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AN EFFECTIVE CURRICULUM FOR TEACHING
COMPUTER NUMERICAL CONTROL MACHINING

A Project
Presented to the
Faculty of
California State University,
San Bernardino

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts
in
Education:
Career and Technical Education

by
Paul Allen Van Hulle

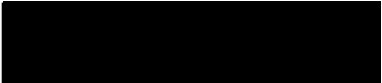
June 2002

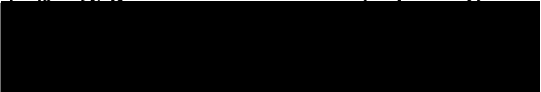
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Approved by:


Joseph A. Scarcella, Ph.D., First Reader


Ronald K. Pendleton, Ph.D., Second Reader

3/2/02
Date

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ABSTRACT

The Access Technology Training Center started out as a welfare-to-work program funded through a grant from the Economic Development Agency. In June 2002 the program will be given to the Mt. San Jacinto College. When the program is turned over to the College, the center will need to become self-sufficient by teaching regular for California State University credit classes to students from the Mt. San Jacinto College. A curriculum needs to be developed for teaching students from the college.

The purpose of this project was to develop and document curricular content for a Computer Numerical Control education program for Mt. San Jacinto Community College. The design of the curriculum focuses on showing students how skills learned in academic classes can be applied to the workplace.

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DEDICATION

To my parents and family, for their guidance and support. Without these things this thesis and my entire education would not have been possible.

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CHAPTER ONE

BACKGROUND

Introduction

The contents of Chapter One presents contents of an overview of the project. The contexts of the problem are discussed followed by the purpose, significance of the project, and assumptions. Next, the limitations and delimitations that apply to the project are reviewed. Finally, definitions of terms are presented.

Context of the Problem

There is a significant need for educational curriculum that will help students not planning on attending college gain skills that will sustain them for life. Preparing students to contribute to society throughout their lives and giving them skills needed for entry into the workforce are crucial to our economy. Interest in establishing industry-driven skill standards is growing. If the United States is to remain competitive internationally states must increase the skills and productivity of the front-line workforce (Illinois Occupational Skill Standards, 1997).

The manufacturing industry has experienced major technological changes. Today's production workers need to

be trained in higher level skills. "Employers need workers with a knowledge of robotics, computers, Computer Numerically Controlled (CNC) machines, and Computer Aided Drafting [CAD]" (Skilled Occupations, 1994, p. 1).

Examples of some skills required of employees related to the Computer Aided Machining field would be the ability to follow written instructions, interpersonal skills, computer skills, metalworking skills, manual dexterity, mathematical skills, and spatial skills (Skilled Occupations, 1994, p. 1).

Purpose of the Project

The purpose of this project was to develop and document curricular content for a Computer Numerical Control education program at Mt. San Jacinto Community College. The design of the curriculum focuses on showing students how skills learned in academic classes can be applied to the workplace.

Significance of the Project

Computer Aided Machining (CAM) is an occupation that requires workers that are highly competent both in academic courses such as math, English, and career and technical education courses. Advancement in the field of Computer Aided Machining requires that workers understand

how skills and theories learned in academic classes are transferable to the workplace. "Most firms usually accept training as a substitute for work experience" (San Diego County 2001 occupational outlook report, 2001, p. 92).

Assumptions

The following assumptions were made regarding the project:

1. It was assumed, instructors using the curriculum would have an understanding of how to do hand or manual programming and how to use Mastercam.
2. It was also assumed the students were taught basic operation of the computer and file management techniques using the Windows environment, measurement, blueprint reading or drafting, and basic shop safety before starting this curriculum.

Limitations and Delimitations

During the development of the project, a number of limitations and delimitations were noted. These limitations and delimitations are presented in the next section.

Limitations

The following limitations apply to the project:

1. The curriculum section of the project was designed for use with Mastercam Computer Aided Machining Software Version 8.
2. The project was limited to Mt. San Jacinto Community College's Access Technology Training Center.

Delimitations

The following delimitations apply to the project:

1. The curriculum may be altered for use in a high school or technical education program.
2. The documentation and curriculum development section of the project could assist other teachers of manufacturing or machining education to develop their own Computer Aided Machining education program.

Definition of Terms

The following terms are defined as they apply to the project.

Absolute Measuring Systems - A method of defining the coordinate locations of point to which the cutter (or

workpiece) is to move based on the fixed machine point (Oberg, 2000).

Applied or Contextual Learning - A learning strategy

emphasizing the context within which a student might apply the skills or knowledge derived from the instruction. It addresses multiple learning styles among students and is based in learning theory indicating the impact learning-by-doing (Hutcheson, 1999).

Cartesian Coordinate System - A coordinate system that

consists of three axes (X, Y, and Z) that are perpendicular to each other. A grid is formed consisting of numerical graduations, representing the distances from the intersection of the three axes called origin (Evans, 2001).

Circular Interpolation - A mode that reduces the number of

calculations required on a numerical control machine to program a curved surface. The circular interpolator in the machine control unit will automatically compute the necessary number of intermediate points to describe the circular cut. It also generates the electronic signals that will run the servos and guide the cutting tool in making the cut (Walker, 2000).

Computer Aided Drafting and Design (CADD) - A

computer-based system used to create, modify, and communicate a plan or product design (Wright, 1996).

Computer Aided Machining (CAM) - A broad term used to

define the use of the computer in many manufacturing activities such as factory simulation, planning analyses and part programming (Oberg, 2000).

Computer Aided Programming - Using CAD/CAM software

systems to generate part programs (Lin, 1998).

Computer Numerical Control (CNC) - The numerical control

system in which a dedicated, stored computer program is built into the control to perform basic and advanced NC functions (Lin, 1998).

Datum - A reference point or plane from which movement or measurements are made (Krar, 2001).

G-Code, The Code, or Code - Preparatory functions (G-Code)

are programmed with an address G, typically followed by two digits, to establish the mode of operation in which the tool moves (Evans, 2001).

Hand or Manual Programming - A part program is prepared by

manually inputting the coded instructions into the controller (Lin, 1998).

Incremental Measuring Systems - A method of identifying

the coordinates of a particular location in terms of

the distance of the new location from the current location (Oberg, 2000).

Mastercam - Computer Aided Machining software program used in schools and industry (Lin, 1998).

Miscellaneous Control Signals - A set of on/off signals to implement the control of the speed and direction of the spindle rotation, control of coolant supply, selection of cutting tool, automatic clamping and unclamping, etc. (Lin, 1998).

Motion Control Signals - A series of electric pulse trains that are used to control the position and the speed of the machine table and spindle (Lin, 1998).

Numerical Control (NC) - A system of control that uses numerically coded instructions to operate motors and other devices that run a machine (Repp, 1984).

Origin - A starting point for the coordinate system used to machine parts; a fixed point on a blueprint from which dimensions are taken (Evans, 2001).

Polar Coordinate System - Points are defined by their linear distance as measured parallel to the fundamental axis from the origin. In polar coordinates, points are defined by their rotational angular position from the reference axis and by the radial distance from the origin (Kibbe, 2002).

Punch Tape - A rarely-used storage medium made of paper, plastic, and polyester laminates, that is used for the permanent storage and loading of CNC part programs, and on which characters are represented by combination of holes (Krar, 2001).

Single step or block - The execution of a single block of information in the program is initiated by activating a switch or button on the control panel. While in this mode, each time to cycle start button is pressed, only one block of information will be executed (Evans, 2001).

Technical Education - A term used to identify a level or sub-set of vocational or occupational education that involves the preparation for or upgrading within occupations that lie some place between the skilled craftsman and the professional. The occupations tend to involve a heavier reliance upon understanding and competence in mathematics and science than might be found in most occupations that require less than baccalaureate level preparation (as cited in Scarcella, 2001).

Organization of the Thesis

The thesis portion of the project was divided into five chapters. Chapter One provides an introduction to the context of the problem, purpose of the project, significance of the project, limitations and delimitations, and definitions of terms. Chapter Two consists of a review of relevant literature. Chapter Three documents the steps used in developing the project. Chapter Four has the budgetary considerations. Chapter Five presents conclusions and recommendations drawn from the development of the project. Project references follow Chapter Five. Finally, the Appendix consists of the project: consists of Coordinate Systems for Computer Aided Machining and Manual Programming; Mastercam Computer Aided Machining Program; Computer Numerical Control Machine Programming Using Manual Methods.

CHAPTER TWO

REVIEW OF THE LITERATURE

Introduction

Chapter Two consists of a discussion of the relevant literature. Specifically, history of Computer Numerical Control, occupational outlook, skills defined, Computer Aided Manufacturing and advanced Computer Numerical Control technical workplace competencies, and The Secretary's Commission on Achieving Necessary Skills Course Competencies.

History of Computer Numerical Control

Numerical Controlled machines had been associated with manufacturing industry for many years. In the past, numerically controlled machines were controlled using punch tape. Punch tape type numerically controlled machines of the past worked on similar principles as the old fashioned player piano (Curran, 2001; Krar, 2001). The player piano of the past blew air through holes punched in a role of paper to control which notes were played. Other examples of machines that used punch tape control were the early weaving machines of the 1800s. "Weaving machines used metal cards with holes punched in them to control the pattern of the cloth being produced" (Curran, 2001, p. 2).

The Numerically Controlled milling and turning machines of the past were controlled by punch tape. The holes in the punch tape would activate switches that sent signals to accurate stepper motors telling them how much to move at the desired feed rate. Many of these early NC machines were non-simultaneous. In other words, only one motor on the machine could be moved at a time. This made it impossible to make complex three-dimensional shapes (Krar, 2001).

The Computer

The development of the computer was a critical turning point for the introduction of CNC. On February 15, 1946 at 7:00 P.M. Eastern Time a press release about the first computer was published. The press release stated: "A new machine that is expected to revolutionize the mathematics of engineering and change many of our industrial design methods was announced today by the War Department" (War Department, 1946, p. 1). The machine was named the ENIAC, which stood for "Electronic Numerical Integrator and Computer" (War Department, 1946, p. 1). The ENIAC took up 1800 square feet of floor space and weighed 30 tons (Stern, 1995). The war department press release further stated:

The ENIAC is capable of computing 1000 times faster than the most advanced general-purpose calculating machine previously built. The electronic methods of computing used in the ENIAC make it possible to solve in hours problems which would take years on a mechanical machine—a time so long as to make such work impractical. (War department, 1946, p. 1)

It can be inferred from the press release that society of the 1940s was concerned that computers would replace human thinking.

The new machine does not remove the need for legitimate experimentation, whose purpose it is to discover fundamental principles and factors which affect those principles. Likewise, it was pointed out that the electronic calculator does not replace original human thinking, but rather frees scientific thought from the drudgery of lengthy calculating work. (War Department, 1946, p. 1)

In 1947, the need for more advanced numerically controlled machines and computer numerically controlled machines was created by the United States Air Force's need for complex shaped aircraft parts such as missile components and helicopter rotor blades. These aircraft components needed to have high precision and uniformity and be created quickly with demanding production schedules that were very hard to meet using manual machining methods. The Massachusetts Institute of Technology (MIT), was contracted by the Airforce to develop Numerical Control and in turn speed up production (Krar, 2001). The

press release about the ENIAC also showed an interest in using the computer for aerodynamics. It stated: "Although the machine was originally developed to compute lengthy and complicated firing and bombing tables for vital ordnance equipment, it will solve equally complex peacetime problems such as nuclear physics, aerodynamics and scientific weather prediction" (War Department, 1946, p. 1).

In 1952, the Massachusetts Institute of Technology demonstrated a Computer Numerically Controlled machine, which made parts through simultaneous three-axis cutting tool movements (Krar, 2001). Integrated circuits, introduced in 1959, helped decrease the size of the CNC machine. An integrated circuit is a tiny electronic circuit used to perform a specific electronic function. Research from 1999 (Encarta) suggested that an integrated circuit measuring the size of a fingernail can contain as many as 5,000 circuit elements.

During recent years, the functional capability of ICs has steadily increased, and the cost of the functions they perform has steadily decreased. This has produced revolutionary changes in electronic equipment—vastly increasing functional capability and reliability combined with great reductions in size, physical complexity, and power consumption. (Encarta, 2000, Integrated Circuits)

Since CNC machines use similar circuitry as a personal computer the CNC machine benefited from the development of the integrated circuit. The integrated circuit improved the functionality, accuracy and size of the CNC machine (Curran, 2001).

The first Computer Numerical Control machines with greater capability than Numerical Control machines were produced in 1976. The major difference between Numerical Control machines and Computer Numerical Control is Numerical Control machines could only read one single step or block at a time and execute it. However, Computer Numerical Control machines could store whole programs. CNC provides greater speed and versatility for making changes to the program (Curran, 2001; Repp, 1984).

Societal Impact of Computer Aided Machining

The history of the societal impact of computers and computer aided machining systems has important implications for the occupational outlook for students considering a career in computer aided machining. As mentioned previously when the ENIAC was introduced society was very concerned that machines would replace human workers. According to Volti (1992) when people think of technological change they often think they will lose their jobs to legions of robots performing work 24 hours per day

without assistance of humans. CAM has exasperated this false assumption. When the product design is completed CAM can be used to run CNC machines to produce the part. There are many problems with the theory that the machine can do all this without the assistance of humans. Humans are still essential for programming the design of the part, machine setup, transporting the part from one operation to the next, and monitoring and adjusting the machine for cutter tool wear.

Current trends show that the manufacturing industry will never become as automated as not to need humans to intervene when problems arise. Workers will need to constantly improve their skills to keep up with advancing technology. The future looks bleak for the mature workers who have not updated their skills (Volti, 1992). Volti suggests this is when well-planned vocational education programs can help retrain under skilled workers.

Occupational Outlook

Computer Numerical Control operators play a major role in producing most of the consumer products, which people rely upon daily (Numerical Control Machine Operators, 1998, p. 1). Even the plastic parts of a cell

phone were molded using a mold that was created on a numerically controlled machine.

The operations of the manufacturing environment can be categorized as NC shop management, NC part programming, tool and fixture design, machine maintenance, and NC machine operations. The following diagram shows some of the job responsibilities in each of these categories. Many of these job responsibilities require people that are skilled in both academics and technical education and to have college or vocational education. Table 1 details the job responsibilities and educational experience of a Computer Numerical Machine operator and programmer.

According to the occupational outlook handbook the outlook for careers in manufacturing was predicted to be excellent; however, to be successful workers must be highly skilled and well trained. Employers report difficulties in finding workers with the skills and knowledge necessary to fill machining and CNC programming openings. Referring to table 2 on the following pages Riverside, and San Bernardino employers find difficulty finding qualified or skilled CNC tool operators and machinists. The occupational outlook handbook reported

Table 1. Computer Numerical Control Career Opportunities

Job Title	Responsibility	Required Job Skills	Education/ Experience
NC manager or supervisor	Oversee NC operations. NC personnel hiring, training and job assignment. Coordination with other departments. Evaluate and acquire new CNC machine tools and CAD/CAM software.	Management Skills. Machining Knowledge. NC programming and Operation background.	4-year college degree with several years of manufacturing experience.
Process planner	Determine what machining processes to be used with what sequence and in what machines. Select cutting tools and work holding devices and fixtures. Prepare operation sheets and tooling sheets.	Overall knowledge of machining, tooling, and capability of available equipment. Good background in manufacturing and CNC.	At least 2-year college degree, 4-year college degree preferred.
Part programmer	Prepare part programs. Prepare NC documents concerning setup instructions. Prepare process plan if needed.	Good command at math, geometry and trigonometry. Sound knowledge of machining. Blueprint reading. Computer skills. Use of CAD/CAM software.	2-year college degree or vocational technical school.
Tool designer	Select standard tooling. Design special-purpose tooling.	Good command at locating and clamping knowledge. Knowledge of tool making. Understanding of standard tooling and fixturing.	At least 2-year college degree with tool and machine experience, 4-year college degree preferred.

Job Title	Responsibility	Required Job Skills	Education/ Experience
Tool maker	Assemble and preset standard tooling. Make special-purpose tooling. Repair damaged tooling items.	Highly skilled in machining. Knowledge in CNC. Print reading and making.	4-year apprenticeship program.
Machine setup person	Set up fixture and cutting tools on the machine. Coordinate the machine. Determine and enter offset and compensation values. Correct errors in tooling and program. Run the program.	Good knowledge in machining and tooling. Understanding of part program and machine functions.	Machinist experience with extensive CNC knowledge.
Machine operator	Load and Unload work pieces. Monitor machining in progress. SPC charting. Regular check-up.	General knowledge of machining.	Technical programs in vocational technical school, area occupational school, community college.

(Lin, 1998, p. 1-5).

slower growth for CNC programmers as compared to machinists "primarily because the machinist occupation is larger" (Occupational Outlook Handbook, 2001). Employment trends also show (as shown in table 3) Riverside, San Bernardino, and Orange Counties expect either growth or stability as opposed to decline in this occupational field.

Table 2. Employment Trends

Employment Development Department
Employment Trends

Occupation Title: Numerical Control, Machine-Tool Operators and Tenders (CNC) or Machinists (Machinists) as listed

	Employment Levels During the Past Year			Employment Levels Projected Over the Next two years		
	Decline	Remain Stable	Grow	Decline	Remain Stable	Grow
Orange CNC, 99	7%	47%	47%	13%	40%	47%
Riverside Machinists, 98	7%	53%	40%	7%	47%	46%
Riverside CNC, 98	13%	53%	34%	7%	40%	53%
San Bernardino Machinists, 99	6%	56%	38%	6%	75%	19%

Orange County data from: (*Orange County 2000 occupational outlook*, 2000, p. 104)

Riverside County data from: (*Labor market information study*, 1999, p. 34 & 42)

San Bernardino County data from: (*County of San Bernardino*, 2000, p. 34)

Most employers will substitute two years of training for experience in the field (San Diego County 2001 occupational outlook report, 2001, p. 92). Students that complete the Access Technology Training Center courses offered through the Mt. San Jacinto Community College would likely fall in the category of experienced but new to the firm. Referring to tables 4 and 5 the pay range for people with experience but new to the firm had a median of \$9.50-12.80 per hour for CNC operators and a median of \$12.00-14.00

per hour for machinists. Considering California's minimum wage as of January 1, 2002 was \$6.75 the wages for CNC operators and Machinists are significantly higher than minimum wage (Minimum wage laws, 2001).

Table 3. Employee Supply and Demand Data

Supply and Demand Data
County's Employers ability to find Experienced or Inexperienced Employees
Occupation Title: Numerical Control, Machine-Tool Operators and Tenders
(CNC) or Machinists (Machinists) as listed

	Experienced/Qualified			Inexperienced		
	Very Difficult	Moderately or Somewhat Difficult	Not Difficult	Very Difficult	Moderately or Somewhat Difficult	Not Difficult
Los Angeles CNC, 99		X			X	
Los Angeles Machinists, 98		X			X	
Orange CNC, 99		X			X	
Riverside Machinists, 98	X			X		
Riverside CNC, 98	X					X
San Bernardino Machinists, 99	X				X	
San Diego Machinists, 98		X			X	

Los Angeles County Machinists data from: (Occupational outlook Los Angeles - a labor market information study, 1998, p. 58)

Los Angeles County CNC data from: (Occupational outlook Los Angeles County - a labor market information study, 1999, p. 72)

Riverside County data from: (Labor market information study, 1999, p. 34 & 42)

San Bernardino County data from: (County of San Bernardino - 1999 occupational outlook report, 1999, p. 33)

San Diego County data from: (San Diego 2001 Occupational outlook report, 2001, p.93)

Skills Defined

Research shows that industries' need for skilled workers have increased. If a person does not have skills to offer companies, they will have difficulty gaining employment working above minimum wage. As shown in the following three figures, "since the 1950's there has been a dramatic increase in the need for skilled workers" (McAlonan, 1999, p. 24).

