up to 400 Mpa and expelled through a sapphire nozzle to form a coherent, high velocity water jet. Abrasive - water jets are formed by mixing abrasives with high-velocity water jets. This water jet and a stream of solid abrasives are introduced into a mixing (and accelerating) nozzle. As a result of the momentum transfer between water and abrasives, a high-velocity abrasive water jet exits the mixing nozzle and performs the cutting action. The use of a water jet for cutting certain materials has been an accepted fact for more than 15 years. The use of this process has grown and been applied in many unique and profitable applications. The use of abrasive jet cutting is a much more recent addition to the engineer's and manufacturer's list of tools. It is a cutting system developed to help in the processing of today's exotic materials.

1.2 Technology of water jet cutting

The fundamental technique of water jet cutting is to use a high velocity stream of water as a cutting tool. It is also called hydrodynamic machining. A collimated jet of water is made to exit through a specially made nozzle with a velocity of 700 m/s. The velocity varies with the material to be cut. A sound of mist begins to form around the tight water jet core at approximately 25 mm from the nozzle. Following the interaction with the air, the shroud of mist diverges rapidly. Cutting action is performed by the tight water jet core. The first step is to filter the water to remove impurities present. Then using the booster pump the pressure of the water is raised

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to 150 psi. This water then passes through an intensifier which generates a very high pressure of 55,000 psi. Then the water is forced through a constricting orifice, which is usually a synthetic sapphire. The pressurized water then exits the orifice in a coherent jet. The material is cut when the force of the water jet impacting the surface exceeds the compressive strength of the material.

There are a number of parameters to be considered which influence water jet cutting. The most important are flow, nozzle diameter, water pressure, traverse speed, standoff distance, and flow rate. In case abrasives are used then abrasive flow rate, abrasive material and abrasive particle size should also be considered. When the traverse speed is increased, the depth of cut will decrease. Also when the standoff distance is increased, the depth of cut will generally decrease. But however, in this case the width of cut increases. It should be noted that cutting with jets always produces a striated surface. The waviness of the produced surfaces varies along the depth of cut. The maximum waviness height occurs at the bottom of the cut.

1.3 Hardware components of a water jet cutting

Intensifier pump

An intensifier is a simple hydraulically driven reciprocating plunger pump. Low pressure hydraulic oil is alternately applied to each side of a large piston causing it to move back and forth. The oil is supplied by a variable volume pressure compensated pump driven by an electric motor. The reciprocating motion is achieved through directional valves. The movement of the large piston drives small diameter high pressure plungers which act against water in the small high pressure cylinders.

The ratio of the large piston area to the small plunger area is in the range of 20 or 40 to 1. It is this ratio which produces the high pressure intensification of the water. For example, if a 20 to 1 ratio is used, 2,000 psi on the large piston will result

40,000 psi pressure in the high pressure cylinder. By varying the oil pressure on the large piston, it is possible to adjust the high pressure output from some minimum value to a maximum system rating(1).

Hydraulic pump

The hydraulic pump supplies oil at pressures up to 2750 psi to drive the reciprocating plunger pump called the intensifier. Electric motors of 30 HP, 40 HP or 60 HP is used to drive the conventional hydraulic pump. The power of the electric motor is chosen depending upon the desired cutting pressure and flow rate. Standard remote pressure compensators are used to control the hydraulic oil pressure, which in turn regulates the output water pressure from the intensifier. The oil circuit also contains an oil cooler and an oil filter.

Primary power unit

The primary power unit consists of a electrically driven, variable displacement, pressure compensated hydraulic pump and supporting components. This power unit is typical of what is found in standard machine tools. Operating pressures range from 8 to 21 MPa (1200 to 3000 psi), and are adjustable throughout the entire range. Diagnostics include oil pressure, temperature, and level, and filter status to insure proper system performance. The pressure compensated pump provides for automatic pressure level control to compensate for nozzle wear. This pressure control is limited by the maximum flow output capacity of the pump.

Nozzle

Nozzles used in water jet cutting are usually made from sapphire with hole diameters from .004 to .024 inches. The sapphire is surrounded with soft brass or similar material which allows it to be pressed into and held by a stainless steel insert

insert. These inserts allow rigid fastening to a cutting head yet can be easily changed in less than a minute. Because man-made sapphire is used, the cost of a complete insert is less than $15 dollars. With an expected life of up to 400 hours, production costs of a few cents per hour replace far more expensive tooling in conventional cutting. With adequate intensifier capacity the nozzle diameter does not affect the velocity of the jet. Since the jet velocity is affected only by the system pressure, calculations are easily made by using Bernoulli's equation for an incompressible fluid(1).