Table 4. Directory of California Wages for Computer Numerical Control

Employment Development Department
2000 Directory of California Local Area Wages
Occupation Title: Numerical Control Machine Tool Operators & Tenders-Metal
& Plastic

	Entry Level No Experience			Experienced New to Firm			Experienced 3 Years with Firm		
	Low	High	Median	Low	High	Median	Low	High	Median
Los Angeles County Non Union, 99	6.50	13.35	7.75	7.00	20.00	12.00	10.60	25.00	16.15
Los Angeles County Union, 99	13.00	13.00	13.00	11.50	15.32	12.80	12.90	19.00	17.34
Orange County, 99	7.50	14.00	9.23	6.14	18.00	10.00	10.50	22.60	15.00
Riverside, 98	5.75	7.00	6.25	6.25	20.00	9.50	9.00	25.00	15.00

All figures are in dollars/hour
San Diego, and San Bernardino had no data

(California employment development department - Labor market information, Numerical-Control machine-tool operators & tenders-Metal & plastic, 2000, p. 1)

Table 5. Directory of California Wages for Machinists

Employment Development Department
 2000 Directory of California Local Area Wages
 Occupation Title: Machinists

	Entry Level No Experience			Experienced New to Firm			Experienced 3 Years with Firm		
	Low	High	Median	Low	High	Median	Low	High	Median
Los Angeles County 98	5.75	16.20	9.00	7.19	25.59	14.00	9.59	29.83	18.00
Orange County, 99	5.75	16.20	9.00	7.19	25.57	14.00	9.59	29.83	18.00
Riverside, 98	5.50	15.00	7.50	10.00	20.00	15.00	11.00	25.00	18.00
San Bernardino, 99	N/A	N/A	N/A	9.00	17.70	12.00	11.00	19.18	14.50
San Diego, Non-Union, 98	5.75	12.00	7.00	6.75	15.00	12.00	8.00	19.00	16.00
San Diego, Union, 98	10.00	10.25	10.13	11.00	16.00	13.50	15.00	22.00	18.50

All figures are in dollars/hour

San Diego, Riverside, San Bernardino, and Los Angeles data from (California employment development department - Labor market information, Machinists, 2000, p. 1)
 Orange Co. data from: (Orange County 2000 occupational outlook, 2000, p. 104)

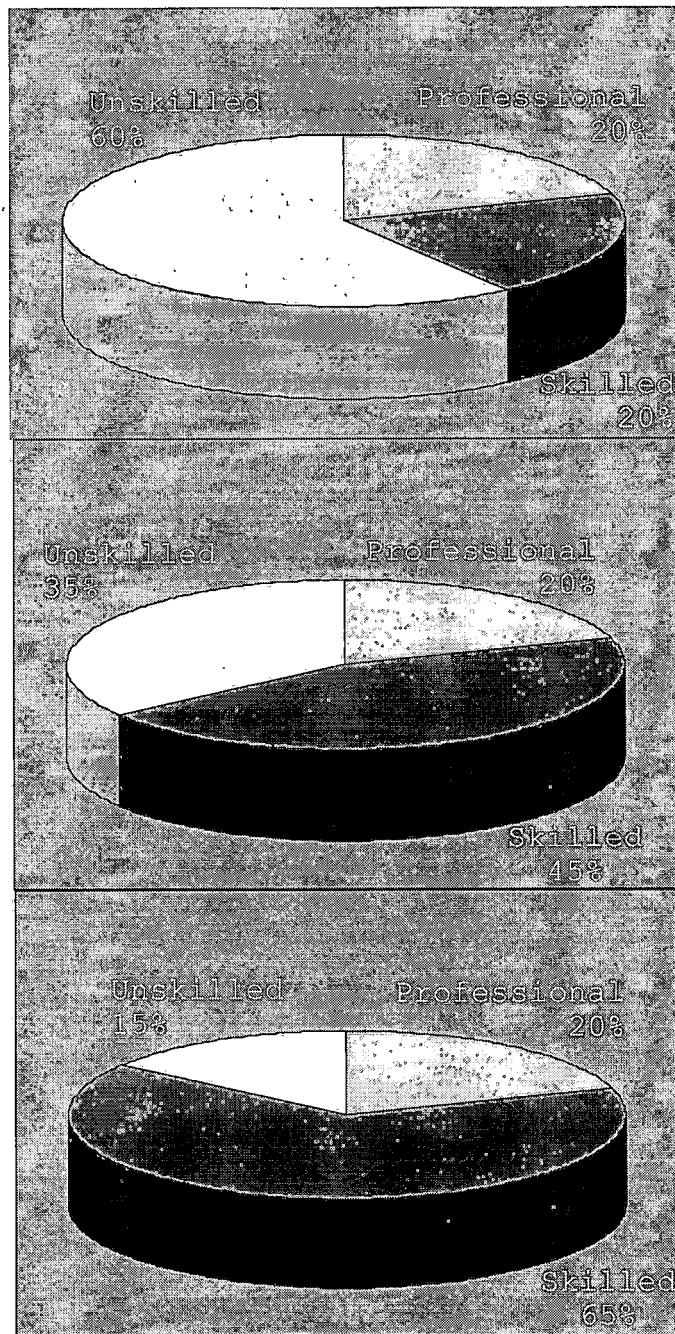


Figure 1. Industries' need for Skilled, Unskilled, and Professional Workers for Years 1950, 1991, and 2000 (McAlon, 1999, p. 24)

Skills are the things that a person knows that can be transferred from one field to another (Bolles, 1994, p. 174). Examples of skills would be the ability to synthesize and interpret data, manage people, and perform part or machine setup. According to Dr. Zargari from Morehead State University technological advancements and competition abroad have a significant impact on the work place. Qualification requirements are always changing. "The danger for the present and future is not lack of jobs, but lack of technological skills" (Zargari, 1997, p. 5). People are in danger of having a critical shortage of workers with the education and training necessary to handle the jobs that need to be filled (Zargari, 1997).

Students must be taught how to work with technology to perform skills. The nature of the work force changed dramatically. Workers are required to be skill adaptive. Low-skill jobs are gradually being replaced by jobs requiring, mathematics, language, technological literacy, and problem-solving skills (Zargari, 1997).

Contextual Learning

Research in reform of education called into question the organization and operation of traditional education systems. This research challenges the validity of the

notion basic skills taught using traditional instruction methods can be applied in context in the real world.

Traditional instruction assumes that:

- (a) competencies can be decomposed into constituent parts, or subskills, that can be learned and then put back together and the competency will be acquired,
- (b) individual skills can be taught out of context on the assumption that they can then be applied appropriately in context. (Milne, 1998, p. 68)

The research into whether or not traditional instruction is showing students how subjects taught in the traditional classroom applies to the real world has resulted in the theory of contextual learning. The process of contextual learning helps students understand how subject matter content relates to real world situations. This process "motivates students to make connections between knowledge and its application to their lives as family members, citizens, and workers" (Blanchard, 2000a). Blanchard defines contextual instruction that:

- Relies on spatial memory,
- Typically integrates multiple subjects,
- Value of information is based on individual need,
- Relates information with prior knowledge,
- Authentic assessment through practical application of solving of realistic problem. (Blanchard, 2000a, p. 2)

As compared to contextual instruction, traditional instruction is instruction which:

- Relies on rote memory,
 - Focuses on a single subject,
 - Value is determined by the instructor,
 - Fills student with deposits of information until needed,
 - Assessment of learning is only for formal academic occasions such as exams.
- (Blanchard, 2000a, p. 2)

As can be seen from the previous section on skills that employers require of employees in the field of Computer Numerical Control operation and programming, Employers require employees that can access information in technical manuals and that can communicate with others to solve problems. According to Milne (1998) "Schools place a large emphasis on the demonstration of student performance without the assistance of resources, such as books, calculators, and other people. These resources are routinely utilized in out of school settings" (p. 72). One of the emphases of contextual based education is students' should be encouraged to practice accessing information to solve real world problems.

The methods proscribed by the research on contextual instruction delivery (Blanchard, 2000a; Milne, 1998) involve fewer lectures and more hands on activities. Much

of the curriculum presented in the project section is based on contextual learning.

Occupational Standards for Computer Numerical Control Education

San Diego City College's Center for Applied Competitive Technologies (CACT) surveyed eight Southern California companies to determine what technical workplace competencies they consider important for training of Computer Numerical Control Programmers/Operators. The competencies researched by San Diego City College focused on training of both Electro-discharge machine operators and CNC operators. The project of this thesis focused on CNC operators and machinists. As shown below the research gives a broad spectrum of the skills required of employees in the field of CNC operation and programming.

Other competencies that should be considered are the skill competencies developed by the secretary's commission on Achieving Necessary Skills (SCANS). The SCANS competencies detailed in table 8 represent the results of U.S. Department of Labor's meetings with public employers, unions, business owners, and workers and supervisors in shops, plants, and stores. The purpose of these meetings was to identify the competencies and skills businesses require of employees. According to the SCANS report

students should develop these competencies if they are to enjoy a productive and satisfying life (What work requires of schools, 1991, p. 10).

Table 6. Computer Aided Manufacturing and Advanced Computer Numerical Control Technical Workplace Competencies

CAM and CNC Technician . . . program, edit, setup, and operate CNC lathes, mills and grinders to perform machining operations necessary to produce work pieces to reference engineering standards.	
A. Practice Safety	<ol style="list-style-type: none"> 1. Use proper safety equipment 2. Identify proper clothing 3. State proper attitudes for safety 4. Handle chemicals properly 5. Identify fire hazards in machining 6. Demonstrate proper personal hygiene 7. Demonstrate proper laboratory cleaning
B. Perform Measurements	<ol style="list-style-type: none"> 1. Identify applications and limitations of measuring instruments 2. Demonstrate use of measuring instruments
C. Apply Mathematical Concepts	<ol style="list-style-type: none"> 1. Perform mathematical computations with calculator 2. Calculate fractions and decimals with calculator 3. Convert Metric and US standard units of measure 4. Perform RPM calculations 5. Perform feed rate calculations 6. Perform depth of cut calculations 7. Perform thread cutting calculations 8. Perform tap drill calculations 9. Interpret reference tables related to machining 10. Apply Cartesian coordinate system to machining 11. Perform trigonometric calculations 12. Perform Pythagorean Theorem calculations 13. Perform polar trigonometric calculations

<p>D. Read Blueprints</p> <ol style="list-style-type: none"> 1. Describe types of blueprint drawings 2. Describe blueprint dimensions 3. Interpret title, notes, revision and material information 4. Interpret blueprint drawings
<p>E. Program CNC machines and EDM</p> <ol style="list-style-type: none"> 1. Demonstrate cutting tool identification and application 2. Identify and describe machine operation nomenclature 3. Identify and describe essentials of CNC systems 4. Identify and describe types of CNC hardware and software 5. Identify and describe machine axes and coordinate systems 6. Describe and interpret CNC coding systems 7. Write NC programs 8. Plan process for NC operations 9. Demonstrate use of electronic discharge machine (EDM)
<p>F. Operate CNC machines & EDM</p> <ol style="list-style-type: none"> 1. Describe vertical machining process and safety 2. Describe vertical machining functions 3. Set-up and program operation of vertical machine 4. Demonstrate machining of objects on vertical machining center 5. Perform CNC turning process, equipment and safety 6. Perform advanced EDM operations 7. Describe turning center 8. Set-up and program operation of turning center 9. Demonstrate machining of objects on turning center
<p>G. Use Computers</p> <ol style="list-style-type: none"> 1. Demonstrate use of computer hardware 2. Select/use computer operating system 3. Demonstrate use of basic DOS commands 4. Demonstrate use of Windows and Windows NT commands 5. Demonstrate use of MACROS in Windows and Windows NT programs 6. Demonstrate use of computer communication systems

H. Use CNC Verification Programs
1. Identify CNC verification software programs
2. Program and create CNC verification using program icons
3. Program CNC verification using pull-down menus
I. Using CAD/CAM Programs
1. Demonstrate understanding of CAD/CAM programs
2. Access CAD program options
3. Create designs with CAD section of CAD/CAM program
4. Demonstrate ability to use program functions
5. Process tool path data

(Machine tool advanced skills, 1996, p. 21-22)

Table 7. Secretary's Commission on Achieving Necessary Skills Course Competencies

Five Competencies:
Resources: Identifies, organizes, plans, and allocates resources
A. <i>Time</i> - Selects goals-relevant activities, ranks them allocates time, and prepares and follows schedules.
B. <i>Money</i> - Uses or prepares budgets, makes forecasts, keeps records, and makes adjustments to meet objectives.
C. <i>Material and Facilities</i> - Acquires, stores, allocates, and uses materials or space efficiently.
D. <i>Human Resources</i> - Assesses skills and distributes work accordingly, evaluates performance and provides feedback.
Interpersonal: Works with others
A. <i>Participates as a Member of a Team</i> - contributes to group effort.
B. <i>Teaches Others New Skills</i> .
C. <i>Serves Clients/Customers</i> - works to satisfy customers' expectations.
D. <i>Exercises Leadership</i> - Communicates ideas to justify position, persuades and convinces others, responsibly challenges existing procedures and policies.
E. <i>Negotiates</i> - works toward agreements involving exchange of resources, resolves divergent interests.
F. <i>Work with Diversity</i> - works well with men and women from diverse backgrounds.

Five Competencies:
Information: Acquires and uses information A. <i>Acquires and Evaluates Information</i> B. <i>Organizes and Maintains Information</i> C. <i>Interprets and Communicates Information</i> D. <i>Uses Computers to Process Information</i>
Systems: Understands complex inter-relationships A. <i>Understands Systems</i> - knows how social, organizational, and technological systems work and operates effectively with them. B. <i>Monitors and Corrects Performance</i> - distinguishes trends, predicts impacts on system operations, diagnoses deviations in systems' performance and corrects malfunctions. C. <i>Improves or Designs Systems</i> - suggests modifications to existing systems and develops new or alternative systems to improve performance.
Technology: Works with a variety of technologies A. <i>Selects Technology</i> - chooses procedures, tools or equipment including computers and related technologies. B. <i>Applies Technology to Task</i> - understands overall intent and proper procedures for setup and operation of equipment. C. <i>Maintains and Troubleshoots Equipment</i> - prevents, identifies, or solves problems with equipment, including computers and other technologies.

(What work requires of schools, 1991, p. 12)

Summary

Many books and articles on the subject of Computer Numerical Control Programming and the history of computers have been written. Chapter Two presented the history of numerical control, including the social implications of automation and computers. A brief section was offered about the skills required and the occupational outlook for CNC programmers and operators. The definition of

contextual learning and how it applied to the development of the project was also presented.

CHAPTER THREE

METHODOLOGY

Introduction

Chapter Three documents the steps used in developing the project. Specifically, the population served by the curriculum is presented. Next, the resources and content validation is discussed. Finally, the design of the curriculum is outlined

Population Served

The curriculum was intended for use in a college level Computer Numerical Control machining class. The curriculum also suitable for implementation and adoption by any High School or trade school that possesses the equipment specified in the budget section of the thesis.

Handbook Development

Handbook Resources and Content Validation

The source of validation for the curriculum was from many sources including ERIC documents, the Machinery's Handbook, various textbooks, RANDS Systems Inc. (Ward, 1995), National Institute for Metalworking Skills, Inc. [NIMS] (*Machining skills level 1*, 1997), and machine instruction manuals. A section validating each lesson will be provided in the handbook.

Handbook Design

Research on contextual learning gives a format for contextual based lesson plans. According to the Horizons Electronic Lesson Plan Resource web page lesson plans should including the following:

- The overview should provide the title of the lesson, recommended grade level, recommended timeframe, subject areas, and the objectives of the lesson.
- A brief introduction of what the lesson is about and how the lesson relates to students' prior knowledge.
- The content standards for the lessons presented in the project section of the thesis will be from the Secretary's Commission on Achieving Necessary Skills Course Competencies and Computer Aided Manufacturing and Advanced Computer Numerical Control Technical Workplace Competencies as presented in the literature review.
- The lesson section included the concepts to be taught, the procedures for teaching these concepts the materials needed during the lesson and how will the students prove that they have learned the objectives of the lesson (Blanchard, 2000b).

Summary

The methodology section of the thesis addressed the population served and the design of the curriculum presented in the handbook. The lesson plan format was based on research on contextual learning.

CHAPTER FOUR

BUDGETARY CONSIDERATIONS

Introduction

Costs vary in a Computer Numerical Control classroom based on the design of the program and the allowable discretionary funds from the administration. The Access Technology Training Center started out as a welfare-to-work program funded through a grant from the Economic Development Agency. In June 2002 the program will be given to the Mt. San Jacinto College. In 1998 the Center's budget plan allocated two million dollars for equipment costs including computers, machinery, tooling, and software (Sutter, 2001).

The following provides a cost analysis of equipment necessary to start a Computer Numerical Control education program. Quantities may vary depending on the amount of students projected. The Access Technology Training Center projected 24 students. However, as of this date the largest class size was 15.

- Dyna EM 3116 Computer Numerical Controlled knee mill: The Dyna CNC machine is a reasonably priced (Under \$20,000) medium sized knee mill. The Dyna Pentium® Mill EM 3116 offers the

complete package to produce high quality parts, to precision tolerances using standard G and M code (F. Paton, personal conversation, November 20, 2001). The director of the Access Technology Training Center recommends three to four students working on this machine. For a class of 24 students, Sutter suggests that a program considering starting a CNC education program purchase six of these machines. For a total cost of \$120,000 plus tooling (W. Sutter, personal conversation, April 10, 2001).

- For a classroom set of twenty-five educational copies of Mastercam the total cost will be approximately \$12,800 (F. Paton, personal conversation, November 20, 2001).
- Twenty-five computers with the power to run Mastercam approximated \$2,000 each for a total of \$50,000.
- According to Sutter tooling including tool holders, cutters, for the machines approximated \$60,000 (W. Sutter, personal conversation, April 10, 2001).

Summary

The total cost for starting a class on CNC programming approximated \$242,800. Sutter the director of the Access Technology Training Center suggested an additional \$20,000 yearly for tool maintenance and replacement.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

Introduction

Included in Chapter Five was a presentation of the conclusions gleamed as a result of completing the project. Further, the recommendations extracted from the project are presented. Lastly, the Chapter concludes with a summary.

Conclusions

The conclusions extracted from the project follows.

1. Curriculum needs to be developed that helps make education more contextual so that students understand how lessons can be applied to the world of work.
2. According to the occupational outlook handbook the outlook for careers in manufacturing was predicted to be excellent; however, to be successful workers must be highly skilled and well trained. Employers report difficulties in finding workers with the skills and knowledge necessary to fill machining and CNC programming openings.

3. Low-skill jobs are gradually being replaced by jobs requiring, mathematics, language, technological literacy, and problem-solving skills.
4. The process of contextual learning helps students understand how subject matter content relates to real world situations. This process "motivates students to make connections between knowledge and its application to their lives as family members, citizens, and workers" (Blanchard, 2000a, para. 1).
5. Research into CNC education showed what competencies industry requires of workers involved in the programming and operation of CNC machines.

Recommendations

The recommendations resulting from the project follows.

1. It was recommended that curriculum for Computer Numerical Control education for the Mt. San Jacinto College be expended to include other Computer Aided Machining programs including Virtual GIBBS®, and Surf CAM®.

2. It was also recommended that the curriculum section of the project be expanded to include advanced manual programming involving cutter compensation, incremental programming and CNC Lathe curriculum.
3. Teachers should strive to produce lessons that include contextual based learning techniques.
4. Lessons should show students how academic subjects apply to the workforce "so that students achieve both academic and occupational competencies" (Lankard, 1992, p. 1).

Summary

Chapter Five reviewed the conclusions extracted from the project. Lastly, the recommendations derived from the project were presented.

APPENDIX
COMPUTER AIDED MACHINING

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CARTESIAN COORDINATE SYSTEM FOR CNC PROGRAMMING

Overview

Grade Level: College

Time: One Hour

Subjects: Math, Geometry

Objectives:

At the conclusion of these activities the student will be able to:

- Specify points in space using the Cartesian coordinate system.
- Describe the relationship of the Cartesian coordinate system to Computer Numerical Control and Computer Aided Drafting.
- Complete a diagram of points using Cartesian Coordinates.

Introduction

The key to understanding numerical control is the rectangular coordinate system. Using the rectangular coordinate system any point in space can be described in mathematical terms.

Any point on a plane can be located by specifying its distance from each of two intersecting lines. When locating points on a workplace, take two straight, intersecting lines, one horizontal and one vertical making right angles with each other. These lines are called "axes" and their intersection point is called the "origin", "datum", or "zero point". The vertical axis is called the Y-axis; the horizontal axis is called the X-axis. The X and Y axis designation can be applied to milling, boring and drilling machines.

When referring to turning machines, the vertical axis is the X-axis and the horizontal axis is labeled Z. (Sherwood, p. 1-3)

Handbook Resources and Content Validation

Most textbooks written for education of Computer Numerical Control contain a section about the Cartesian coordinate system. The following textbooks contain a section on the Cartesian coordinate system:

- *CNC machining handbook* (Madison, 1996, p. 8-14).
- *Computer numerical control: Operation and programming (2nd ed.)* (Curran, 2001, p. 22-26).
- *Computer numerical control simplified* (Krar, 2001, Unit 1-4).
- *Machinery's handbook* (Oberg, 2000, p. 36).
- *Math for part programmers* (Sherwood, p. 1-9).
- *Programming of CNC machines (2nd ed.)* (Evans, 2001, p. 17-29).

Standards

WORKPLACE STANDARDS

Computer Aided Manufacturing and Advanced Computer Numerical Control Technical Workplace Competencies

B. Perform Measurements

1.0 Identify applications and limitations of measuring instruments.

2.0 Demonstrate use of measuring instruments.

C. Apply Mathematical Concepts

10.0 Apply Cartesian coordinate system to machining.

E. Program CNC machines and EDM

5.0 Identify and describe machine axes and coordinate systems.

(Machine tool advanced skills, 1996, p. 21-22)

Secretary's Commission on Achieving Necessary Skills Course Competencies. (SCANS)

Systems: Understands complex inter-relationships

A. Understands Systems - knows how social, organizational, and technological systems work and operates effectively with them.

Technology: Works with a variety of technologies

B. Applies Technology to Tasks - understands overall intent and proper procedures for setup and operation of equipment.

(What work requires of schools, 1991, p. 12)

CALIFORNIA CONTENT STANDARDS

MATHEMATICS Grade 4

Measurements and Geometry

2.0 Students use two-dimensional coordinate grids to represent points and graph lines and simple figures (Mathematics framework for California public schools, 2000, p. 54).

MATHEMATICS Grade 5

Algebra and Functions

1.0 Students use variables in simple expressions, compute the value of the expression for specific values of the variable, and plot and interpret the results (Mathematics framework for California public schools, 2000, p. 61).

MATHEMATICS Grades 8-12

Geometry

1.0 Students demonstrate understanding by identifying and giving examples of undefined terms, axioms, theorems, and reasoning (Mathematics content standards for California public schools, 1997, p. 51).

Mathematical Analysis

1.0 Students are familiar with, and can apply, polar coordinates and vectors in the plane. In particular, they can translate between polar and rectangular coordinates and can interpret polar coordinates and vectors graphically (Mathematics content standards for California public schools, 1997, p. 58).

Lesson: Teacher Section

It is suggested that the teacher present the topic of Cartesian coordinates using the following steps:

- a. Present the topic of a horizontal number line. Show the students that on a number line 0 is placed at the center of the line and all numbers to the left of zero are negative numbers and to right are positive.
- b. Next, label the number line negative “X” and positive “X”.
- c. After labeling the “X” number line present another number line perpendicular to the “X” number line known as the “Y” number line. Label the “Y” number line with positive pointing upwards and negative pointing downwards.
- d. At this time demonstrate to the students that when labeling points for a milling machine on a Cartesian coordinate system X always is label first, Y second and Z third. (X,Y,Z,). As for the lathe or the turning machine the coordinates are labeled (Z,X).
- e. Next, demonstrate to the students the positioning of the quadrants on the axes including:
 1. “I” is (+X,+Y).
 2. “II” is (-X,+Y).
 3. “III” is (-X,-Y).
 4. “IV” is (+X,-Y).
- f. Have the students next read the entire handout and complete the assignment on the last two pages.
- g. At this point the instructor should show the students a protractor and have them specify various lines based on the Cartesian coordinate system either by using the Manual Data Input command on the machine or Mastercam.

Coordinate Systems

By Paul A. Van Hulle

Cartesian or Rectangular Coordinates

When you have finished this assignment
please have your instructor sign this sheet
in your signoff workbook.

Student Name:

Instructor's signature

Competency achieved Yes or No: _____

Cartesian or Rectangular Coordinates

The key to understanding numerical control is the rectangular coordinate system. Using the rectangular coordinate system any point in space can be described in mathematical terms.

Any point on a plane can be located by specifying its distance from each of two intersecting lines. When locating points on a workplace, take two straight, intersecting lines, one horizontal and one vertical making right angles with each other. These lines are called "axes" and their intersection point is called the "origin", "datum", or "zero point". The vertical axis is called the Y-axis; the horizontal axis is called the X-axis. The X and Y-axis designation can be applied to milling, boring and drilling machines.

When referring to turning machines, the vertical axis is the X-axis and the horizontal axis is labeled Z (Sherwood, p. 1).

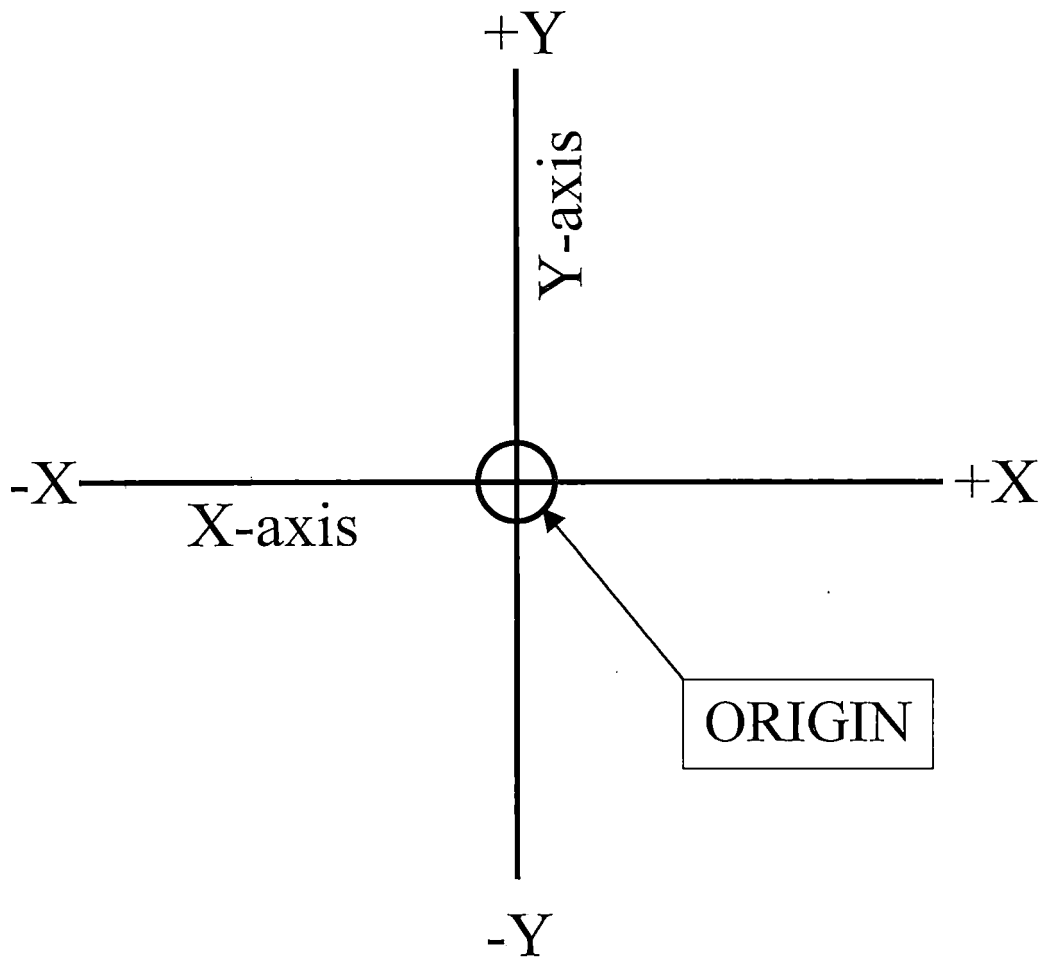


Figure 1 - Mill axes

(Sherwood, p. 2)

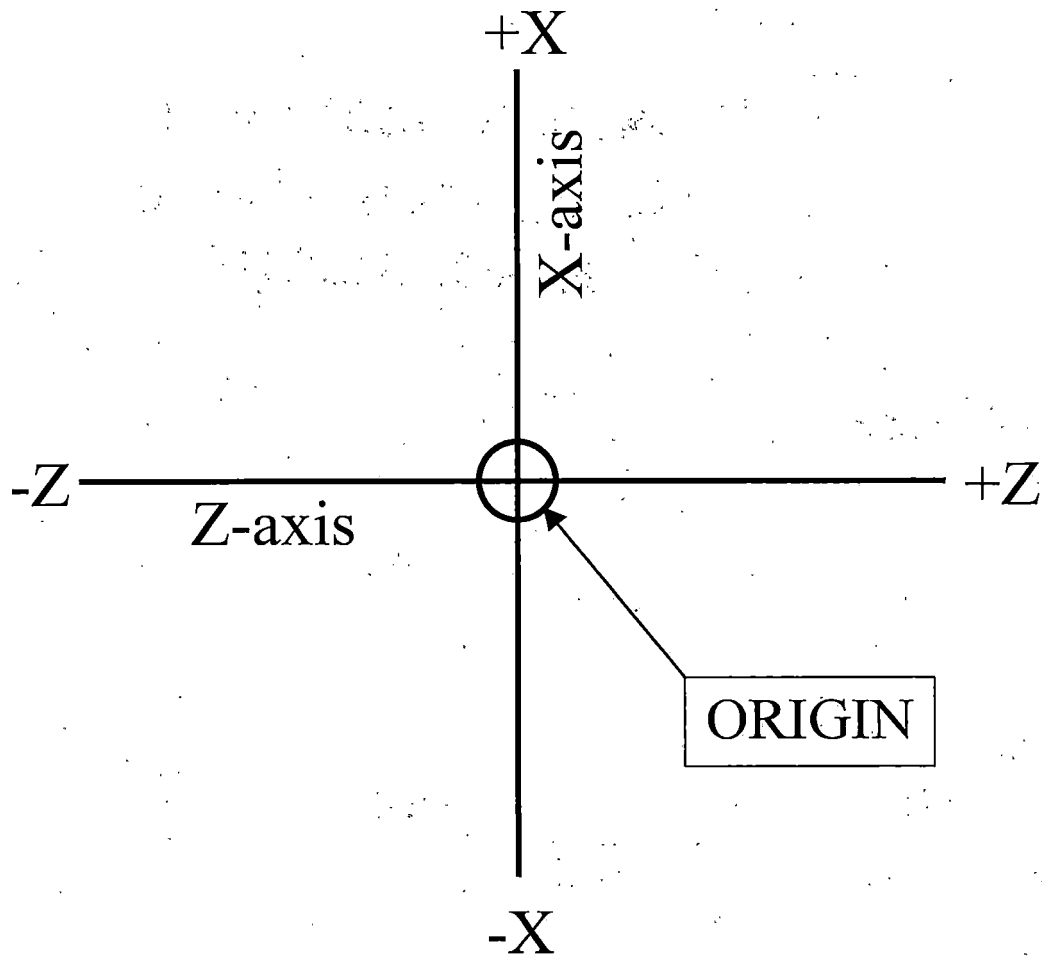


Figure 2 - Lathe axes

(Sherwood, p. 2)

In figure 3, point “A” may be described as being located 3 units to the right of the Y-axis and 2 units above the X-axis. However, in order to avoid saying “to the left of” and “to the right of”, “below” or “above”. Values to the right of the Y-axis are positive (+) and to the left are negative (-). Distances above the X-axis are positive and below are negative.

Locate B in Figure 3. It is 4 units to the right of the Y-axis and 3 units below the X-axis. Therefore the position of B is $X = +4$, $Y = -3$.

As a rule, the distance to the right or left of the Y-axis is given first and the distance above or below the X-axis is given second (Sherwood, p. 3).

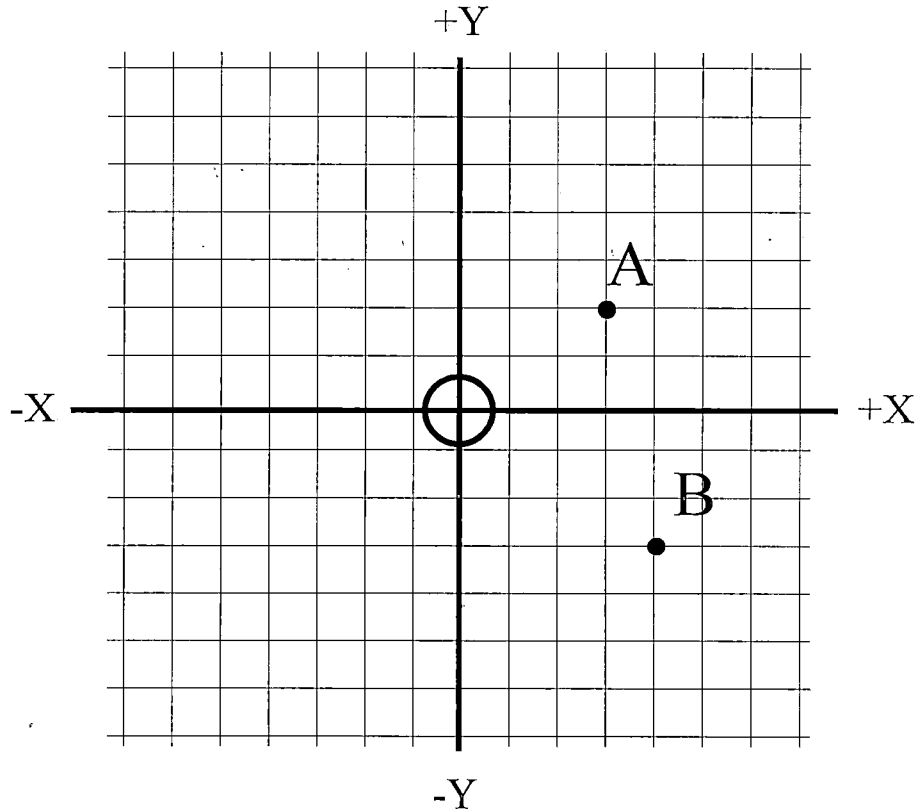


Figure 3 - Point location with
coordinates

(Sherwood, p. 2)

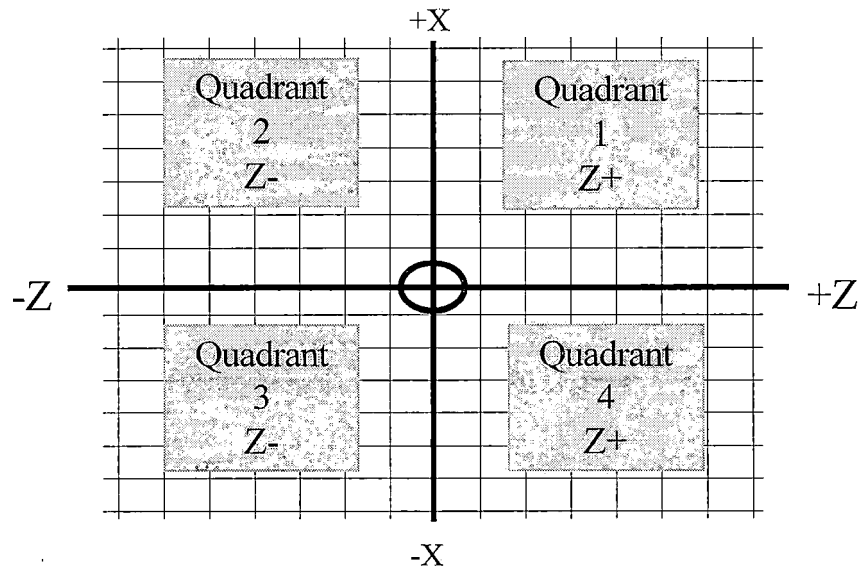
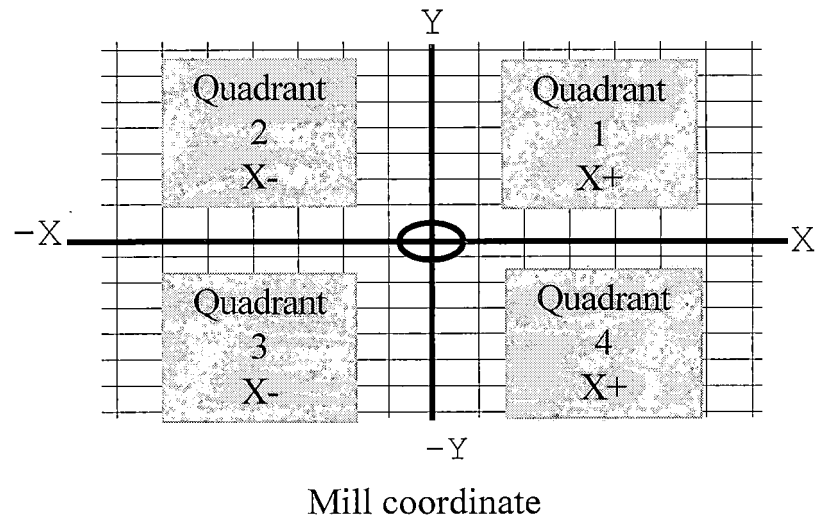


Figure 4 -- Coordinate system quadrants

The graph formed by the intersections of the two axes can be divided into four parts called quadrants. Quadrant 1 is the upper right section. Quadrants 2, 3 and 4 are located in a counterclock-wise direction from Quadrant 1. (See Figure 4)

When the rectangular coordinate system is shifted from the blue print to the table of a machine tool, we have the necessary dimensions for numerical control.

Simple two axis drilling machines are based on the coordinate system.

As an example, assume that the diagram in Figure 5 represents a drilling machine table and that there is a workpiece located in the upper right quadrant. The origin or datum point would be located on the lower left corner of the workpiece. The series of drill holes in the workpiece are specified by locations in the X-Y coordinate values. All values are positive because the points are in the 1st quadrant.

Point 1 in figure 5 is located at:

X1.Y1.

Point 2 is located at: X1.Y4.

Point 3: X5.Y1.

Point 4: X5.Y4.

(Sherwood, p. 4)

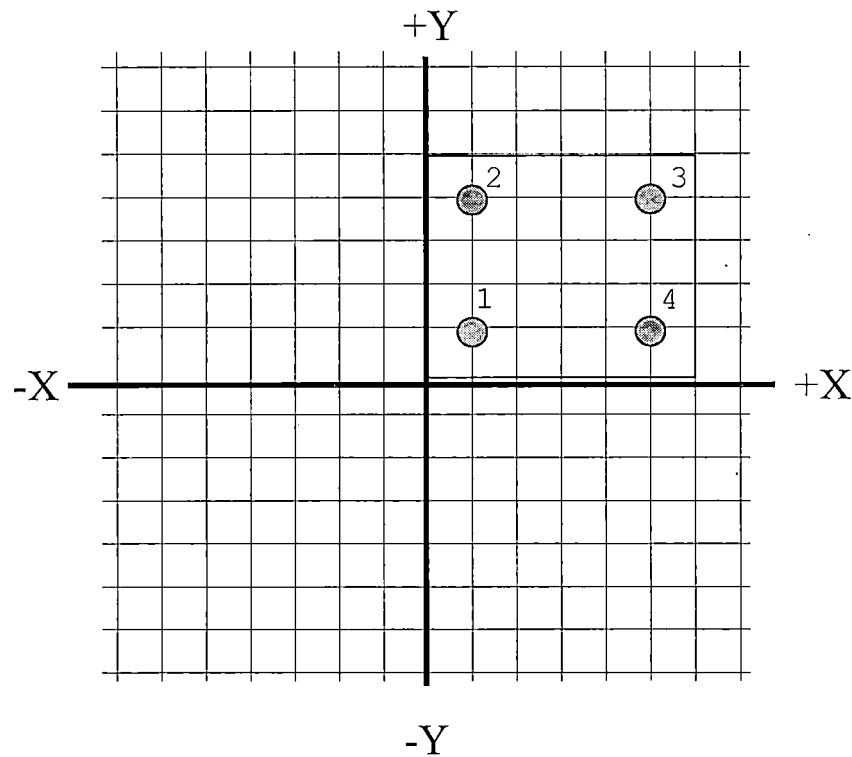


Figure 5 - Drill table

(Sherwood, p. 4)

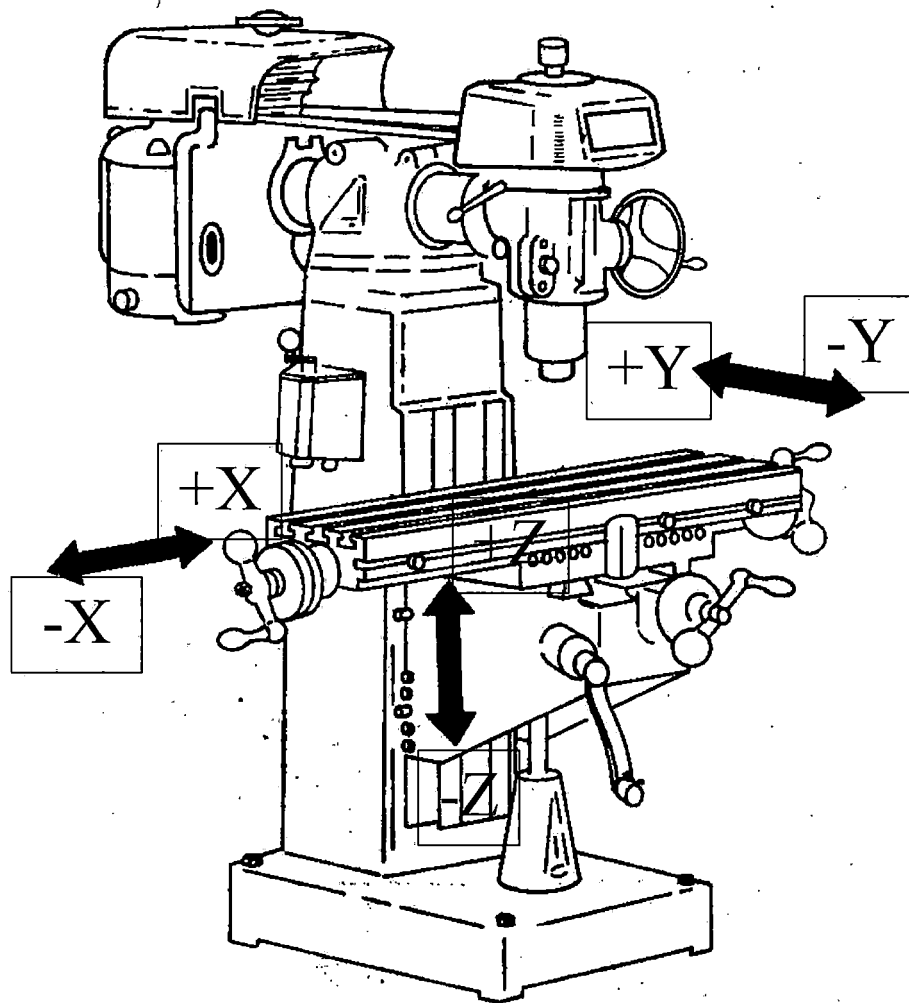


Figure 6 -- Mill Coordinates.

By using a third plane or dimension called the Z-axis, which is perpendicular to the plane comprised of the X and Y axes, more complicated work can be completed.

Using the previous example of drilling holes in a flat workpiece in the X-Y plane, if the hole depth is given as a specific distance along the Z-axis, we have the use of 3 axis programming. For example if the holes in figure 5 are .25 deep and the top of stock is Z0. The 3 axis coordinates would be specified as:

Point 1: X1.Y1.Z-.25

Point 2: X1.Y4.Z-.25

Point 3: X5.Y1.Z-.25

Point 4: X5.Y4.Z-.25

(Sherwood, p. 5)

Exercise 1 -- Mill Coordinate System

Refer to the points plotted on the illustrated Cartesian coordinate plane of a milling machine and determine the values of the corresponding X and Y locations. See Figure 7.