Accumulator

An accumulator is placed in the output line of the intensifier. This is required because water is about 12 percent compressible at pressures of around 55,000 psi and the intensifier uses about 1/8 of its stroke after reversing direction to build to this pressure. The accumulator acts as a storage chamber for compressed water during this time and thus provides a continuous cutting jet which is free from pulsations. Variations of about 5 percent are achieved in this way; whereas, without an accumulator 50 percent drops are possible(1).

High pressure components

Water is carried from the pumping unit to the cutting head of commercially available high pressure tubing. It is readily available in 1/4", 3/8", and 9/16" diameter. Multi axis nozzle movement is obtained by winding circular coils in the tubing or by installing single-acting or double acting, low torque, rotary swivels. A manual or remote control (on/off) valve starts and stops the cutting action. A unique, compact and lightweight, remote-controlled on-off valve, called Instajet, has been developed. This high pressure valve for instantaneous on/off control has the high pressure control valve integrated into the liquid culminating chamber directly

upstream of the nozzle orifice. The orifice itself then serves as a valve-seat. As a result, pressure is constant over the entire system (from the accumulator to the nozzle), pressure spikes are eliminated, and there is no fatigue induced by depressurization at each valve cycle.

Receiver

Due to the high velocity and energy content of a cutting jet, the receiver plays an important role in any water jet system. In addition to collecting spent cutting fluid and small particles from the material being cut, the receiver provides sound reduction from noise created by Mach 3 jet velocities as well as eliminating undue hazard which results from the exposed jet.

An open exposed jet can generate noise levels up to 120 or 130 DB. The receiver therefore, should be as close to the nozzle as possible for maximum reduction of noise while still allowing sufficient space for the material being cut to pass freely under the jet. Noise is emitted into the environment at levels far below OSHA standards. The receiver need be nothing more than a piece of tubing or pipe with sufficient length to allow dissipation of the jet. Usually 18 to 24 inches of length is required depending on nozzle size and pressure. If a receiver of proper length cannot be used such as with a hand held or manually operated head, a short tube may be used with a hardened insert which may be replaced after a period of time. Depending on the system, other types of catchers or receivers can be provided such as moving slots or just plain open tanks. Noise levels, however, will be somewhat higher than if a tube type receiver is used.

1.4 Applications of water jet cutting

There are innumerable applications of water jet cutting. Any company or industry that uses a nonmetallic or composite material in its product or process has a

potential water jet application. With the addition of abrasive jet, the cutting of all materials has potential applications. Five typical applications of the water/abrasive jet cutting are as follows :

1.4.1 The first application is water jet cutting in the production of pressed wood fiber interior door panels for automobiles. These panels are being trimmed with a water jet system that has been integrated with a 5-axis gantry robot and control. This is a full production system running 24 hours per day and trimming door panels at a rate of 60 per hour using a .010 diameter jet stream and 43,000 Psi. In this application the tool never gets dull and there is minimal or no dust(1).

1.4.2 The second application is a water/abrasive jet cutting application where .125 to .350" thick graphite/epoxy composites are contour cut. A 5-axis gantry robot and control is also used in this application to move the water/abrasive jet stream across the part at 20 inches per minute. This application demonstrates a cutting process that produces no delamination in the layered material. The fixture design is also simplified because of the minimal forces induced into the part(1).

1.4.3 The third application relates to using the water/abrasive cutting process to cut titanium, inconel, 58 Rockwell "C" vanadium steel and other metallic and non-metallic materials. In this third application a cutting process is used which can cut any material and produce no heat affected zone or thermal stresses(1).

1.4.4 The fourth application comes from the shoe industry. The size of hides from which the shoe components are cut is a function of the size of the originating cow. Historically, the patterns which have been stamped or cut out of the material have been controlled by skilled craftsmen and, based on their skill, the number of parts

which can be cut from a particular piece of material has been controlled. In order to improve on this productivity, research programs in the 1970's combined computer control and water jet cutting. The result has been the installation of such systems in factories with significant economic benefit to the manufacturers. One of the studies, in the United Kingdom showed that using typical materials required for ladies shoes, material savings of between 5 and 15% were possible, leading to an immediate benefit of the order of $20 per hour in material. The single shoe pieces were cut at a velocity of approximately 40 cm/sec, giving a cutout time of approximately 3 sec/piece, depending upon the intricacy of the part. Support of the workpiece has been a continuing problem for this application, however(4).