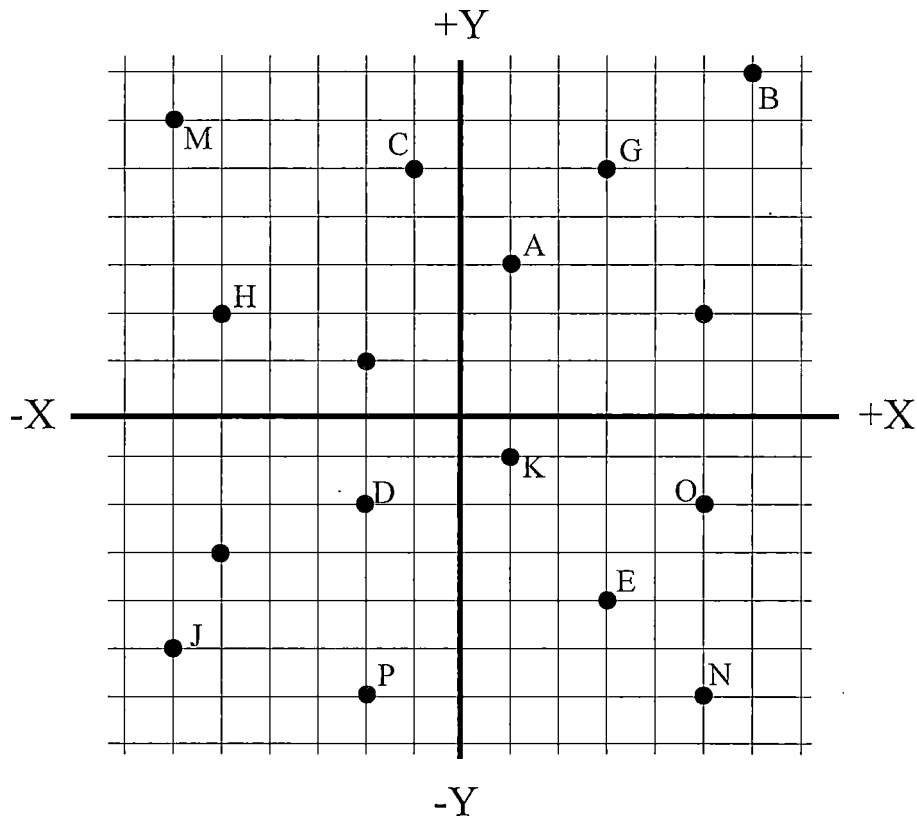


Figure 7 - Mill coordinate system

A <u> X1.Y3. </u>	I <u> </u>
B <u> </u>	J <u> </u>
C <u> </u>	K <u> </u>
D <u> </u>	L <u> </u>
E <u> </u>	M <u> </u>
F <u> </u>	N <u> </u>
G <u> </u>	O <u> </u>
H <u> </u>	P <u> </u>

Name:

Date:

Exercise 2 -- Lathe Coordinate System

Refer to the points plotted on the illustrated Cartesian coordinate plane of a lathe machine and determine the values of the corresponding X and Z locations. See Figure 8.

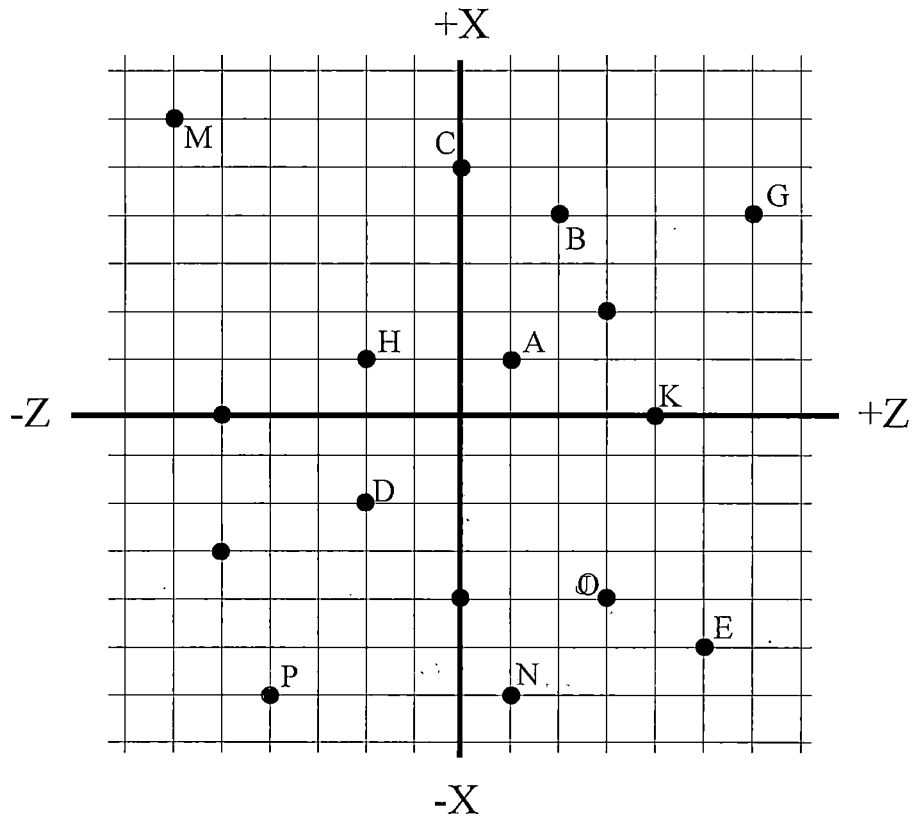


Figure 8 - Lathe coordinate system

A _____	I _____
B <u>Z2.X4.</u>	J _____
C _____	K _____
D _____	L _____
E _____	M _____
F _____	N _____
G _____	O _____
H _____	P _____

Name: _____

Date: _____

Mill Cartesian Coordinate System Lesson: Answers

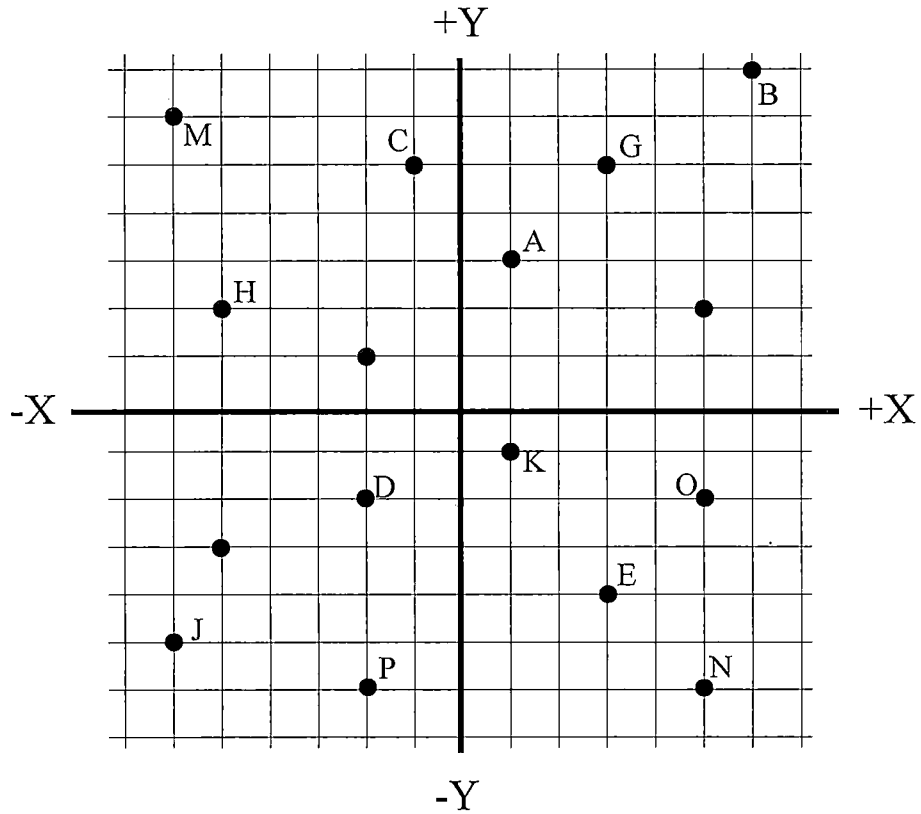


Figure 7 - Mill coordinate system

A	<u>X1.Y3.</u>	I	<u>X-5.Y-3.</u>
B	<u>X6.Y7.</u>	J	<u>X-6.Y-5.</u>
C	<u>X-1.Y5.</u>	K	<u>X1.Y-1.</u>
D	<u>X-2.Y-2.</u>	L	<u>X-2.Y1.</u>
E	<u>X3.Y-4.</u>	M	<u>X-6.Y6.</u>
F	<u>X5.Y2.</u>	N	<u>X5.Y-6.</u>
G	<u>X3.Y5.</u>	O	<u>X5.Y-2.</u>
H	<u>X-5.Y2.</u>	P	<u>X-2.Y-6.</u>

Lathe Cartesian Coordinate System Lesson: Answers

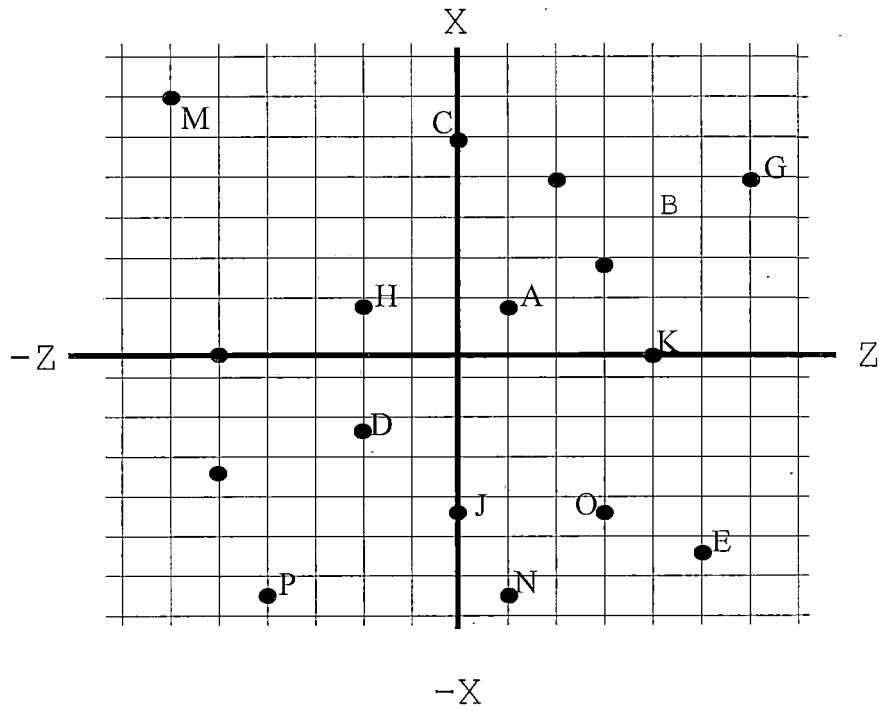


Figure 8 - Lathe coordinate system

A	<u>Z1.X1.</u>	I	<u>Z-5.X-3.</u>
B	<u>Z2.X4.</u>	J	<u>Z0.X-4.</u>
C	<u>Z0.X5.</u>	K	<u>Z4.X0.</u>
D	<u>Z-2.X-2.</u>	L	<u>Z-5.X0.</u>
E	<u>Z5.X-5.</u>	M	<u>Z-6.X-5.</u>
F	<u>Z3.X2.</u>	N	<u>Z1.X-6.</u>
G	<u>Z6.X4.</u>	O	<u>Z3.X-4.</u>
H	<u>Z-2.X1.</u>	P	<u>Z-4.X-6.</u>

Special thanks to *Math for part programmers* for providing the Cartesian coordinate system assignment student handout. (Sherwood Media).

POLAR COORDINATE SYSTEM FOR CNC PROGRAMMING

Overview

Grade Level: College

Time: One half Hour

Subjects: Math, Geometry

Objectives:

At the conclusion of these activities the student will be able to:

- Specify points in space using the Polar coordinate system.
- Describe the relationship of the Polar coordinate system to Computer Numerical Control and Computer Aided Drafting.
- Complete a diagram of points using Polar Coordinates.

Introduction

Some CNC controls, Mastercam, and AutoCAD use polar coordinates to define the location of points. Polar coordinates define the position of a point by its distance and angle from a fixed reference point. The distance between points represents a radius value and the direction refers to the angle between the positive X-axis and the point to be defined.

Handbook Resources and Content Validation

The polar coordinate system was addressed in many of the textbooks about Computer Numerical Control programming. The following textbooks contain a section on the polar coordinate system:

- *Computer numerical control: Operation and programming (2nd ed.)* (Curran, 2001, p. 27).
- *Machinery's handbook* (Oberg, 2000, p. 36).
- *Math for part programmers* (Sherwood, p. 20-22).
- *Programming of CNC machines (2nd ed.)* (Evans, 2001, p. 21).

Standards

WORKPLACE STANDARDS

Computer Aided Manufacturing and Advanced Computer Numerical Control Technical Workplace Competencies

B. Perform Measurements

1.0 Identify applications and limitations of measuring instruments.

2.0 Demonstrate use of measuring instruments.

C. Apply Mathematical Concepts

13.0 Perform polar trigonometric calculations.

E. Program CNC machines and EDM

5.0 Identify and describe machine axes and coordinate systems.

(Machine tool advanced skills, 1996, p. 21-22)

Secretary's Commission on Achieving Necessary Skills Course Competencies. (SCANS)

Systems: Understands complex inter-relationships

A. Understands Systems - knows how social, organizational, and technological systems work and operates effectively with them.

Technology: Works with a variety of technologies

B. Applies Technology to Tasks - understands overall intent and proper procedures for setup and operation of equipment.

(What work requires of schools, 1991, p. 12)

CALIFORNIA CONTENT STANDARDS

MATHEMATICS Grades 8-12

Trigonometry

15.0 Students are familiar with polar coordinates. In particular, they can determine polar coordinates of a point given in rectangular coordinates and vice versa.

(Mathematics content standards for California public schools, 1997, p. 48).

Geometry

1.0 Students demonstrate understanding by identifying and giving examples of undefined terms, axioms, theorems, and reasoning (Mathematics content standards for California public schools, 1997, p. 51).

Mathematical Analysis

1.0 Students are familiar with, and can apply, polar coordinates and vectors in the plane. In particular, they can translate between polar and rectangular coordinates and can interpret polar coordinates and vectors graphically (Mathematics content standards for California public schools, 1997, p. 58).

Lesson: Teacher Section

It is suggested that the teacher present the topic of Cartesian coordinates using the following steps:

- a. First explain that the polar coordinate system is based on specifying the length and angle of a line (length of line<angle of line). Demonstrate the topic of a horizontal and a vertical line perpendicular to each other. The location of where the two lines cross represent the start of the desired line. Similar to a protractor, angles are specified based on degrees with 0 degrees pointing horizontally towards the right. One complete circle makes up 360 degrees with 360 divisions. From the crossing point of the two lines pointing to the right is 0 degrees, pointing straight upwards would be 90 degrees, pointing to the left is 180 degrees and pointing downwards represents 270 degrees.
- b. Once the students understand the concept of how to specify points using the polar coordinate practice what was taught by completing the last page of the handout.
- c. At this point the instructor should show the students a protractor and have them specify various lines based on the Polar coordinate system either by using the Manual Data Input command on the machine or Mastercam.

Coordinate Systems

By Paul A. Van Hulle

Polar Coordinates

When you have finished this assignment
please have your instructor sign this sheet
in your signoff workbook.

Student Name:

Instructor's signature

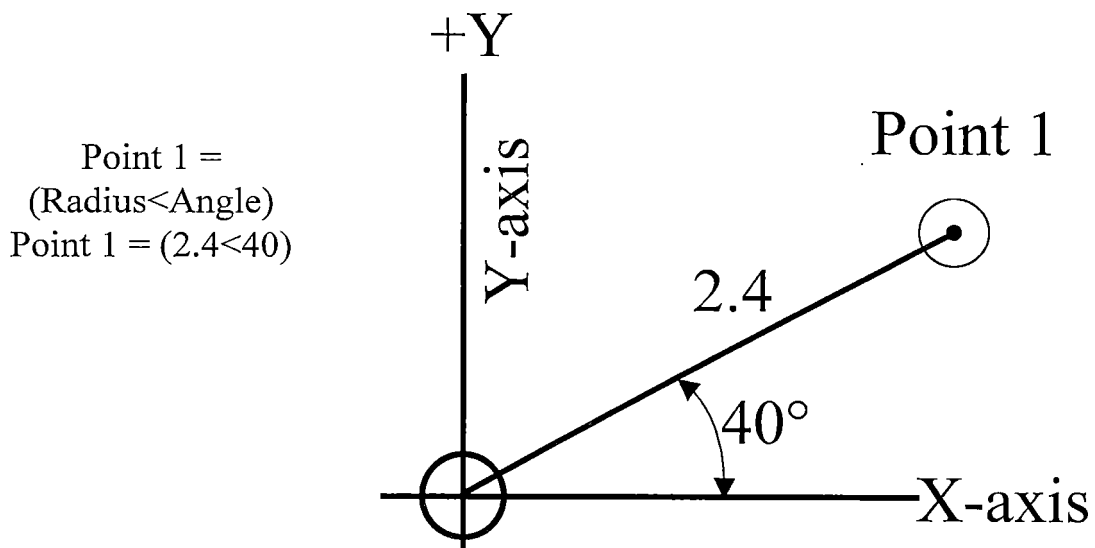
Competency achieved Yes or No: _____

Polar Coordinates

Some CNC controls Mastercam, and AutoCAD use polar coordinates to define the location of points. The drilling of holes in a circular pattern is a good application for the use of polar coordinates.

Polar coordinates define the position of a point by its distance and direction from a fixed reference point (origin) which has a value of zero.

The distance between points represents a radius value and the direction refers to the angle between the positive X-axis and the point to be defined (Sherwood, p. 20). See Figure 1.

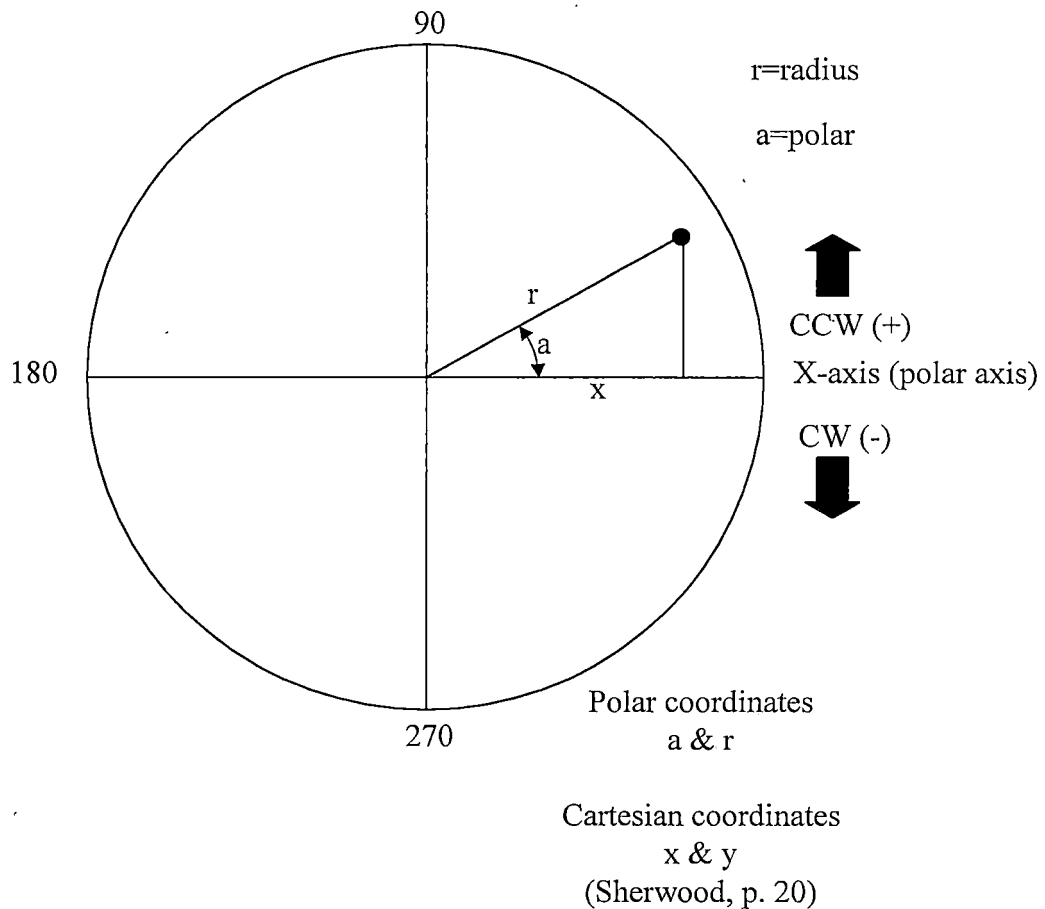


F Figure 1

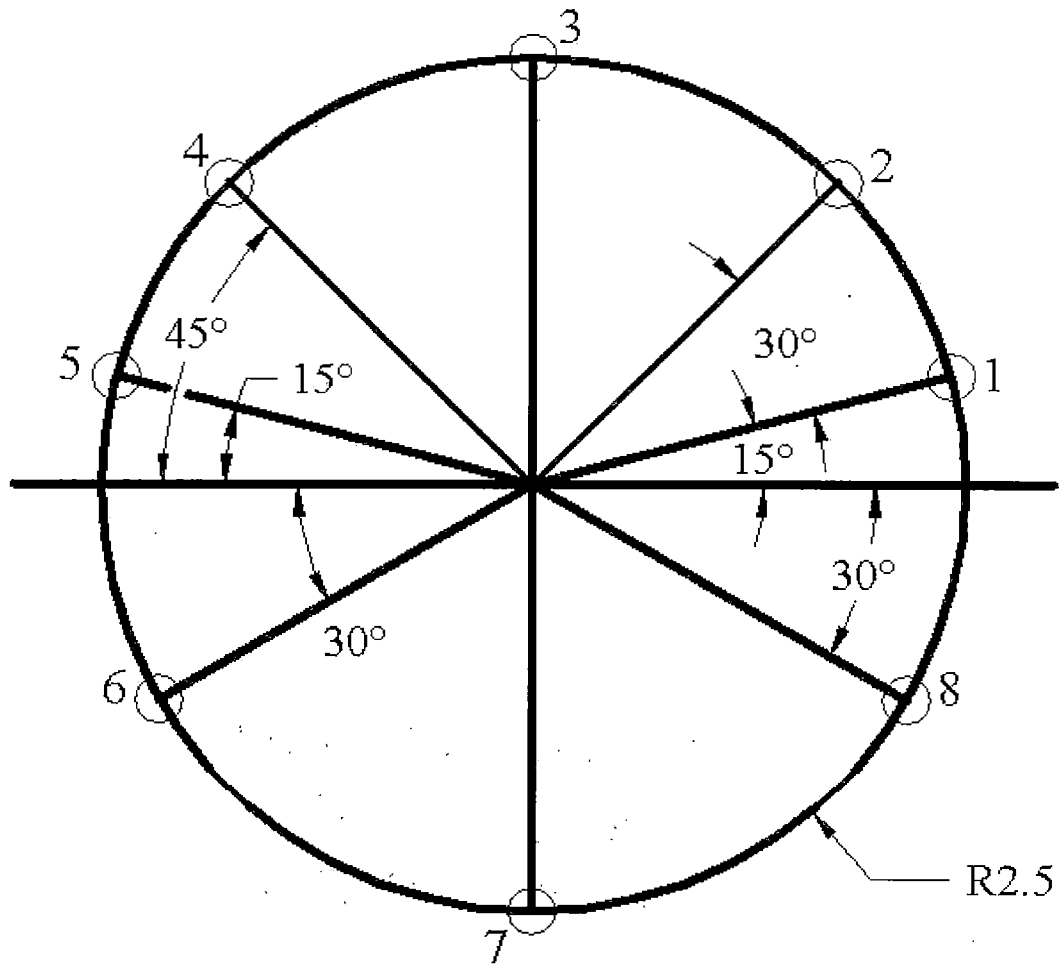
(Sherwood, p.