1.4.5   The fifth application is in mining. Many rocks cannot be cut at the lower pressures which were available for conventional mining. At the same time only a few coal seams around the world have the necessary conditions for hydraulic mining to be carried to a successful conclusion. If water jets were to have a success in the more commonly prevailing conditions of most coal mines, where the seams lie relatively flat and the floor will soften to an unacceptable degree if too much water is applied, then a better method of using water will be required. An increase in pressure will allow some reduction in flow volume, and if this is taken with a modification of the design of the machine , so that the water jet does not do all the cutting of the material then an effective machine can be developed. This requirement has been part of the reason for the recent success of the water jet assisted cutting techniques. A new system has been developed in which high pressure water jets are placed at the leading edge of cutting tools. The success that this allows can, simplistically be illustrated by comparison. As a general rule a mechanical cutting machine of the type used in many mines requires greater weight to cut stronger rock. Thus to cut an 18,000 psi rock, the machine, must normally weigh around 100 tons. Where a water

jet assistance was added to the cutting tools, however, a 25 ton machine was able to cut rock of over 19,000 psi strength. The difference in the cost of the machines approaches $500,000(4).

1.5 Advantages of water jet cutting

1.5.1 Minimal or no dust.

1.5.2 Increased cutting speeds are available.

1.5.3 Multidirectional cutting capability.

1.5.4 No dulling of the cutting tool (the jet).

1.5.5 No thermal or deformation stresses.

1.5.6 No fire hazards associated with the cutting process.

1.5.7 Reduced operating costs result from lower maintenance and downtime.

1.5.8 Product quality is enhanced because of cleaner cuts without crushing, deformation or delamination resulting in fewer rejects.

1.5.9 Most of the heat generated by the cutting process is carried away by the jet. Material structure and mechanical properties of the material remain unchanged. Fusing of the material is eliminated.

1.5.10 It offers increased cutting efficiency over conventional methods.

1.5.11 It can be easily integrated with automated equipment(3,5,1).

1.6 Limitations of water jet cutting

1.6.1 Hard materials such as metals, ceramics, high-strength composites, and hard rocks cannot be cut.

1.6.2 High power levels are needed for reasonable cutting rates in many applications.

1.6.3 Delamination or striation occasionally result(5,1).

1.7 Advantages of abrasive water jet cutting

The advantages of abrasive-water jet cutting systems include those mentioned above for water jet cutting and the following,

1.7.1 Any material can be cut.

1.7.2 Power requirements are decreased.

1.7.3 Delamination does not occur and striation is reduced.

The abrasive water jet is easily adaptable to existing water jet cutting systems and automation equipment. It can be readily adapted to remote control operations(1).

1.8 Study of safety precautions

Safety is an very important aspect to be considered while working with an water jet cutting machine because of the enormous pressure with which the water jet flows. Hence a careful study of the requirements, precautions and guidelines in case an injury occurs is deemed important.

1.8.1 Protective measures

1.8.1.1 Eye protection

Eye protective devices should be worn by the operator at all times when operating or assisting operation of a high pressure water jet equipment. Commonly used devices are goggles, full hood with shield and visor. In some cases a combination of these may also be used.

1.8.1.2 Head protection

Suitable head devices should be worn at all times during or while assisting operation. In cases of very high pressure and where greater amount of injury is sensed, the shield worn should also cover the face.

1.8.1.3 Body protection

This involves wearing suitable waterproof clothing with regard to the work in operation. In some cases chemical resistant suits would be deemed appropriate.

1.8.1.4 Hearing protecting

OSHA specifies standards for suitable ear protectors which should be followed strictly because the noise produced during operation will normally exceed 110 decibels which is a very high sound for the normal human ear.

1.8.1.5 Foot protection

Suitable waterproof boots with steel toecaps should be worn during operation. Jetting gun operators should use a metatarsal guard.

1.8.2 Operational measures

The general operational measures must be strictly followed. A description of the required measures can be found in the manual that comes with the water jet cutting machine. Apart from these, only well trained operators should be allowed near the premises of the machine. In general most water jet cutting systems require at least two operators at any particular time. These operators should work as a team headed by one. It is also advisable that the team members should rotate their duties after a certain amount of time to avoid fatigue to the operator holding the gun. Work should be immediately stopped if there are any leaks, if the alarm goes on or if any hazardous situation is sensed by the operator. A personal training program before the operator starts his assignment is highly recommended. Frequent inspection and periodic maintenance checks should be performed.

1.8.3 Accidental measures

In case an accident occurs the person should be immediately given proper medical care. The injury may seem very insignificant when observed from outside. But due to the very high pressure of the water jet, it is capable of puncturing the skin, flesh and

organs which will not be observable and may also not be felt by the injured. A delay of just two days in getting proper medical treatment may improve considerably the need for amputation of the injured part(10,2).

CHAPTER 2

SERIES 8200 ROBOT CONTROL

2.1. What is series 8200 robot control?

The Allen-Bradley series 8200 robot control is a minicomputer-based industrial controller designed to control the path of nozzle motion, traverse speed and on/off of water and abrasive supply valves. The path motion can be programmed in absolute mode or incremental mode.

2.2. Hardware components

2.2.1 Controller assembly

The controller assembly consists of three individual units namely processor section, power supply and the interface section. The processor section is the heart of robot control and its function is to govern all control operations. It monitors inputs from other control components, as well as the robot, and controls the output to these devices. It operates according to the instructions of an executive or diagnostic program stored in its memory. The function of the interface section is to support input and output modules. It has 9 slots available for this purpose. There are several types of interface modules available namely a keyboard module, a communication module, digital I/O module and servo interface modules. The function of a power supply is to convert the 120vac input to the required output voltages in vdc. The output voltages then power the control electronics, including the main memory.

2.2.2 Main control panel

The main control panel contains the switches and indicators necessary to run a robot task program. It can be used in a high production area where operator intervention is held to be a minimum. It consists of a control on/off switch, cycle

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start/stop switch, program select and program enable, mode select, speed override, fault, emergency stop and emergency stop reset switch.

2.2.3 Secondary control panel

The main function of an secondary control panel is to aid in the development of robot task programs. It is kept under security behind a lockable door to prevent unauthorized personnel from altering existing programs.

2.2.4 Teach pendant

The teach pendant is an manual way of teaching the robot its required program one step at a time. It contains an edit function which allows to insert, delete or modify task program blocks. The teach pendant, in fact, is the simplest way to teach the robot by manual methods.

2.2.5 CRT/keyboard assembly

This contains an alphanumeric keyboard which allows to enter commands that initiate control operations. It can also be used to enter and edit robot task programs. In addition it allows to change to task program's function codes and axis positions. Data blocks can be inserted, deleted and modified.

2.2.6 Data cartridge recorder

Its function is to allow data to be stored on an Allen-Bradley mini-data cartridge. The cartridge uses a 2-track magnetic tape, and can store 72K words of data on each track.

2.3 Programming

2.3.1 Basic concepts

The purpose of a task program is to define a sequence of robot motion operations. The task program is divided in to a number of blocks, each of which defines one step of the robot motion process. The task program block in turn is divided into one or more task program words. A task program word has two parts namely : Address - This is a letter which specifies word function.

Value - This is a number that further qualifies or quantifies the response the word is to produce.

There is a required format for each task program word which specifies the number of digits one may program in the word. Let us consider two examples namely G2 and X3.4. G2 is a G-code format. A G code is a preparatory function code. The 2 following G means that a G-code may contain no more than 2 digits. The X is the axis name. The format with a decimal point specifies the number of digits one may program left and right of the decimal point. 3.4 following X means that one may program 3 digits to the left of the decimal point and 4 digits to the right. If an illegal word address is used and the control attempts to execute it then it will go in to a cycle stop and would display "Illegal Program Format" on the CRT.

2.3.2 G-codes

G-codes along with M-codes are the essence of all program codes that can be developed for a water jet cutting machine. Hence it is to our advantage to have a complete understanding of those two codes. G-codes are called preparatory function codes and they establish the modes of operation. It consists of the key word G followed by a two digit number. A G-code can either be modal or non-modal. A modal G-code is one which after execution will stay active until a G-code that cancels it is executed. A non-modal G-code is one which is active only for the block

in which it is programmed. There are some rules in the execution of the modal G-code. At any particular time only one code from each modal group can be active. When the control executes a G-code, it cancels any other code from the same modal group as the newly executed code. In other words they are organized into groups of mutually exclusive codes. Another rule to be known is that, for each task program block, the control will accept only one G-code from each modal group. In case a block contains more than one G-code which is from the same modal group, then the control will accept only the one closest to the end of block character. The most frequently used G-codes are G01, G02, G03 and G04. G01 represents linear interpolation mode. It is used for slope contouring with one or more linear axis. This code is modal. G02 and G03 represent circular interpolation. When either of these two are active the control generates circular arcs by coordinated motion of two linear axes. Both the arc and point and the arc center must be specified by a block which calls for circular motion. Both G02 and G03 are modal. G04 represents the dwell mode. When this mode is active the control stops task program execution for a programmed length of time. The dwell time should be specified in seconds. G04 is non-modal and is active only for the block in which it is programmed.

2.3.3 M-codes

M-codes are Miscellaneous function codes. Their function is to initiate machine tool functions and establish control conditions. M03 and M04 represents water on and water off respectively and are most frequently used M-codes. Most of the M-codes are modal. So if they are activated once, they will remain active until cancelled by execution of another programmed M-code. The format for the M-code is M2. The typical functions of the M-code are to control outputs, gripper functions, and other auxiliary functions. Only one M-code can be programmed in a task program block. In case the control tries to execute a block that contains more than one M-code, it

activates only the last one programmed. The last block of a task program must be an M02 OR M30. M02 represents end of program. M30 represents end of program, rewind. If M02 is executed it activates G40 which represents cutter diameter compensation not active. No other G-codes are affected by M02(8).