The angle is positive (+) in the counterclockwise direction (CCW) and negative (-) in the clockwise (CW) direction.

Using a circle; if we draw a reference line horizontally from the origin out to the periphery of the circle, that line becomes the polar axis. A line drawn from the origin to the desired point is the vector defined as a radius and the angle formed from the vector (radius) and the polar axis (X) is called the polar angle (Sherwood, p. 20). See Figure 12.



Problem: Give the polar coordinates of the drilled holes in the following example (Sherwood, p. 20).

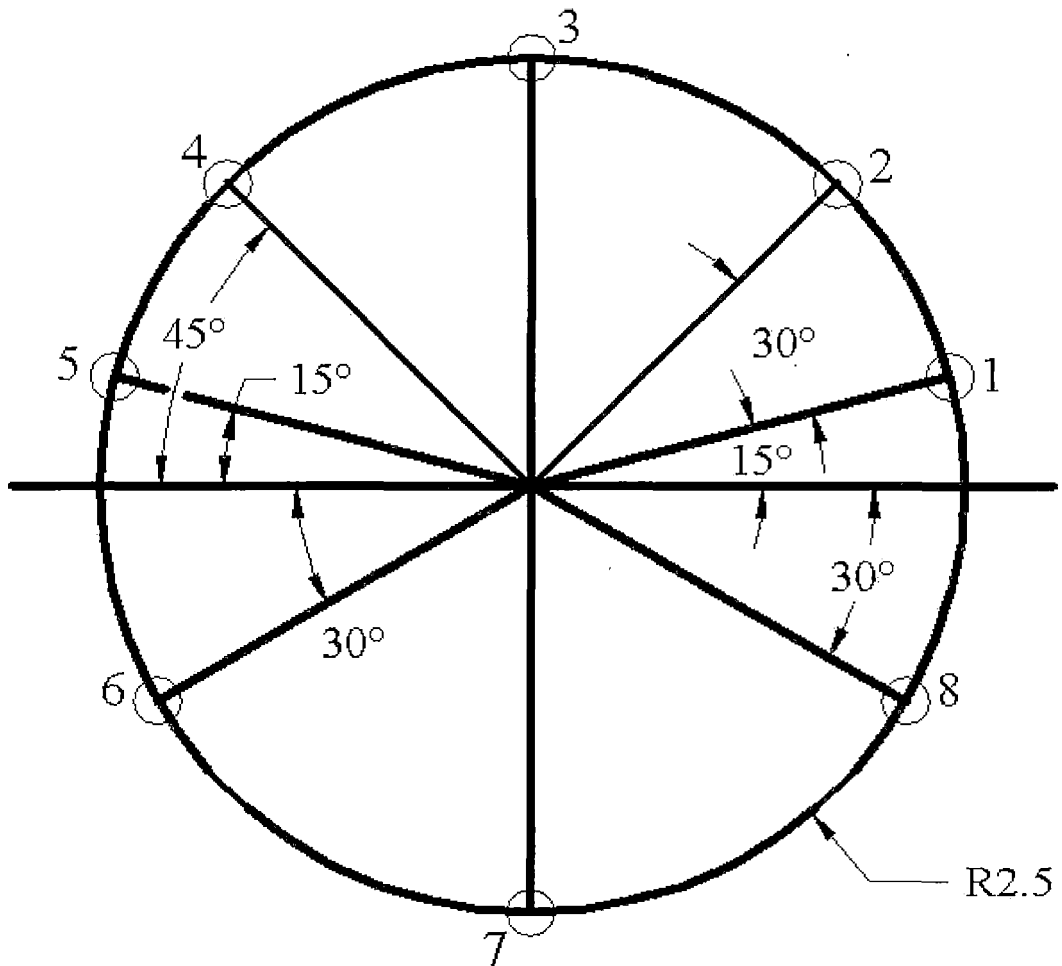


1. _____
2. _____
3. _____
4. _____
5. _____
6. _____
7. _____
8. _____

Name: _____

Date: _____

Polar Coordinate system Lesson: Answers



1. (2.5<15)
2. (2.5<45)
3. (2.5<90)
4. (2.5<135)
5. (2.5<165)
6. (2.5<210)
7. (2.5<270)
8. (2.5<330)

Special thanks to Math for part programmers for providing the polar coordinate system assignment student handout. (Sherwood Media).

ABSOLUTE AND INCREMENTAL (RELATIVE) MEASURING SYSTEMS FOR CNC PROGRAMMING

Overview

Grade Level: College

Time: One hour

Subjects: Math, Geometry

Objectives:

At the conclusion of these activities the student will be able to:

- Describe the difference between incremental and absolute.
- Differentiate between the G-codes used for specifying absolute and incremental.
- Describe the mistakes that can be made when machining in incremental mode.
- Specify locations of point positions and machine movement using incremental and absolute coordinate systems.

Introduction

Two methods of specifying an endpoint or location are recognized by machine control units, each dealing with the type of reference coordinate system designated by the programmer or operator; one is called absolute, the other is called incremental. Both use the same distance measurement system, whether decimal or metric, but differ in their point of reference.

Handbook Resources and Content Validation

Details for teaching the difference between the absolute and incremental measuring systems in a Computer Numerical Control education program was addressed in many of the textbooks about Computer Numerical Control programming. The following textbooks contain a section on the difference between the absolute and incremental measuring systems:

- *An introduction to CNC machining and programming* (Gibbs, 1991, p. 124-125).
- *Basic CNC operation. Training workbook* (1994, p. 17-19).
- *CNC machining handbook* (Madison, 1996, p. 47-50).
- *Computer numerical control: Operation and programming (2nd ed.)* (Curran, 2001, p. 27-28).
- *Computer numerical control simplified* (Krar, 2001, Unit 7).
- *Machinery's handbook* (Oberg, 2000, p. 1248).
- *Math for part programmers* (Sherwood, p. 10-19).
- *Programming of CNC machines (2nd ed.)* (Evans, 2001, p. 28, 264).

Standards

WORKPLACE STANDARDS

Computer Aided Manufacturing and Advanced Computer Numerical Control Technical Workplace Competencies

B. Perform Measurements

1.0 Identify applications and limitations of measuring instruments

2.0 Demonstrate use of measuring instruments

C. Apply Mathematical Concepts

1.0 Perform mathematical computations with calculator

Calculate fractions and decimals with calculator

10.0 Apply Cartesian coordinate systems to machining

11.0 Perform trigonometric calculations

D. Read Blueprints

2.0 Describe blueprint dimensions

4.0 Interpret blueprint drawings

E. Program CNC machines and EDM

- 2.0 Identify and describe machine operation nomenclature
- 3.0 Identify and describe essentials of CNC systems
- 5.0 Identify and describe machine axes and coordinate systems.
- 6.0 Describe and interpret CNC coding systems
- 7.0 Write NC programs

(Machine tool advanced skills, 1996, p. 21-22)

Secretary's Commission on Achieving Necessary Skills Course Competencies. (SCANS)

Systems: Understands complex inter-relationships

- A. Understands Systems - knows how social, organizational, and technological systems work and operates effectively with them.

Technology: Works with a variety of technologies

- B. Applies Technology to Tasks - understands overall intent and proper procedures for setup and operation of equipment.

(What work requires of schools, 1991, p. 12)

Lesson: Teacher Section

It is suggested that the teacher present the topic of incremental and absolute coordinate systems using the following steps:

- a. The first topic that should be presented is absolute coordinate system. Students should understand that in the absolute measuring system (coordinate) uses a fixed reference point (origin). All the locations to which the tool will be moved must be given dimensions relating to that original reference point. In other words in the absolute coordinate system 0,0 or the origin of the part always remains in the same place.
- b. Once the students understand the essential concept of absolute coordinates they should complete the assignment on the absolute side of the mill axis assignment in the student handout. In this assignment students are asked to specify points for an actual dimensioned blueprint. Students should have already received instruction on reading a blueprint, subtraction and addition of decimals, and trigonometry.
- c. After completing this assignment the instructor should give the details of the incremental coordinate system. The incremental measuring

system uses a floating reference point. Each new location uses the last location as a reference point each time the tool is moved.

- d. The students should complete the incremental side of the assignment.
- e. The students should next be introduced to how to set the machine for using absolute and incremental coordinates. Then show the students how to manually input coordinates on the machine using both incremental and absolute coordinates.

Measurement Systems

By Paul A. Van Hulle

Absolute and Incremental

When you have finished this assignment
please have your instructor sign this sheet
in your signoff workbook.

Student Name:

Instructor's signature

Competency achieved: Yes or No: _____

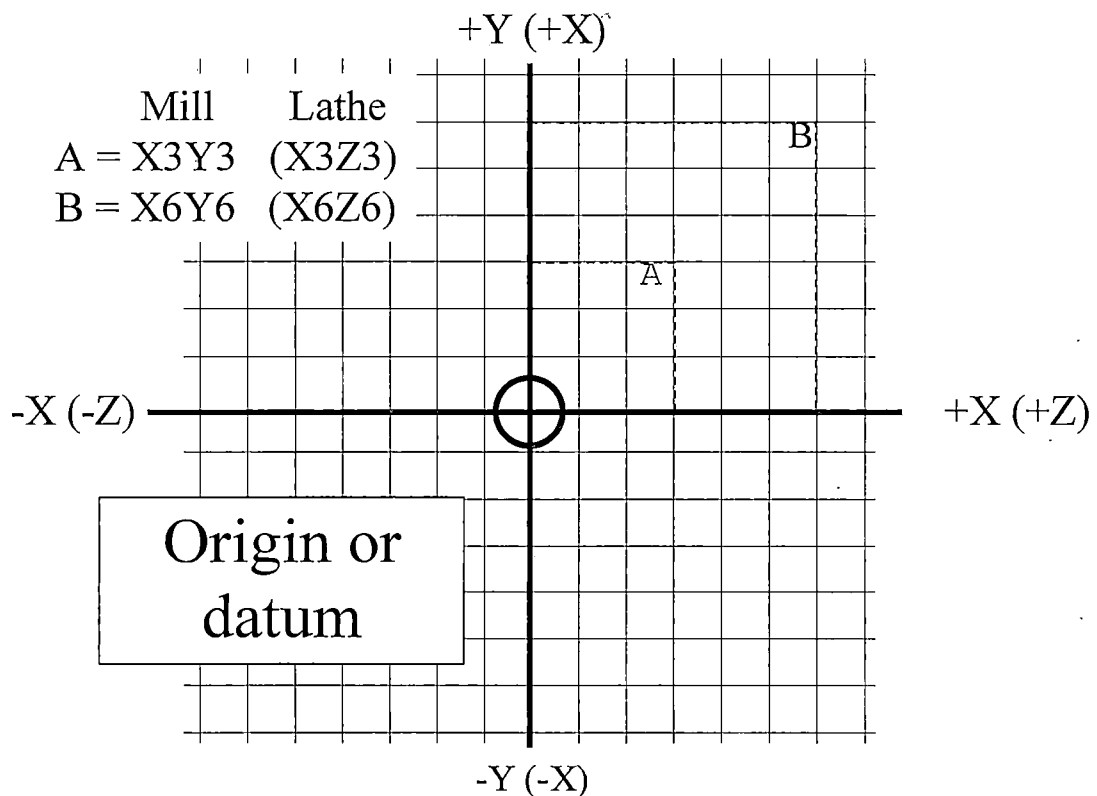
Measurement Systems

Two methods of specifying an endpoint or location are recognized by machine control units, each dealing with the type of reference coordinate system designated by the programmer or operator; one is called absolute, the other is called incremental. Both use the same distance measurement system, whether decimal or metric, but differ in their point of reference

(Sherwood, p. 10).

Absolute

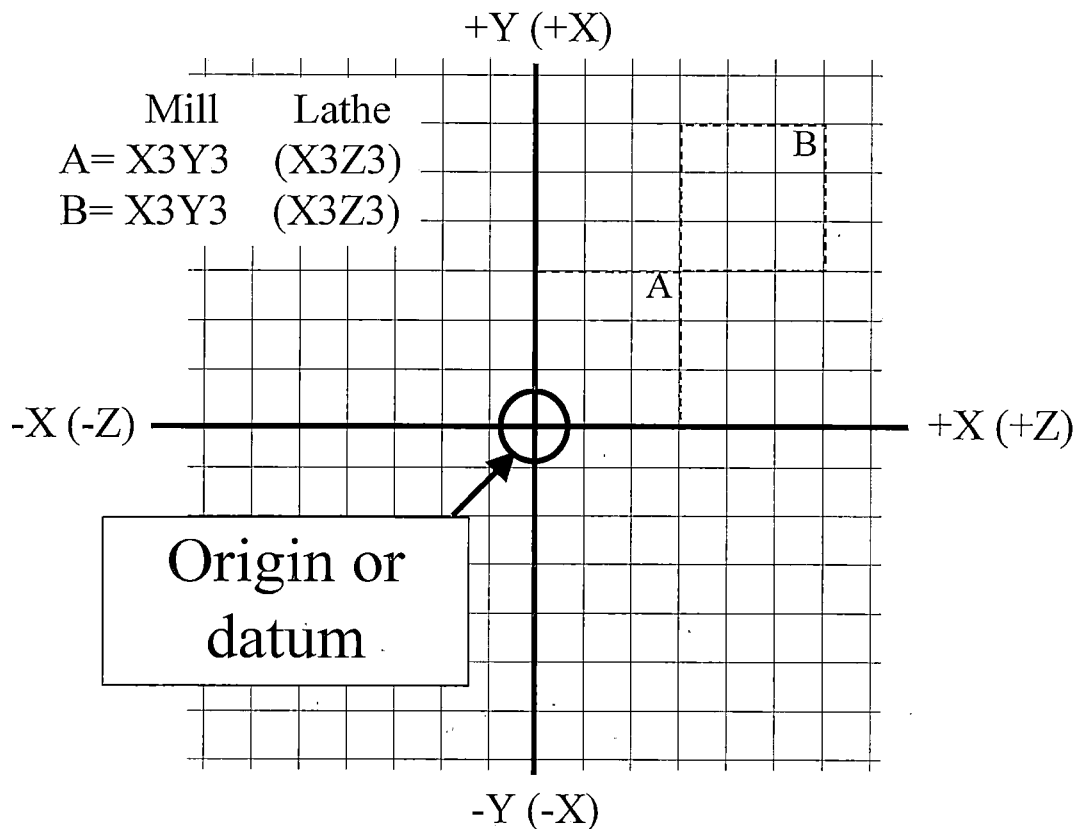
The absolute measuring system (coordinate) uses a fixed reference point (origin). All the locations to which the tool will be moved must be given dimensions relating to that original reference point (Sherwood, p. 10). See figure below



Absolute measuring systems base all locations from a fixed reference called datum or origin (Sherwood, p. 10).

Incremental

The incremental measuring system uses a floating reference point. Each new location uses the last location as a reference point each time the tool is moved (Sherwood, p. 11). See figure below



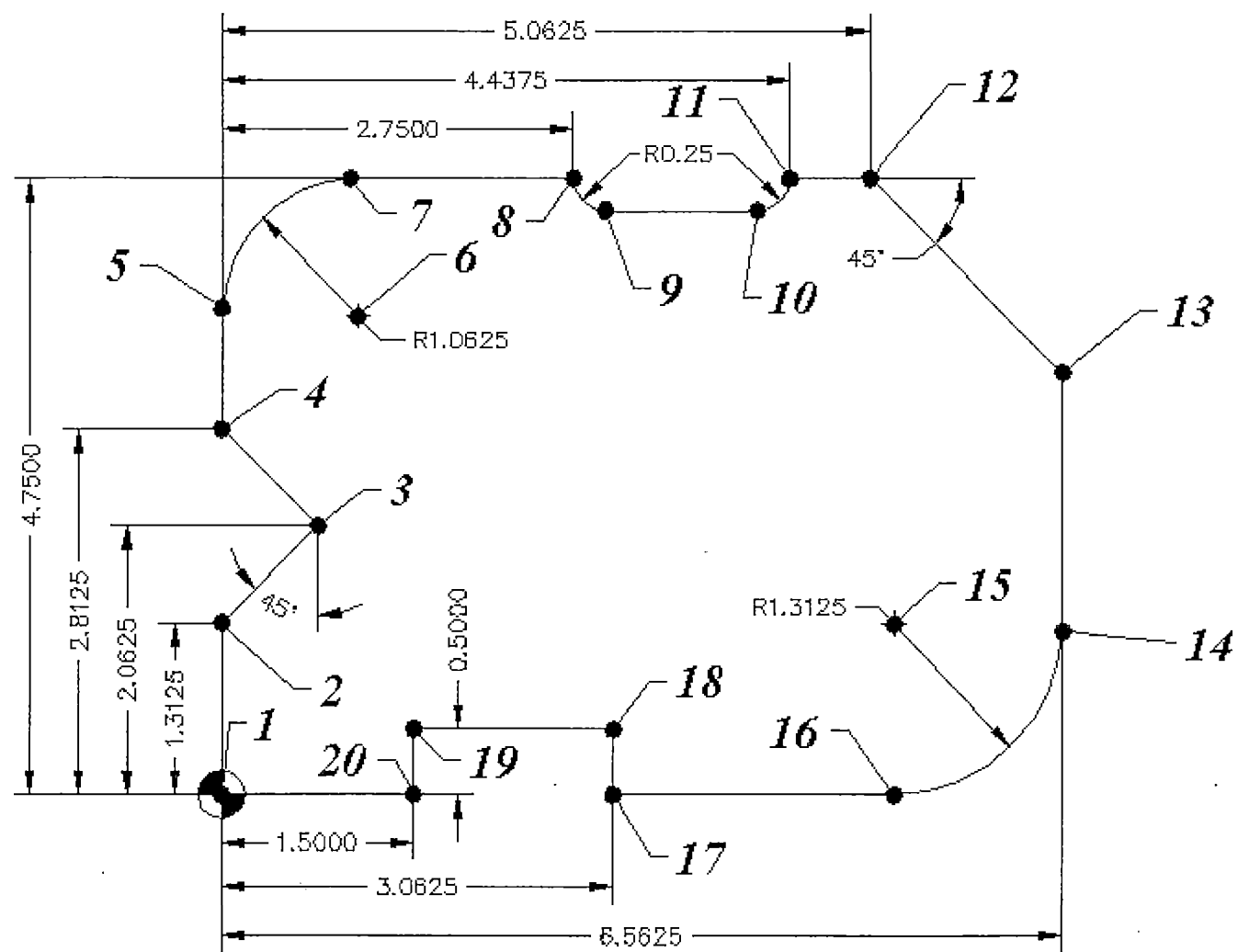
Incremental measuring systems use a new origin (datum) for each succeeding move. (Sherwood, p. 11)

Name: _____

Date: _____

Directions: List X & Y
coordinates for points 1-20 on
the following drawing in both
absolute and incremental
measuring systems (Sherwood, p. 12)

	ABSOLUTE		INCREMENTAL	
	X	Y	X	Y
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				



Absolute and Incremental Measuring Systems Lesson: Answers

	ABSOLUTE		INCREMENTAL	
	X	Y	X	Y
1	0	0	0	0
2	0	1.3125	0	1.3125
3	0.75	2.0625	0.75	0.75
4	0	2.8125	-0.75	0.75
5	0	3.6875	0	0.875
6	1.0625	3.6875	1.0625	0
7	1.0625	4.75	0	1.0625
8	2.75	4.75	1.6875	0
9	3	4.5	0.25	-0.25
10	4.1875	4.5	1.1875	0
11	4.4375	4.75	0.25	0.25
12	5.0625	4.75	0.625	0
13	6.5625	3.25	1.5	-1.5
14	6.5625	1.3125	0	-1.9375
15	5.25	1.3125	-1.3125	0
16	5.25	0	0	-1.3125
17	3.0625	0	-2.1875	0
18	3.0625	0.5	0	0.5
19	1.5	0.5	-1.5625	0
20	1.5	0	0	-0.5

Special thanks to *Math for part programmers* for providing the absolute and incremental assignment student handout. (Sherwood Media).