Series 8200 Robot Legal Word Addresses (Courtesy : Allen Bradley Company)

Word Address	Description
N G L	Sequence Number Preparatory Function Paramacro Label
--- --- --- ---	Axis Position
--- --- ---	Arc Center (G02, G03, G22, G23)
D	Accel/Decel
F F F F F	IPM/MMPM Feedrate (G94) V/D Feedrate (G93) Dwell Time (IPM) (G93 G94) Variable Speeds (G96) Time Feedrate (G97)
H	Fixture Offset
T	Tool Word
M	Miscellaneous Function
S	PAL Axis Word
X,Y,Z, U,V,W, A,B,C	Axis Names (OEM Defines Which Exist in a Given System)
I,J,K	Integrands-Circular (OEM Defines Which Exist in a Given System)
P	Parameter Number

Series 8200 Robot G - Codes(Courtesy : Allen Bradley
Company)

Code	Function
G00	Positioning/Rapid
G01	Linear Interpolation
G02	Circular Interpolation
G03	Circular Interpolation
G21	Linear Interpolation with Delay
G22	Circular Interpolation with Delay
G23	Circular Interpolation with Delay
G25	Joint Coordinate System
G26	World Coordinate System
G27	Hand Coordinate System
G28	Hand Coordinate System with Control Point at Tool Point
G29	Hand Coordinate System with Control Point at Wrist Point
G13	Axis 1 Select Code
G14	Axis 2 Select Code
G15	Axis 3 Select Code
G16	Axis 4 Select Code
G17	Axis 1-2 Plane Selection
G18	Axis 3-1 Plane Selection
G19	Axis 2-3 Plane Selection
G04	Dwell
G50	Enable PCAC Mode
G51	Disable PCAC Mode
G70	Inch format
G71	Metric format
G74	Single Quadrant Circular
G75	Multi-Quadrant Circular
G76	Multi-Quadrant Circular
G90	Absolute Programming
G91	Incremental Programming
G92,G98	Insert CAR Presets
G93	V/D Feedrate Coding
G94	IPM/MMPM Feedrate Coding
G95	IPR/MMPR Feedrate Coding
G96	Variable Speeds Coding
G97	Time Feedrate Coding
G99	Cancel CAR Presets

Series 8200 M-Codes (Courtesy Allen Bradley Company)

Code	Function
M00	Program Stop
M01	Optional Stop
M02	End of Program
M03	Water ON
M04	Water OFF
M13	Abrasive ON
M14	Abrasive OFF
M16	Dual compensation ON low pressure
M17	Dual compensation OFF, High Pressure ON
M30	End of Program, Rewind
M48	Enable Overrides
M49	Disable Overides

CHAPTER 3

SERIES 8400 ROBOT CONTROL

Series 8400 robot control contains very much enhanced capabilities compared to series 8200 robot control. Programming aspect has been highly developed. CNC control features are key enhancements. Certain new G-codes and M-codes have been introduced.

3.1 CNC Control

CNC control is achieved by a group of G word data blocks.

The key G-codes are G60, G62 and G66 (Courtesy, Allen-Bradley Company).

3.1.1 G60

G60 is called Zone inhibited feature and it provides the ability to program soft limits on the six axis of motion. It is possible to program the limits relative to the machine zero or relative to the current position. The six axis are designated as x,y,z,u,v,w. The positive limits are the following parameters x,y,z,u,v,w and the negative limits are i,j,k,a,b,c respectively. These parameters can be absolute or incremental. An absolute parameter sets the corresponding limit versus machine zero and an incremental parameter sets the corresponding limit versus the current location. Let us consider an example to explain clearly about zone inhibition. Consider this word in a data block,

G60 X6.7 I-6. Y1.3 J-2. #

Consider X,Y,I and J to be set to absolute mode. Then the above defines an inhibited zone on the X axis from '-6.0000 to +6.700' and on the Y axis from '-2.0000 to +1.3000'.

In case no axis limit is specified in the G60 command then the it would be set to the soft limit for that axis provided there is one. So a G60 without any parameters will cancel the inhibited zone, setting all the axes limits to the soft limits provided they exist. If there is no soft limit for an axis, there will be no limit on that axis when that inhibited zone is cancelled.

3.1.2 G62

G62 is also called override inhibit. It's feature is to let the programmer choose whether the operator is allowed to use certain override functions. If nothing is specified then all overrides will be enabled as the default condition. There words are key to this namely F, S, and Q. F is the feedrate override switch. S is the spindle speed override switch and Q is the cycle stop button. If one of these words are programmed then it inhibits a zero value thereby not allowing the operator to use it. If suppose the word has a non zero value then the override is enabled thus allowing the operator to use it.

3.1.3 G66

G66 is known as Graphics control. The function of this is to control characteristics of the graphics display from within an executing program. In case a G66 is programmed by itself in a data block then the graphics display would be erased automatically. The key words for such control are Q, R and W. Q toggles the grid feature. If it is off grid will be turned on and if it is on grid will be turned off. If there is no Q programmed then the control will not take any action with the grid. R toggles the rapid feature similarly as above . W is for w/o erase and inhibits erasure of the graphics display when programmed. If the G66 block does not contain a W then the display is automatically erased(9).

Series 8400 Robot G-CODES (Courtesy : Allen Bradely Co)

Code	Function
G00	Point-Point
G01	Linear
G02	Arc Cw
G03	Arc Ccw
G04	Dwell
G05	Arc Tangent
G17	XY Plane
G18	ZX Plane
G19	YZ Plane
G30	Cancel Mirror
G31	Axes Mirror
G40	Cancel Ctr Comp
G41	Cutter Left
G42	Cutter Right
G45	Fixture Offset
G22	Helix Cw
G23	Helix Ccw
G24	Bolt Circle
G25	Step/Repeat
G26	Pocket Mill
G27	Post Mill
G29	Exec Autocycle
G39	Para Subprog
G59	Pal
G79	Global
G75	Cavity
G79	Programmable
G80	Cancel
G81	Drill
G82	Counter Bore
G83	Peckdrill
G84	Tap
G85	Bore
G89	Restore
G60	Zone Inhibit
G62	Override Inhibit
G66	Graphics Control
G70	Inch
G71	Metric
G72	Scaling
G74	Rotation
G90	Absolute
G91	Incremental
G92	Preset Prog 0
G94	Per Time Feed
G97	Acc/Dec Inhibit
G99	Cancel Presets

Series 8400 Robot M codes (Courtesy Allen Bradley Company)

Code	Function
M00	Program Stop
M01	Opt Program Stop
M02	Program End
M30	Program End/Rew
M03	Spindle Cw
M04	Spindle Ccw
M05	Spindle Off
M07	Coolant On-Mist
M08	Coolant On-Flood
M09	Coolant Off
M10	Clamps On
M11	Clamps Off
M13	Spindle Cw
M14	Spindle Ccw
M06	Prog Stop Man Tc
M20	Tool Out -Atc-
M21	Turret Cw -Atc-
M22	Turret Ccw -Atc-
M23	Tool In -Atc-
M27	Turret Home -Atc-
M24	Rpm Up
M25	Rpm Down
M28	Low Gear
M29	High Gear

CHAPTER 4

SOFTWARE DEVELOPMENT - CPS

4.1 Introduction

Cutting Path Simulation (CPS) is a Software nearing completion, developed by a team headed by Mr Katkuri Ram Reddy . By using this software 2-dimensional (2-d) and 3-dimensional models can be created. This software is written in Hierarchical Object Oriented Software (HOOPS) embedded in the powerful C language. Basic geometric entities like point, line, arc, circle and spline can be drawn. Any number of objects or geometric models can be created by a combination of the above entities. Such created objects can be rotated, extruded and zoomed. A simulation of the cutting path of the tool can be performed and report generated using G&M codes.

4.2 Menu Structure

The menu structure of the software is best explained by the figures in the accompanying pages.

4.3 Debugging

4.3.1 B-Spline

4.3.1.1 Introduction: B-Spline is a curve which has no simple mathematical definition. We use the idea of interpolation to generate it. We take an array of sample points and draw an approximation to such a curve. It is then possible to guess what the curve should look like between the sample points. If the curve is smooth and our samples are close enough together, we can make a pretty good guess as to what the missing portions should look like. The guess may not be

with pieces of known curve which pass through the nearby sample points. Since the known and unknown curves share these sample points in a local region, we assume that in this region, the two curves look pretty much alike. The next step is to fit a portion of the unknown curve with a curve that we know. Then the gap between the sample points is filled by finding the coordinates of points along the known, approximating curve and connecting those points with line segments.

4.3.1.2 Bug

The B-Spline created using CPS had a bug. The curve created using 4 or 5 points did not go through all the points and did not end at the last point. Instead it was leading and tracing to the end of the screen and was going out of the screen limit.

4.3.1.3 Investigation Conducted

A systematic investigation towards eliminating this bug was conducted. First the formulas for the blending functions was checked and found to be errorless. It was then proposed that there could have been a possible error in the algorithm and subsequent implementation of the End-B-Spline. This was checked and found that there were no errors. The next reason investigated was that the curve was not recognizing the last sample point as to be the last one and hence with no objective as to where to end, it was tracing towards the end of the screen. To eliminate this, the first sample point and the last sample point was chosen as the same. It means that out of 5 points the first point and the fifth point were chosen to be with the same x,y,z coordinates. It was interpreted that since the curve understood the first sample point at a particular x,y,z value it would also understand the last sample point because it was chosen at the same x,y,z value of the first sample point. But the curve failed to understand it and was still tracing the end of the screen.