COMPUTER AIDED MACHINING USING MASTERCAM

ZOOMING AND MUNIPULATING VIEWS

Overview

Grade Level: College

Time: One Hour

Subjects: Computer Aided Machining/Computer Aided Drafting, Computers

Objectives:

At the conclusion of these activities the student will be able to:

- Apply Mastercam's zoom commands to zoom in and out of a drawing in order to produce detailed drawings.
- Apply techniques to manipulate views for navigating in 3-deminsional drawings.
- Differentiate between zooming and the scale command.
- Demonstrate the use of the following commands:
 - Zoom
 - Unzoom
 - Scale geometry
 - Fit geometry
 - Repaint

Introduction

When producing detailed drawings for part creation the student must understand how to zoom into different parts of the drawing.

Handbook Resources and Content Validation

Many textbooks about CAD/CAM dedicate a section to teaching how to zoom into different parts of a drawing. The following textbooks contain a section on zooming and manipulating views:

- *Mastercam Handbook, Volume 1* (Mastercam Handbook, 2001, p. 2-20).
- *Mastercam Version 7* (Lin, 1998, p. 3-6).

Standards

WORKPLACE STANDARDS

Computer Aided Manufacturing and Advanced Computer Numerical Control Technical Workplace Competencies

G. Use Computers

1.0 Demonstrate use of computer hardware

I. Using CAD/CAM programs

1.0 Demonstrate understanding of CAD/CAM programs

2.0 Access CAD program options

3.0 Create designs with CAD section of CAD/CAM program

4.0 Demonstrate ability to use program functions

(Machine tool advanced skills, 1996, p. 21-22)

Secretary's Commission on Achieving Necessary Skills Course Competencies. (SCANS)

Systems: Understands complex inter-relationships

A. Understands Systems - knows how social, organizational, and technological systems work and operates effectively with them.

Technology: Works with a variety of technologies

B. Applies Technology to Tasks - understands overall intent and proper procedures for setup and operation of equipment.

(What work requires of schools, 1991, p. 12)

Lesson: Teacher Section

The handout provided for the lesson is fairly self-explanatory. The student should be able to follow the directions of the lesson handouts and perform the activities virtually without teacher's assistance.

Mastercam

By Paul A. Van Hulle

Zooming and Manipulating Views

When you have finished this assignment
please have your instructor sign this sheet
in your signoff workbook.

Student Name:

Instructor's signature

Competency achieved Yes or No: _____

Zooming

Starting Mastercam

- Choose Start in the lower left corner of your screen by clicking on it with your mouse.
- Choose Programs.
- Choose Mastercam 8.
- Choose Mill v8.

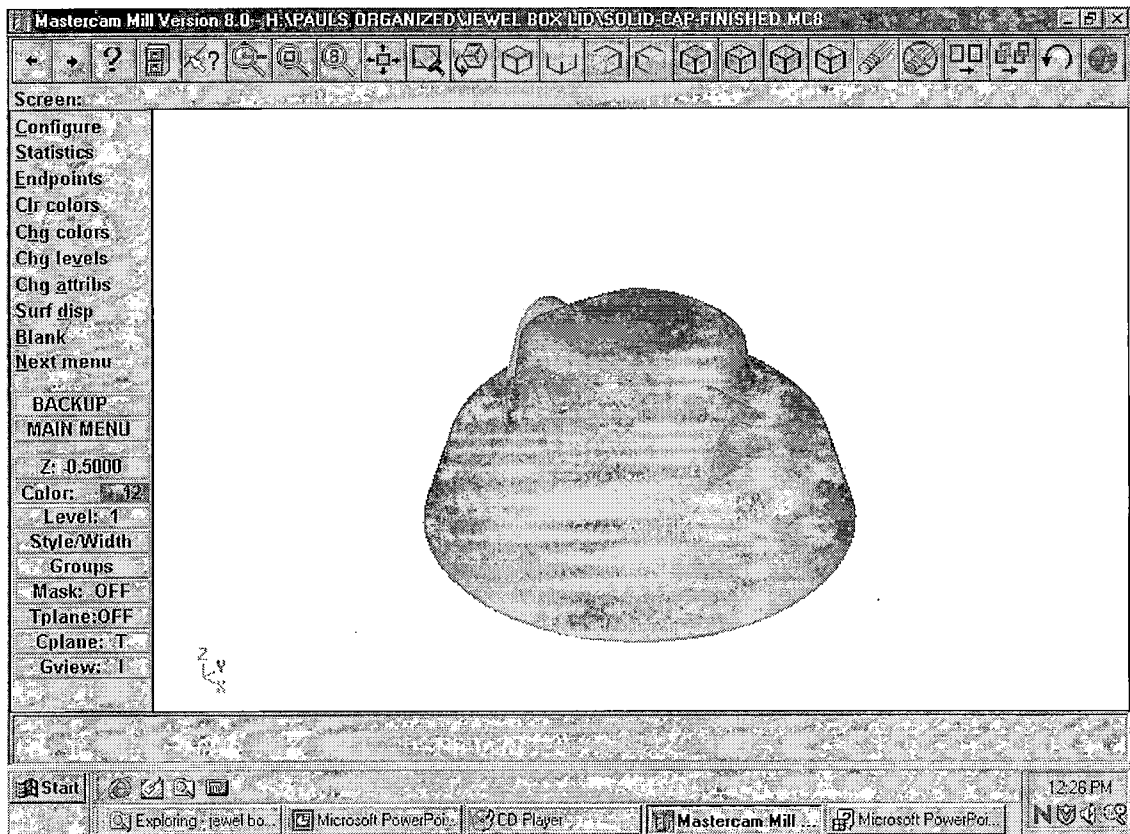
From the main menu choose:

- Main Menu
- File
- Get

Select: SOLID-CAP-FINISHED.MC8

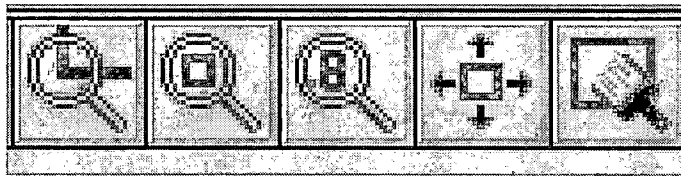
Choose **Open**. The following representation (shown on the next page) should be on the screen. If it is not, ask the instructor for help.

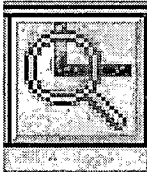
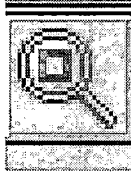
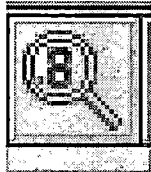
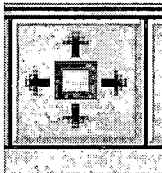
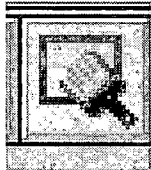
- Refer to your Mastercam Default key assignments handout (In the middle of Page A-7) and look up which command makes shading active.



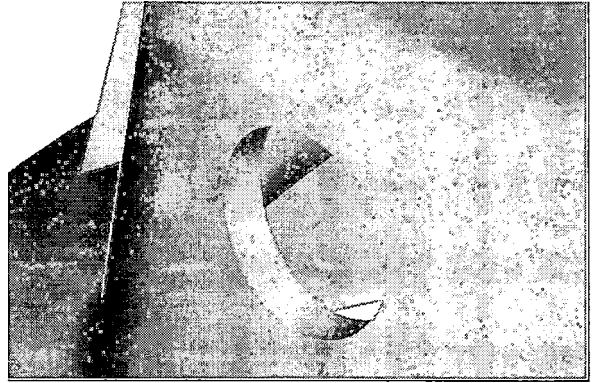
The above representation should be on the screen. If it is not, ask the instructor for help. (Note: you may have a black background. I use a white background during presentations to decrease the amount of ink used.)

In the tool bar these 5 buttons are used to make objects larger and smaller



Function	Description	Toolbar key	Keyboard Key(s)
Zoom	Activates the zoom-in window. Use the zoom window to magnify part of your geometry.		F1
Unzoom	Zooms out from your geometry reducing its size on your screen.		F2
Scale geometry	Zooms out from the displayed image in increments of 0.8		ALT-F2
Fit geometry	Fits the displayed image to the graphic screen area.		ALT-F1
Repaint	Redisplays the graphic screen to clean up any display remnants.		F3

1. Try zooming in on the large circle of the solid cap



2. Next, use the Fit command to fit the geometry to the size of the screen.
3. Then, use the scale geometry command to unzoom the geometry by 0.8
4. Next, use the Fit command to fit the geometry to the size of the screen.
5. Then, use the unzoom command to unzoom the geometry by 0.5.
6. Repeat steps 2-5 and compare the difference in size of the geometry between the scale geometry and the unzoom command.

Manipulating Views

Starting Mastercam

- Choose Start in the lower left corner of your screen by clicking on it with your mouse.
- Choose Programs.
- Choose Mastercam 8.
- Choose Mill v8

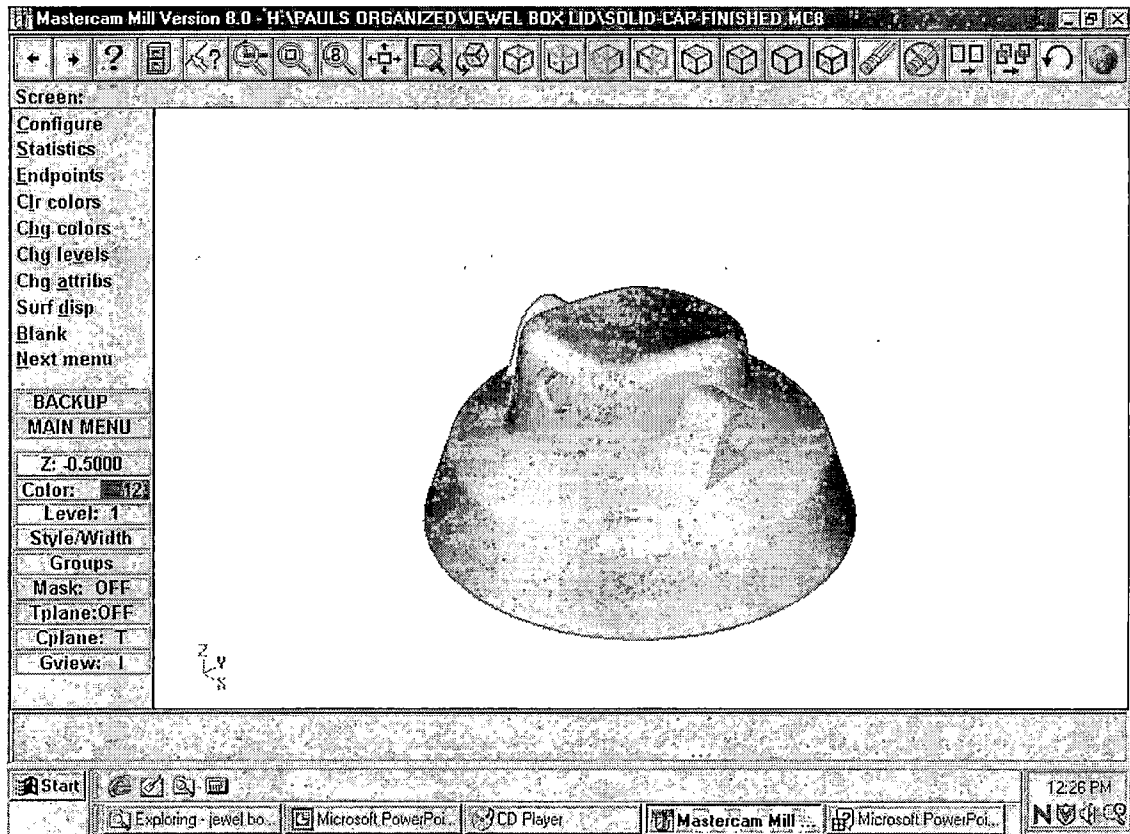
From the main menu choose:

- Main Menu
- File
- Get

Select: SOLID-CAP-FINISHED.MC8

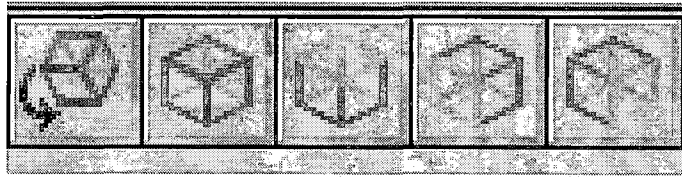
Choose **Open**. The following representation (shown on the next page) should be on the screen. If it is not, ask the instructor for help.

- Refer to your Mastercam Default key assignments handout (In the middle of Page A-7) and look up which command makes shading active.



The above representation should be on the screen. If it is not, ask the instructor for help. (Note: you may have a black background. I use a white background during presentations to decrease the amount of ink used.)

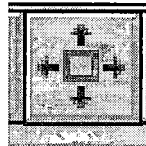
In the tool bar these 5 buttons are used to manipulate how the object is viewed.



5. Choose  from the tool bar menu

A view of the top of the work piece is shown.

6. Press [Alt] and [F1] at the same time to fit the drawing to the screen, or select the fit screen icon.

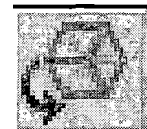


7. Choose

- Gview (at the bottom of the screen)
- Dynamic



- Bring the cursor to the middle of the part and click the mouse. Now slowly move the mouse around and watch the part revolve and move around on the screen.
- Click the left mouse button again to hold that view.



COMPUTER AIDED MACHINING USING MASTERCAM

CREATING OBJECTS

Overview

Grade Level: College

Time: Two Hours

Subjects: Computer Aided Machining/Computer Aided Drafting, Computers

Objectives:

At the conclusion of these activities the student will be able to:

- Apply Mastercam's creating objects commands to create drawings
- Apply Mastercam's delete commands to erase objects
- Demonstrate the use of the following commands:
 - Create line
 - Create arcs and circles
 - Create fillets
 - Delete and undelete objects

Introduction

When producing detailed drawings for part creation the student must understand how to create objects.

Handbook Resources and Content Validation

Many textbooks about CAD/CAM dedicate sections to teaching how to create objects within Mastercam. The following textbooks contain a section on zooming and manipulating views:

- *Mastercam Handbook, Volume 1* (Mastercam Handbook, 2001, Chapters 2-4).

- *Mastercam Version 7* (Lin, 1998, Chapters 3-5).

Standards

WORKPLACE STANDARDS

Computer Aided Manufacturing and Advanced Computer Numerical Control Technical Workplace Competencies

G. Use Computers

1.0 Demonstrate use of computer hardware

I. Using CAD/CAM programs

1.0 Demonstrate understanding of CAD/CAM programs

2.0 Access CAD program options

3.0 Create designs with CAD section of CAD/CAM program

4.0 Demonstrate ability to use program functions

(Machine tool advanced skills, 1996, p. 21-22)

Secretary's Commission on Achieving Necessary Skills Course Competencies. (SCANS)

Systems: Understands complex inter-relationships

A. Understands Systems - knows how social, organizational, and technological systems work and operates effectively with them.

Technology: Works with a variety of technologies

B. Applies Technology to Tasks - understands overall intent and proper procedures for setup and operation of equipment.

(What work requires of schools, 1991, p. 12)

Lesson: Teacher Section

The handout provided for the lesson is fairly self-explanatory. The student should be able to follow the directions of the lesson handouts and perform the activities virtually without teacher's assistance.

Mastercam

By Paul A. Van Hulle

Creating Objects and Deleting Objects

When you have finished this assignment
please have your instructor sign this sheet
in your signoff workbook.

Student Name:

Instructor's signature

Competency achieved Yes or No: _____

Creating and Deleting Objects

Starting Mastercam

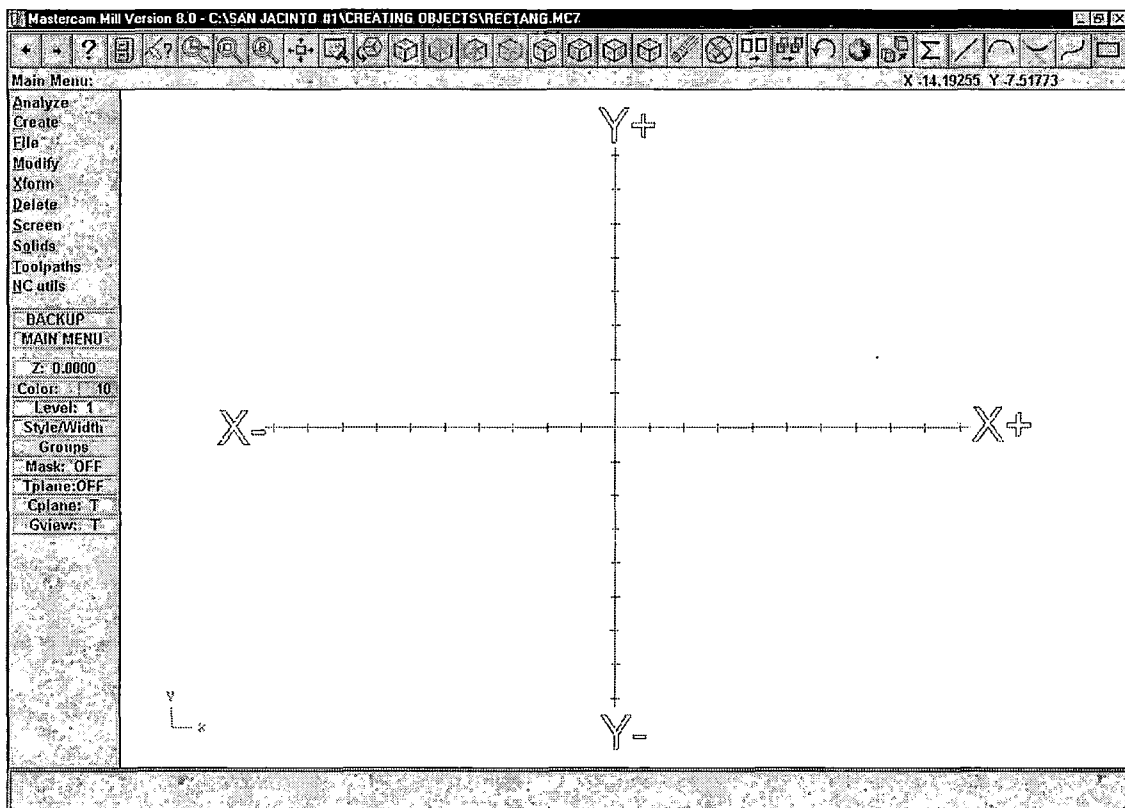
- Choose Start in the lower left corner of your screen by clicking on it with your mouse.
- Choose Programs.
- Choose Mastercam 8.
- Choose Mill v8

From the main menu choose:

- Main Menu
- File
- Get

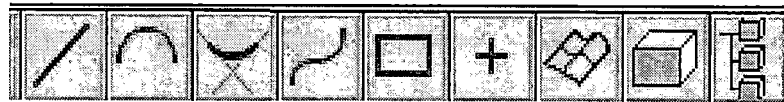
Select: rectang.MC8

Choose **Open**. The following representation (shown on the next page) should be on the screen. If it is not, ask the instructor for help.

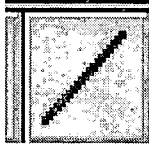




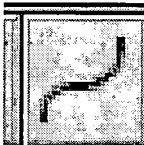
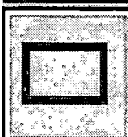


The above representation should be on the screen. If it is not, ask the instructor for help. (Note: you may have a black background. I use a white background during presentations to decrease the amount of ink used.)

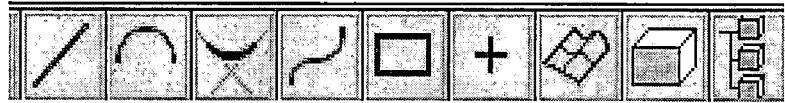
In the tool bar
these 9 buttons
are used to
create objects

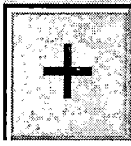
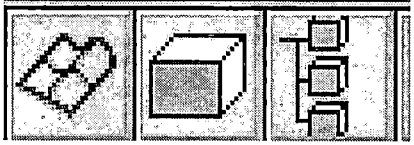
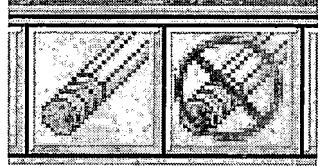
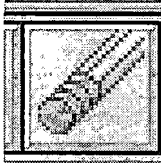



Using the keyboard pressing the
underlined letter selects the
command.

Function	Description	Toolbar key	Keyboard Key(s) From Main Menu
Create line	Activates the line menu (Used for making lines).		<u>C</u>reate; <u>L</u>ine
Create arcs and circles	Activates the arc menu (Used for making arcs).		<u>C</u>reate; <u>A</u>rc
Create fillets or rounds	Activates the fillet menu. (FILLET rounds or fillets the edges of two lines, arcs, circles, or splines with an arc of a specified radius).		<u>C</u>reate; <u>F</u>illet
 <p>before FILLET</p>  <p>after FILLET</p>			
Create splines	Activates the spline menu (A spline is a smooth curve that is based on a sequence of points).		<u>C</u>reate; <u>S</u>pline
Create Rectangle	Activates the rectangle menu.		<u>C</u>reate; <u>R</u>ectangle

In the tool bar these 9 buttons are used to create objects

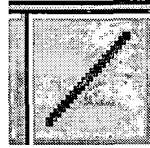


Function	Description	Toolbar key	Keyboard Key(s) From Main Menu
Create Point	Used for entering points (An example of use of this function would be for entering points for drilling holes).		<u>C</u>reate; <u>P</u>oint; <u>P</u>osition
Create surface, Create solids, Create Solids-History	These are advanced functions of Mastercam; we will skip these until later.		
In the tool bar these 2 buttons are used to delete and undelete objects			
Delete object	The delete menu gives you options for deleting entities.		<u>D</u>elete
Undelete object	The undelete operation gives you the ability to restoring deleted entities. Mastercam restores entities in the reverse order in which they were deleted.		<u>D</u>elete; <u>U</u>ndelete

Creating Lines

Create line

Activates the line menu
(Used for making lines).