4.4 Menu Creation

Two additional sub-menus were created and implemented. Previous work done had created water jet ON/OFF sub-menus under path selection. Abrasive ON/OFF was added under the sub menu because some materials would be needing an abrasive water jet to perform a cutting action on them. It was tested and found to work well.

4.5 G & M Codes

G & M codes were written for problems. The codes generated by CPS software were compared and found to be compatible to certain extent. Future work should strive to achieve full compatibility.

Problem :

The problem is to machine a plastic square plate of dimension 8" per side with two holes of diameter 1" each. The figure of the plate is shown on the next page.

Program code for Water jet cutting :

Program code for the water jet cutting are nothing but a collection of blocks. Each block will contain one or more program words.

Block1

G91G17G70G94F25.0

G91....Incremental entry of measurements for the tool path.

G17.... X-Y Plane

G70.... Inch Format

G94.... IPM/MMPM Feedrate Coding

Block2

G04MO3F0.5

G04...Dwell Mode

MO3...Water ON

F0.5..Dwell for 0.5 seconds

Block3

G01X-8.0

G01... Linear Interpolation

X-8.0.. Moves 8" along the negative X direction from the start point i.e from A to B.

Block4

GO1Y-8.0

Y-8.0... Moves 8" along the negative Y direction i.e from B to C.

Block5

GO1X8.0

X8.0.... Moves 8" from C to D.

Block6

G01Y8.0

Y8.0...Moves 8" from D to A.

Block7

GO4F0.5

Block8

G02X-4.0Y-1.5

Moves 4" along negative X-axis and 1.5" along the negative Y-AXIS.

Block9

G02Z-0.5

G02...Circular Interpolation

Cuts the hole with 0.5 radius along the negative Z axis.

Block10

G02Z0.5

Goes to the initial position before cutting.

Block11

G02Y-5.0

Aligns with the center of the next hole to be cut.

Block12

G02Z-0.5

Cuts the second hole with 0.5 radius along the negative Z axis.

Block13

G04M04F0.5

MO4....Shut of Water

G04....Dwell

Block14

M2

M2...End of Program

The N word numbering should precede each code while entering it into water jet machine. The above codes collected with the N word are :

N0001G91G17G70G94F25.0

N0002G04M03F0.5

N0003G01X-8.0

N0004G01Y-8.0

N0005G01X8.0

N0006G01Y8.0

N0007G04F0.5

N0008G02X-4.0Y-1.5

N0009Z-0.5

N0010G02Z0.5

N0011G02Y-0.5

N0012G02Z-0.5

N0013G04M04F0.5

N0014M2

Solution using CPS :

Step1

Login to the Sun System and invoke windows by typing "Suntools"

Step2

Type CPS in the windows.

Step3

The menu with options of 2-d and 3-d will appear. Click with the help of a mouse choosing 2-d.

Step4

Sub menu with options to draw basic geometric entities like point, line, arc , circle, spline would appear. Click at point.

Step5

Option for entering coordinates through keyboard or through mouse would appear. If mouse is chosen then X & Y spacing, and X & Y divisions should be entered. If keyboard is chosen then the coordinates for the point should be entered. Choose Keyboard entry and enter coordinates for the four ends of the square and centers of the two circles. Type d/q to quit when done.

Step6

Choose line in the submenu and click the four points to draw the square.

Step7

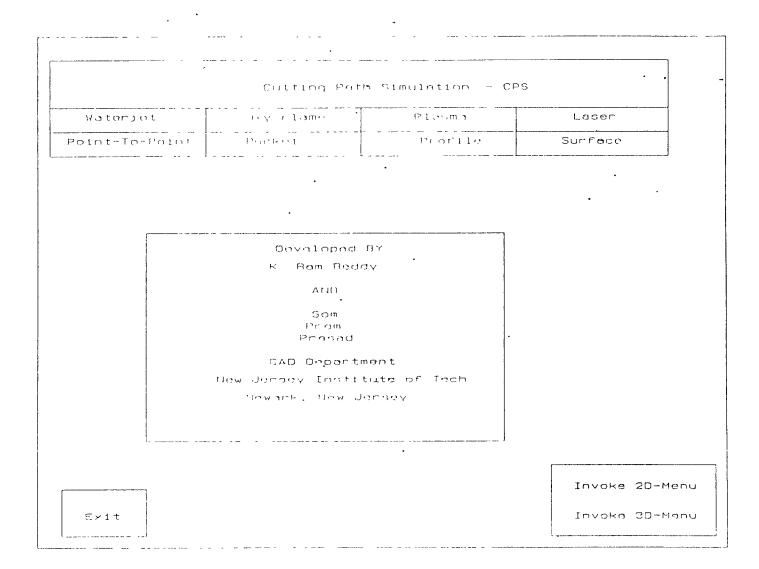Choose circle in the submenu and click the center and enter radius to draw the two circles.