**Create;
Line**

<p>Line:</p> <p>Horizontal</p> <p>Vertical</p> <p>Endpoints</p> <p>Multi</p> <p>Polar</p> <p>Tangent</p> <p>Perpendiclr</p> <p>Parallel</p> <p>Bisect</p> <p>Closest</p>	<p>The line menu contains 10 different methods of creating lines. In this lesson you will learn about the first 6 including:</p> <p>Horizontal - used for creating lines at 0 or 180 degrees.</p> <p>The command ask for: Enter two points for the endpoints of the line. In the prompt area, enter a value to position the line on the vertical axis.</p> <hr/> <p>Vertical - used for creating lines at 0 or 90 degrees.</p> <p>Enter two points for the endpoints of the line. In the prompt area, enter a value to position the line on the horizontal axis.</p> <hr/> <p>Endpoints - Creating a line between any two points</p> <p>Enter two points for the endpoints of the line.</p>
<p>Multi - Creating multiple lines connected at their endpoints</p> <p>Enter a point for the first endpoint of the first line.</p> <p>Enter a point for the second endpoint of the line.</p> <p>Press [Esc] to exit the function.</p>	
<p>Polar - a line based on a distance and angle.</p> <p>Enter a point for the first endpoint of the line.</p> <p>In the prompt area, enter the angle of the line.</p> <p>Enter the length of the line.</p>	<p>0.5";45 degrees</p>
<p>Tangent - The Tangent Line menu gives you options for creating lines that are tangent to arcs and splines. Tangent means the line only passes through one point on the arc.</p>	

Creating Horizontal Lines

Horizontal - used for creating lines at 0 or 180 degrees.

The command ask for:

Enter two points for the endpoints of the line.

In the prompt area, enter a value to position the line on the vertical axis.

Try this:

Start the horizontal line command:

MAIN MENU

Create

Line

Horizontal

Specify the start point at (0,1) by typing **0,1 [Enter]**

Enter the end point at **4,0**

(Notice that the line is actually sitting at 0,1 and 4,1. The reason for this is Mastercam places the horizontal line at the vertical position of first point placement).

The next prompt will ask you for where the line should be placed along the vertical axis Enter **4.0** Notice that the point is moved from y1 to y4.

Click on **ESC** or **MAIN MENU**

Note: Our main objective in drawing objects is to draw them accurately. This objective is obtained by using one of the following methods: entering points by typing their Cartesian coordinates, by using Mastercam's AutoCursor or using point entry menu. (see below for more information about AutoCursor)

By entering points you define positions in 3D space. You can enter points using one of two methods: Mastercam's AutoCursor™ feature or the Point Entry menu.

The AutoCursor™ is a point entry feature that is available whenever Mastercam displays the Point Entry menu and prompts you to enter a point. AutoCursor eliminates menu steps by detecting and snapping to points as you move the cursor over geometry on the screen.

Endpoints and midpoints of curves, arc center points, and point entities are all detected and highlighted by AutoCursor. If AutoCursor doesn't detect any points, the AutoCursor defaults to the Sketch Point Entry menu option, letting you enter a point at any position.

At any time while AutoCursor is active, you can override the auto-selected point by using the mouse or keyboard shortcut keys to access Point Entry menu options. In complex geometry there may be more than one point that lies within the detection range of the cursor. In these cases, the AutoCursor uses the order shown below to detect and snap to points (Mastercam's Help Menu, 2000, AutoCursor).

Creating Vertical Lines

Vertical - used for creating lines at 0 or 90 degrees.

Enter two points for the endpoints of the line.

In the prompt area, enter a value to position the line on the horizontal axis.

Do this:

Start the vertical line command:

MAIN MENU

Create

Line

Vertical

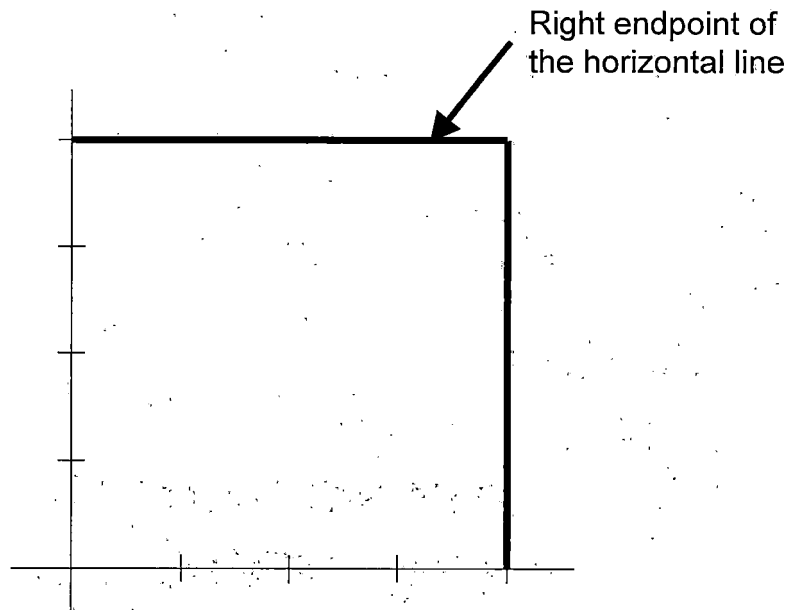
Endpoint (on the point entry menu)

- Specify the start point at the right endpoint of the horizontal line.

- Enter the end point at **4,0**

- The next prompt will ask you for where the line should be placed along the horizontal axis accept the default: **4.0**

- Click on **ESC** or **MAIN MENU**



Your drawing should look like the above picture if it does not ask for help.

Creating Lines at Endpoints

Endpoints - Creating a line between any two points
Enter two points for the endpoints of the line.

Do this:

Start the endpoints line command:

MAIN MENU

Create

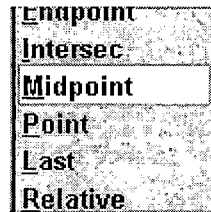
Line

Endpoints

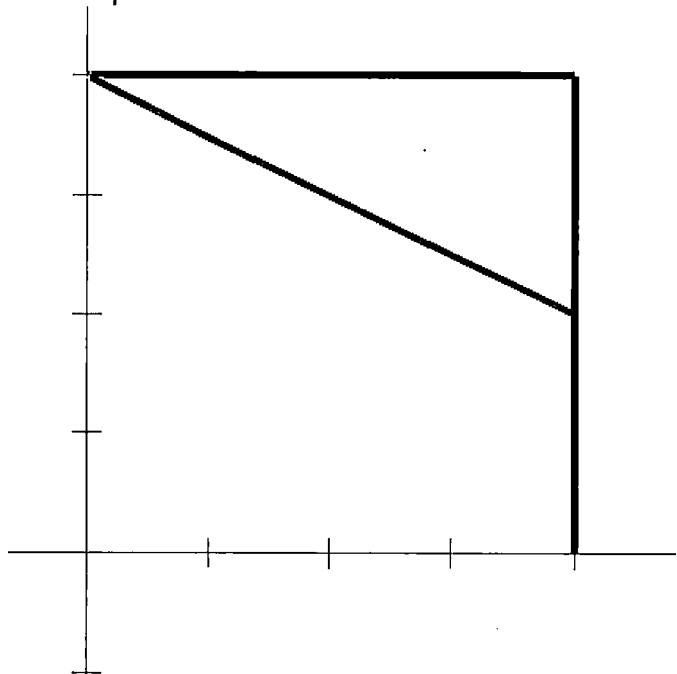
Endpoint (on the point entry menu)

Click on the left endpoint of the horizontal line

- Move your cursor over the midpoint of the vertical line. Notice the sticky box comes on when you move over the midpoint. Also notice the midpoint line on the point selection menu turns white. This indicates that you are over the exact midpoint of that line.
- With the sticky box on click on the midpoint of the vertical line.
- The line is placed at the midpoint of the vertical line.



Your drawing should look like the picture at the right if it does not ask for help.



Creating Lines using the Multi Command.

Endpoints - Creating a line between any two points
Enter two points for the endpoints of the line.

Do this:

Start the multi line command:

MAIN MENU

Create

Line

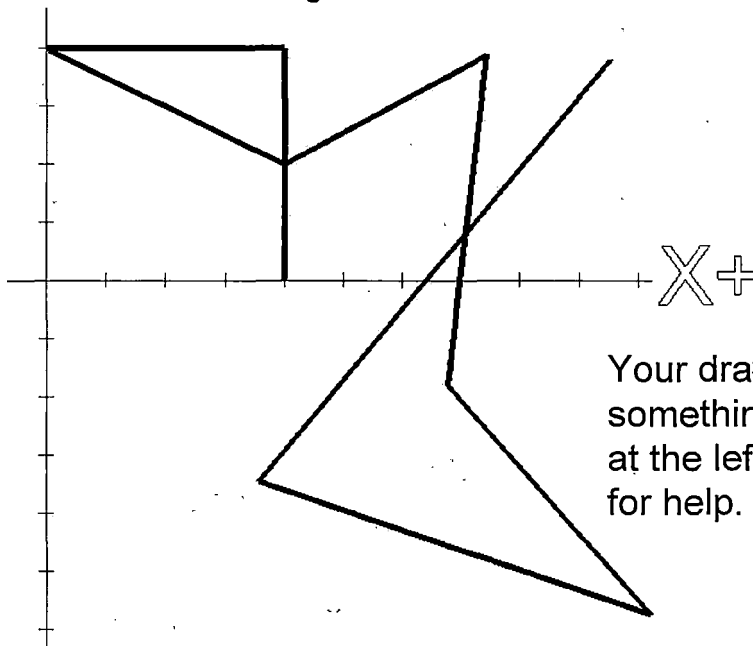
Multi

Intersec(on the point entry menu).

Click on the angled line and the vertical

The beginning of the multi line starts should start at the intersection of the two lines.

Continue sketching four to five other lines.



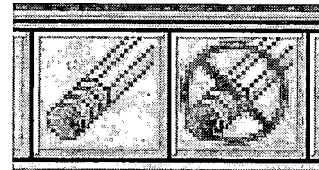
Your drawing should look something like the picture at the left if it does not ask for help.

Go back to the main menu when you are finished.

Deleting Objects.

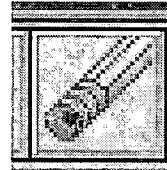
In the tool bar these 2 buttons are used to delete and undelete objects

We will revisit the line commands on the next page.



Delete object

The delete menu gives you options for deleting entities.



Delte

Undelete object

The undelete operation gives you the ability to restore deleted entities. Mastercam restores entities in the reverse order in which they were deleted.



**Delte;
Undelete**

Do this:

Start the delete command:

MAIN MENU

Delte

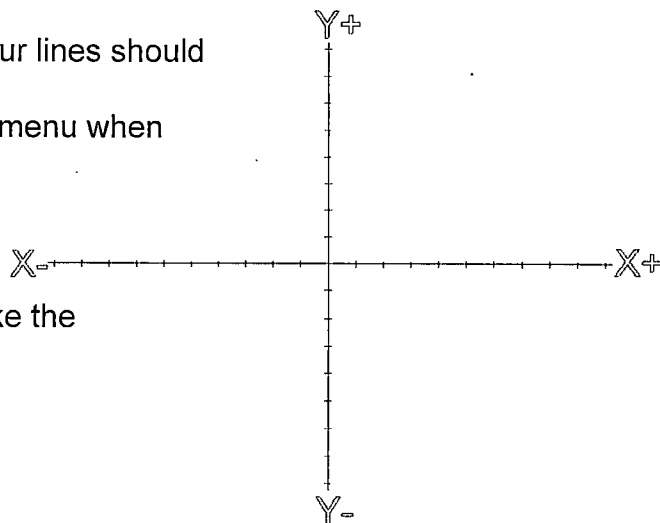
Chain

Select on one of your lines

If you have completed the previous activities all of your lines should be selected for deletion

Click on **Done**; all your lines should disappear.

Go back to the main menu when you are finished



Your drawing should look like the picture at the right.

Creating Lines using the Polar Command.

Polar - a line based on a distance and angle.

Enter a point for the first endpoint of the line.

In the prompt area, enter the angle of the line.

Enter the length of the line.

Do this:

Start the polar line command:

MAIN MENU

Create

Line

Polar

First line:

Start point: 0,0

Angle in Degrees: **0**

Distance: **4**

Second line:

Start point: 0,0

Angle in Degrees: **45**

Distance: **4**

Compare the difference between the first line and the second. While both the second and first line have the same length, the major difference between the first and second line is the second line is rotated slightly (at 45 degrees from 0 degrees).

Recall the polar coordinate system lesson; any of these angles from that lesson can be used.

Click on **ESC** when you are finished.

Try these lines:

Start point: 0,0

Angle in Degrees: **135**

Distance: **4**

Start point: 0,0

Angle in Degrees: **165**

Distance: **4**

Start point: 0,0

Angle in Degrees: **210**

Distance: **4**

Start point: 0,0

Angle in Degrees: **-35**

Distance: **4**

Go back to the main menu when you are finished

Deleting Objects.

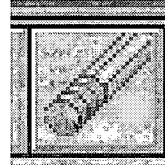
In the tool bar these 2 buttons
are used to delete and undelete objects



We will revisit the line commands on the next page.

Delete object

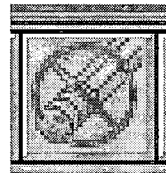
The delete menu gives you
options for deleting
entities.



Delte

Undelete object

The undelete operation
gives you the ability to
restore deleted entities.
Mastercam restores
entities in the reverse
order in which they were
deleted.



Undelete;
Undelete

Do this:

Start the delete command:

MAIN MENU

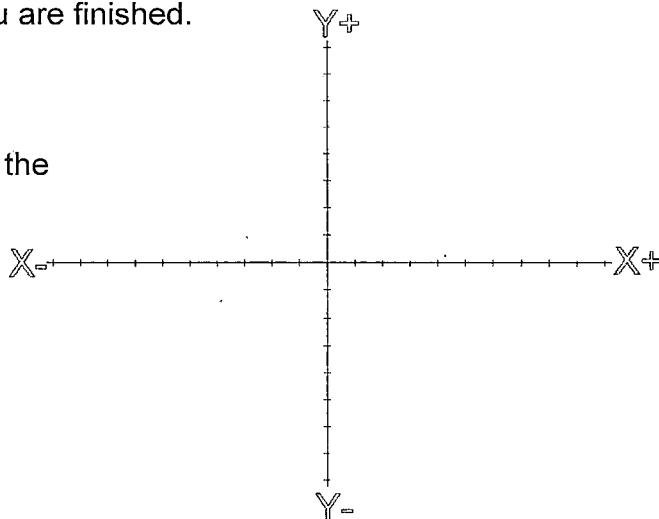
Delte

**Select all of the entities that you created during the previous
screen.**

Click on **Done**; all your lines should disappear.

Click on **ESC** when you are finished.

Your drawing should look like the
picture at the right.



Uses for Creating Lines using the Polar Command

The create, line, polar (C,L,P) command can be used almost exclusively to rapidly create 2d drawings. For example, consider the rocker beam pictured below.

Do this: Start the polar line command:

MAIN MENU

Create

Line

Polar

First line:

Start point: **0,0**

Angle in degrees: **0**

Distance: **2+11/32**

Second line:

Start point: **endpoint of the first line**
(use the sticky box or the endpoint selection method to select the exact endpoint of the first line)

Angle in degrees: **90**

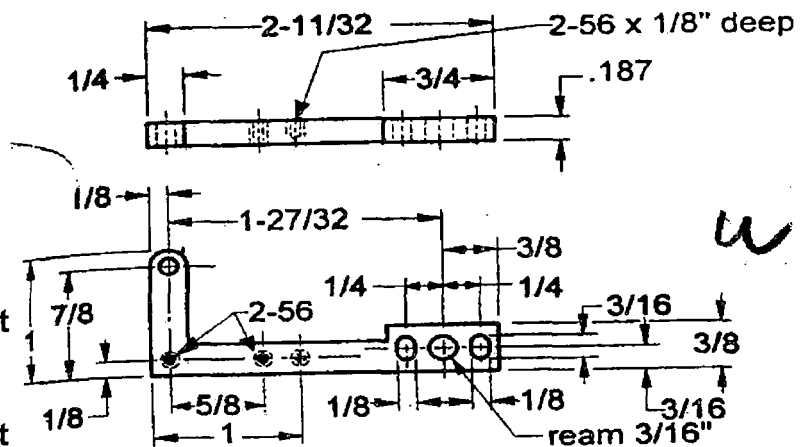
Distance: **3/8**

Third line:

Start point: **endpoint of the second line**

Angle in degrees: **180**

Distance: **3/4**



ROCKER BEAM
aluminum
1 required

Feel free to zoom in or out as needed.

Continued on the next page

111

Deleting Objects.

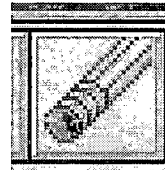
In the tool bar these 2 buttons are used to delete and undelete objects



We will revisit the line commands on the next page.

Delete object

The delete menu gives you options for deleting entities.



Delete

Undelete object

The undelete operation gives you the ability to restore deleted entities. Mastercam restores entities in the reverse order in which they were deleted.



Delete;
Undelete

Do this:

Start the delete command:

MAIN MENU

Delete

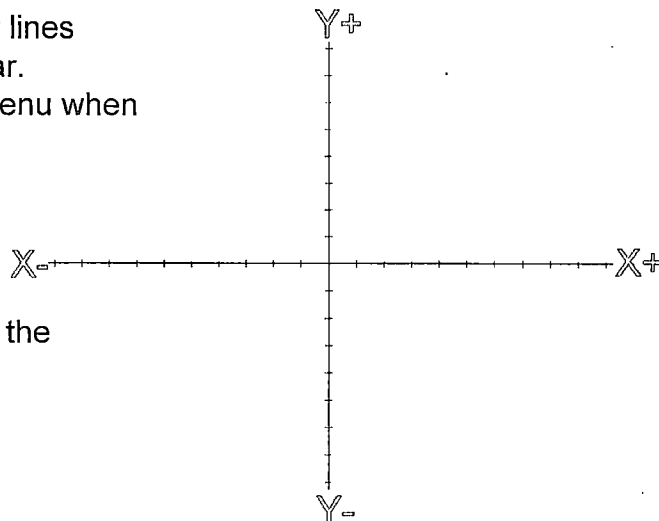
Chain

Select on one of your lines

If you have completed the previous activities all of your lines should be selected for deletion

Click on **Done**; all your lines should disappear.

Go back to the main menu when you are finished



Your drawing should look like the picture at the right.

Creating Lines using the Tangent command.

Tangent - The Tangent Line menu gives you options for creating lines that are tangent to arcs and splines. Tangent means the line only passes through one point on the arc.

Do this:

MAIN MENU

Create

Arc

Circ pt+Dia

Enter Diameter: **2**

Start point: **0,0**

MAIN MENU

Create

Line

Tangent

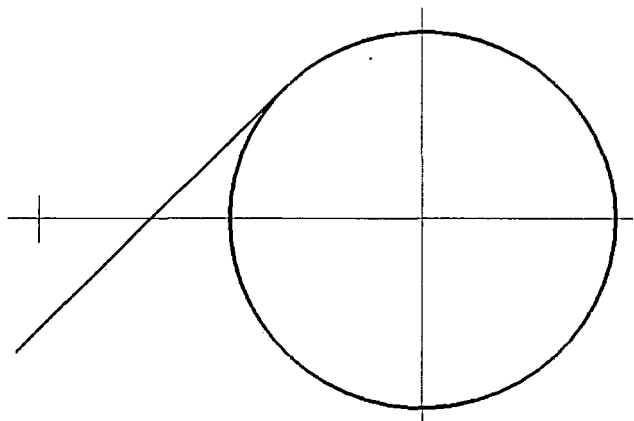
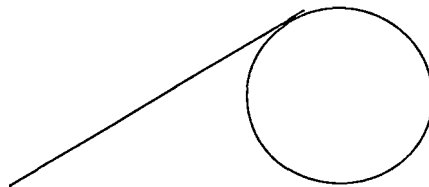
Angle

Select arc or spline: **select the circle you just created**

Enter angle in degrees: **45**

Line length: **2**

Select line to keep: **select the left part of the line**



Your drawing should look like the picture above.

Creating Lines using the Tangent command.

Tangent - The Tangent Line menu gives you options for creating lines that are tangent to arcs and splines. Tangent means the line only passes through one point on the arc.

Do this:

MAIN MENU

Create

Arc

Circ pt+Radius

Enter Radius: **1**

Start point: **2,2**

MAIN MENU

Create

Line

Tangent

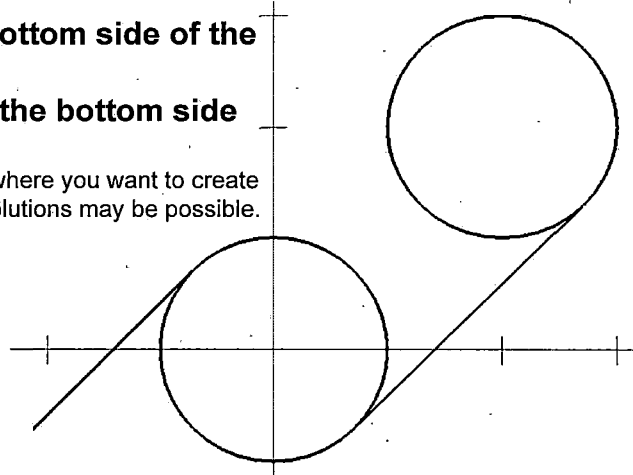
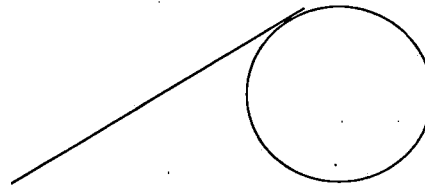
2 Arcs

Select an arc: **select the bottom side of the first circle**

Select another arc: **Select the bottom side of the second circle**

Note: Select both entities close to where you want to create the tangent line because multiple solutions may be possible.