Step8

Choose path selection to enter the path and format of cut. Click Inch format, Incremental mode, and X-Y plane. Click update to update the information to the software. Click water ON and abrasive OFF.

Step9

Choose Simulation to view how the material is going to be cut.

Step10

Choose Report Generation to get a copy of the output file.

Cutting Path Simulation — CPS			
Waterjot	Hy+Lame	Plasma	Laser
Point-To-Point	Pocket	Profile	Surface

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                    Developed BY

                 K   Ram Reddy

                      AND

                      Som
                     Prom
                    Prasad

                 CAD Department
        New Jersey Institute of Tech
           Newark, New Jersey
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Exit

Invoke 2D-Menu

Invoke 3D-Menu

Cutting Path Simulation - CPS			
Waterjet	Oxy flame	Plasma	Laser
Point-To-Point	Pocket	Profile	Surface

Draw	Extrude	Rotate	Zoom	Photo	Reset	Help	Color

CPS - Main
Construct
IGES Translator
Path selection
View Options
Simulation
Report generation
G&M Code
Main

Done	Save
Grid	Fetch

Cutting Path Simulation - CPS						
Waterjet		Oxy Flame		Plasma		Laser
Point-To-Point		Pocket		Profile		Surface

Draw	Extrude	Rotate	Zoom	Photo	Reset	Help	Color

Point	
Line	
Arc	
Circle	
Fillet	
Spline	
Delete	
Previous Menu	
Done	Save
Grid	Fetch

Cutting Path Simulation - CPS

Waterjet	Oxy-Flame	Plasma	Laser
Point-To Point	Pocket	Profile	Surface

Draw	Extrude	Rotate	Zoom	Photo	Reset	Help	Color

Point
Line
Arc
Circle
Fillet
Spline
Delete
Previous Menu

Resize Window	Key-In	Mouse

Done	Save
Grid	Fetch

Format (Metric, Inch)	Inch	M
Mode (Incr/Abs)	Ab	Inc
X-Y Plane	Yes	No
X-Z Plane	Yes	No
Y-Z Plane	Yes	No

Update	Done

CPS – Main	
Construct	
IGES Translator	
Path selection	
View Options	
Simulation	
Report generation	
G&M Code	
Main	
Done	Save
Grid	Fetch

Abrasive ON	Abrasive OFF	Water ON	Water OFF

Draw	Extrude	Rotate	Zoom	Photo	Roll	Help	Color

Point-to-Point
Material

CHAPTER 5
CONCLUSION

The Computer is an information processing machine and is used for storing, manipulating, and correlating data. It has now been made possible to generate or collect and process information on a scope never before possible. The information thus gained gives us superior control capabilities and helps us to make decisions.

But if computers had only the capability to print thousands of pages then it would be of not much value. Computer Graphics comes to help in that case, thus providing data both on the screen and on the pages. The powerful feature of Computer graphics is its ability to establish a dialogue with its user . That is why it derives the name of interactive computer graphics. This interaction feature combined with pictorial feature has made design and manufacturing more powerful and innovative.

Computer Graphics, Computer Aided Design has been the latest technology in association with Computer Aided Manufacturing which have paved way to many new research and development in the field of cutting technology. The interface between CAD and a cutting machine provides many functional values to the machine and gives better product to the market. Enhanced product quality, longer life, ability to achieve closer tolerance, multi directional cutting capability, ability to control from remote areas, simpler redesigning features, simulation capabilities etc are some of the powerful advantages. High initial cost, requirement of well trained operators, suitable for only large batch size, hardware requirements, etc are some of the limitations.

Cutting path simulation (CPS) is a powerful CAD Software developed to create, modify and down load 2-d and 3-d models to any cutting machine, specifically water jet cutting system as of this case. Additional menus to perform specified functions were created. Bugs existing in the creation of B-Spline and other geometric entities

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were removed. G & M codes were generated and sample problems were solved. Investigation was conducted on the feasibility of down loading the models created, to water jet cutting machine and was found successful. Two possible solutions for presenting the object of how it is going to be after cutting were derived at a conceptual stage. One was in IDEAS and the other was in HOOPS. Future work should involve in developing functional codes for a few existing menus. Generating 3-d functional models is another area which needs concentration.

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