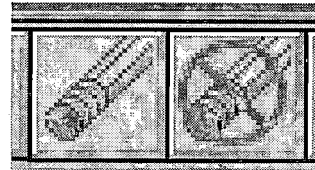
Your drawing should look like the picture at the right.



Deleting Objects.

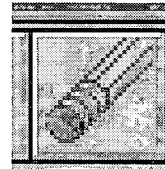
In the tool bar these 2 buttons
are used to delete and undelete objects

We will revisit the line commands on the next page.



Delete object

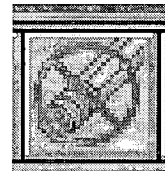
The delete menu gives you
options for deleting
entities.



Delete

Undelete object

The undelete operation
gives you the ability to
restore deleted entities.
Mastercam restores
entities in the reverse
order in which they were
deleted.



Delete; Undelete

Do this:

Start the delete command:

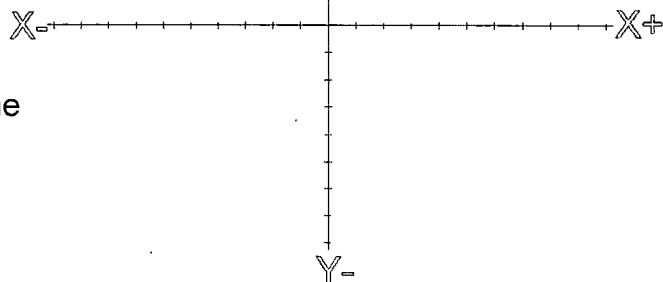
MAIN MENU

Delete

**Select all of the entities that you created during the previous
screens.**

Click on **Done**; all your lines should disappear. **Y+**

Click on **ESC** when you are finished



Your drawing should look like the
picture at the right.

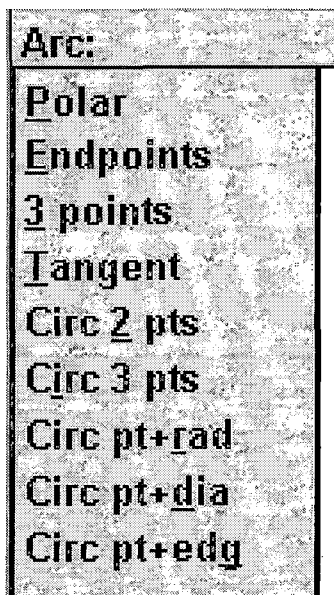
Creating Arcs

Create
arcs and
circles

Activates the arc menu
(Used for making arcs).



Create; Arc



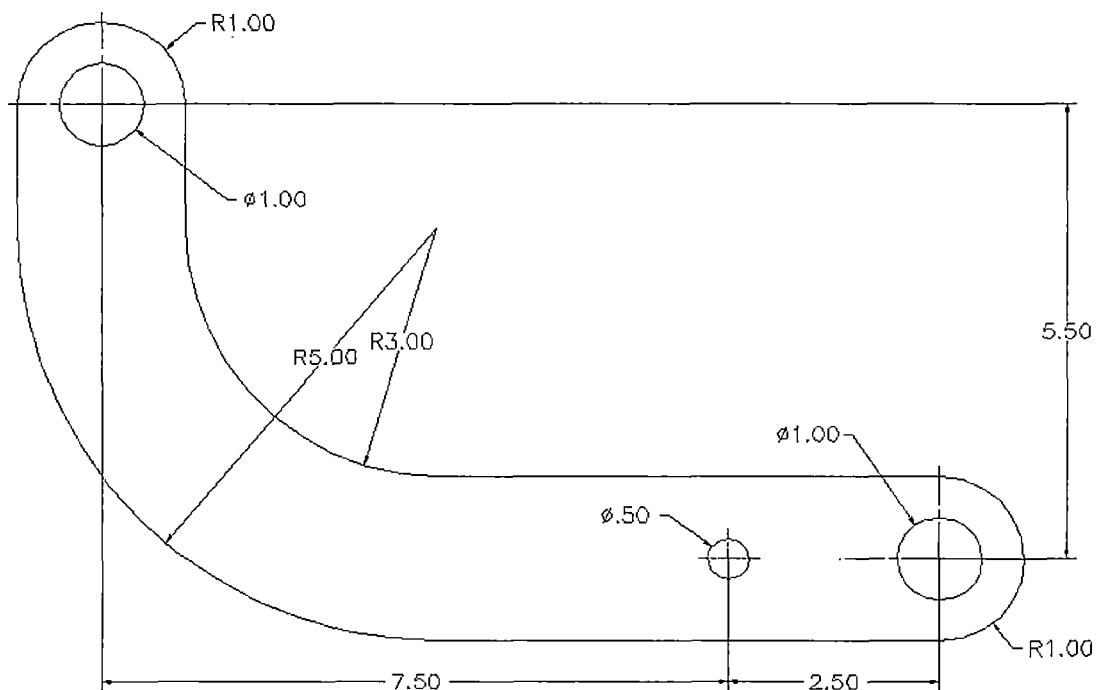
The line menu contains 9 different methods for creating arcs. Please see the Mastercam help menu if you need to learn more about the other types of arcs. The four that I have detailed on the next few pages are enough to get you started in Mastercam. In this lesson you will learn about the following 4 including:

- Circ pt+dia – Creating a circle with a defined center point and diameter.
- Circ pt+rad – Creating a circle with a defined center point and radius.
- Polar – The Polar Arc menu gives you options for creating arcs using Polar coordinates.
- Fillet – The Fillet command (found in the create and the modify menu) gives you options for filleting curves. When you fillet curves, you insert an arc of a defined radius tangent to the curves. You can access the Fillet menu by choosing Main Menu, Modify, Fillet or by choosing Main Menu, Create, Fillet.
- Tangent – The Tangent Arc menu gives you options for creating arcs that are tangent to curves and points.

Creating Arcs using Circ pt+Dia

Creating a circle with a
defined center point and diameter

Consider the drawing of the Rod Support located at the right;
during the next screen you will use the Circ pt+Dia command to
add the 3 circles to this drawing.



Creating Arcs using Circ pt+Dia

Creating a circle with a defined center point and diameter

The two 1" diameter circles that you need to create are located at 0,0 & 7.5+2.5,-5.5

The ½ diameter circle is located at 7.5,-5.5

Do this:

Main Menu

File

Get

Select: arcs.mc8

Main Menu

Create

Arc

Circ pt+dia

Enter the dia: 1

Point entry: 0,0

Point entry:

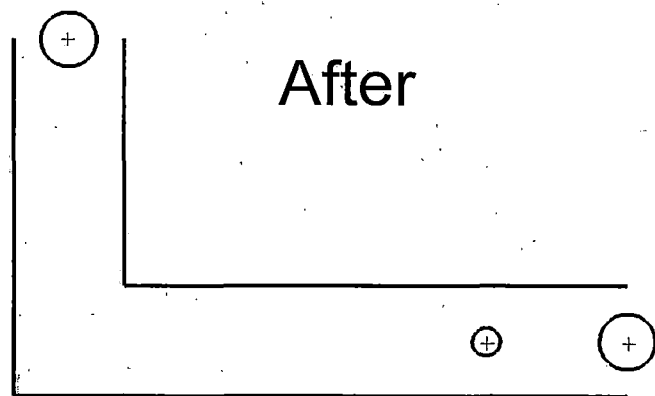
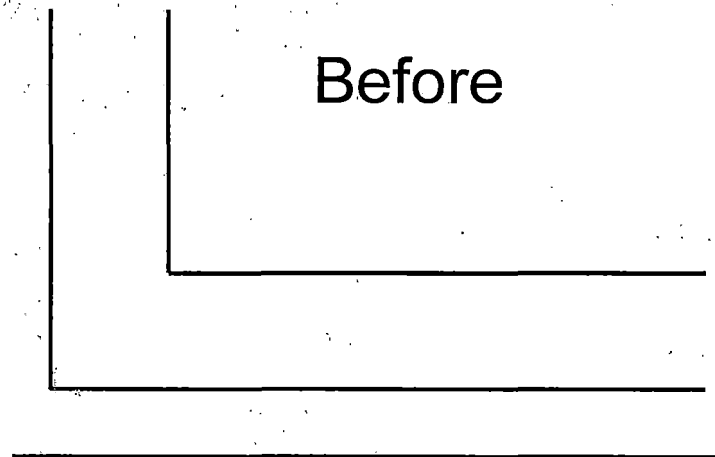
7.5+2.5,-5.5

ESC Once

Circ pt+dia

Enter the dia: .5

Point entry: 7.5,-5.5



Creating Arcs using Circ pt+Rad

Creating a circle with a defined center point and radius

The two 1" radius circles that you need to create are located at 0,0 & 7.5+2.5,-5.5

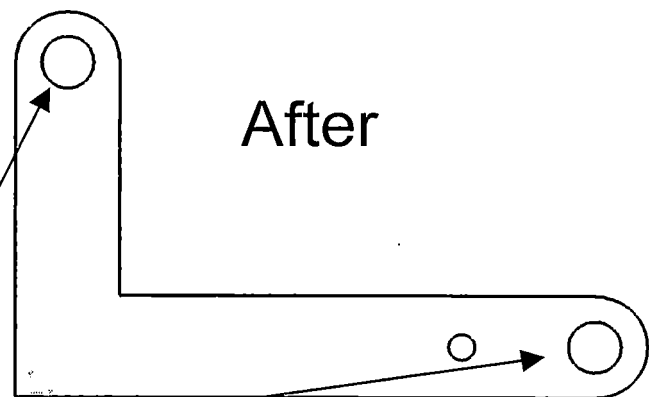
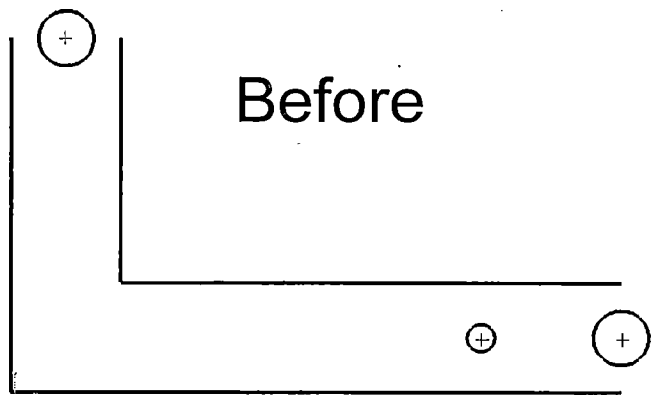
Do this:

Main Menu
Create
Arc
Circ pt+rad
Enter the rad: 1
Point entry: 0,0
Point entry: 7.5+2.5,-5.5

Main Menu
Modify
Break
At inters
All
Entities
Done

Main Menu
Delete
Select the bottom of
the top circle.

Select the left of
the right circle.



Creating Arcs using Polar, Center pt

Creating a polar arc with a defined center point and start/end angles

Another method of creating the same type of arc that you created on the previous screen is to use the create, arc, polar, center pt. Command.

The first arc is located at 0,0 and has a initial angle of 0 degrees and a final angle of 180 degrees.

The second arc is located at 7.5+2.5,-5.5 and has a initial angle of 90 degrees and a final angle of 270 degrees

Do this:

Main Menu

File

Get

Select: arcs2.mc8

Main Menu

Create, Arc, Polar, Center pt.

Point entry: 0,0

Enter the radius: 1

Initial angle: 0 degrees

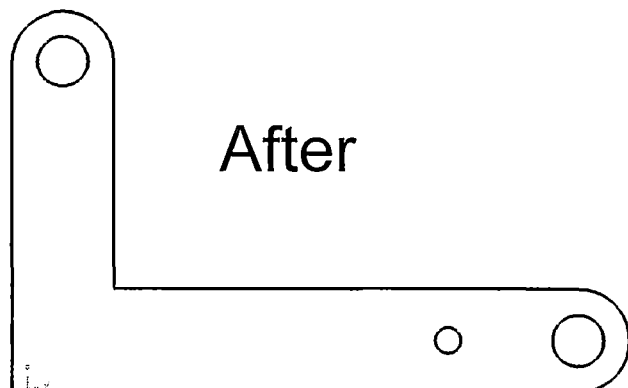
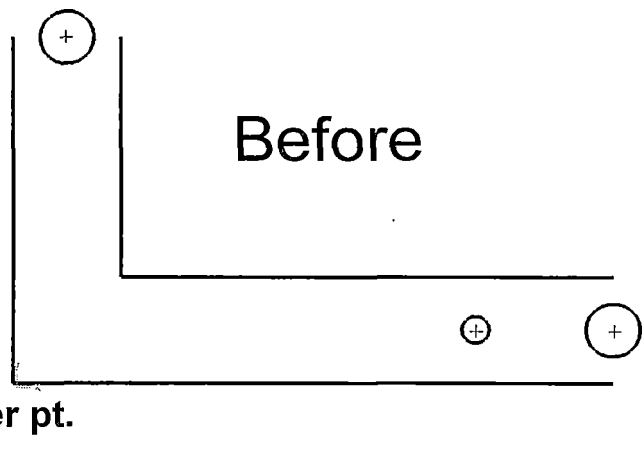
Final angle: 180 degrees

Point entry: 7.5+2.5,-5.5

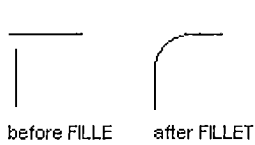
Enter the radius: 1

Initial angle: 270 degrees

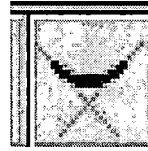
Final angle: 90 degrees



Create fillets or rounds



Activates the fillet menu.
(FILLET rounds or fillets the edges of two lines, arcs, circles, or splines with an arc of a specified radius).



**Create;
Fillet**

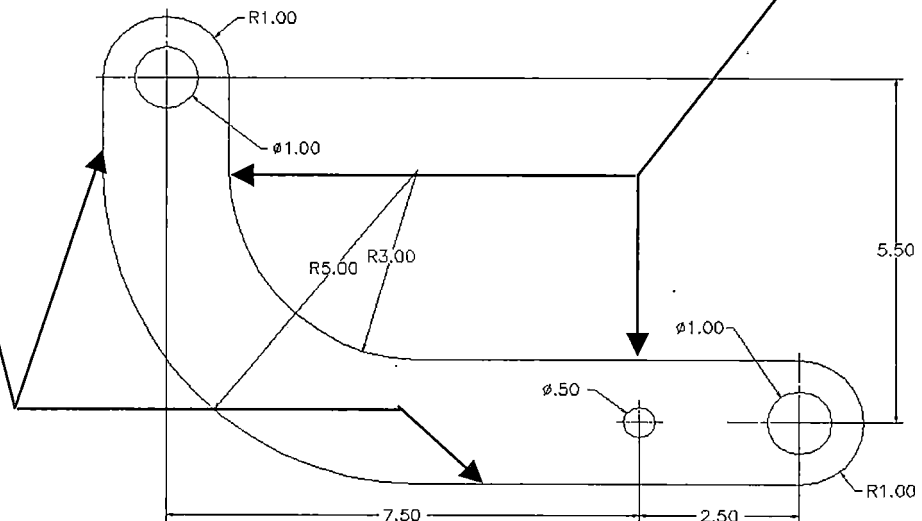
Fillet – The Fillet command (found in the create and the modify menu) gives you options for filleting curves. When you fillet curves, you insert an arc of a defined radius tangent to the curves. You can access the Fillet menu by choosing Main Menu, Modify, Fillet or by choosing Main Menu, Create, Fillet. You will need to put a fillet between two lines of the Rod support. One of the fillets is 3" and the other is 5"

Do this:

**Main Menu
Create
Fillet**

**Radius: 3 (Change the radius to 3")
Select the two lines that you would like to fillet**

**Radius: 5 (Change the radius to 5")
Select the two lines that you would like to fillet**



Creating Arcs using the Tangent command

- Tangent – The Tangent Arc menu gives you options for creating arcs that are tangent to curves and points.

Do this:

MAIN MENU

File

Get

Select: Tangent.mc8

Main Menu

Create

Arc

Tangent

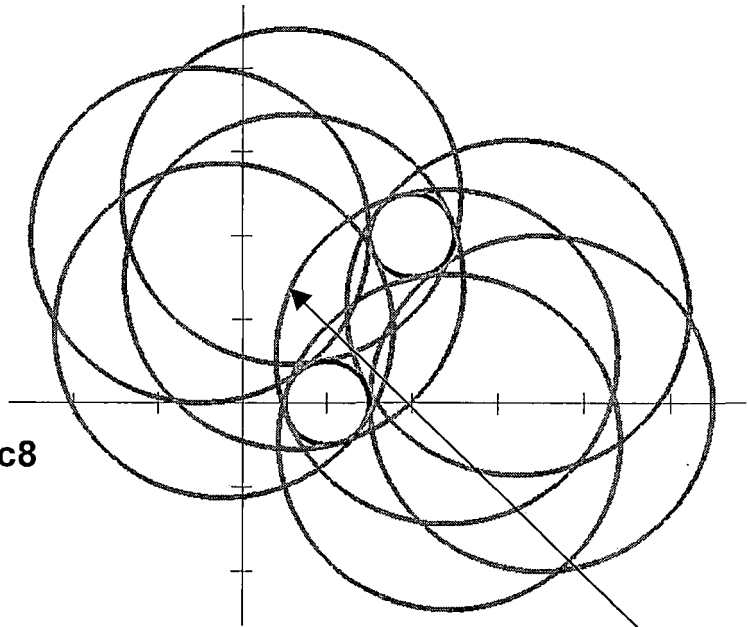
2 entities

Radius: 2

Select the two arcs

It now gives you the option of picking the arc that you would like to keep.

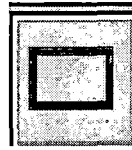
Select this arc



Creating a Rectangle

Create
Rectangle

Activates the
rectangle menu.



Create;
Rectangle

The Rectangular Shape menu gives you options for creating rectangles

The first method uses one point to position the rectangle in the graphics window. The method requires you to select point placement either in one of 9 corners and the width and height of the rectangle.

The second method uses two point to position the rectangle in the graphics window. The two points that you enter are from opposite corners of the rectangle.

One last note:

This document talked about many of the different ways that objects can be created. There are many other issues about creating objects that still need to be addressed. For example, how to create splines, etc. You can use the help menu at any time within Mastercam. Help (hitting on the question mark in the tool menu) will usually give you instant access to information about whatever command you are currently using.

ABSOLUTE PROGRAMMING

Overview

Grade Level: College

Time: Fourteen Hours

Subjects: Math, Geometry

Objectives:

At the conclusion of these activities the student will be able to:

- Create toolpaths using manual programming methods.
- Demonstrate use of many types of G-Codes movements including rapid movements (G0) and feedrate movements (G1) without concern for cutter diameter compensation.
- Demonstrate correct use of cutter height compensation commands.
- Setting machine preparatory functions including:
 1. Reference planes (G54, G55, G56, G57, G58 and G59).
 2. X-Y Plane selection (G17).
 3. Codes that cancel previous commands (G40, G49, G50 and G80).
 4. Rapid movement setting.
 5. Inch or Metric.
 6. Absolute or incremental.

- Differentiate between modal and non-modal commands.
- Demonstrate the correct use of human notes within the code.
- Demonstrate correct use of the tool change command.

Introduction

Before starting the assignments contained in this section the student should have already completed the first three assignments located in appendix A. These first three assignments are titled:

1. Cartesian coordinate system for CNC Programming
2. Polar coordinate system for CNC programming
3. Absolute and incremental (Relative) measuring system for CNC programming

The first three assignments are required for understanding both manual and computer aided programming methods. Using manual programming methods “a part program is prepared by manually inputting the coded instructions into the controller” (Lin, 1998).

During this assignment the student will write a CNC program using absolute programming methods.

Handbook Resources and Content Validation

Many textbooks dedicate a section to teaching how to make the machine write code using manual programming methods. The following textbooks contain a section on manual programming:

- *CNC machining handbook* (Madison, 1996, p. Chapters 3-4).
- *CNC mill master* (Ward, 1995, p. 1-11).

- *The CNC workbook* (Nanfara, 1995, Chapters 3-5).
- *Machinery's handbook* (Oberg, 2000, p. 1225-1286).
- *Mastercam Version 7* (Lin, 1998, Chapter 1).
- *Programming of CNC machines (2nd ed.)* (Evans, 2001, p. 212-241, 263, 104-108, 214-222).

Standards

WORKPLACE STANDARDS

Computer Aided Manufacturing and Advanced Computer Numerical Control Technical Workplace Competencies

C. Apply Mathematical Concepts

10.0 Apply Cartesian coordinate system to machining.

D. Read blueprints

4.0 Interpret blueprint drawings

E. Program CNC machines and EDM

1.0 Demonstrate cutting tool identification and application

2.0 Identify and describe machine operation nomenclature.

3.0 Identify and describe essentials of CNC systems

4.0 Identify and describe types of CNC hardware and software

5.0 Identify and describe machine axes and coordinate systems.

6.0 Describe and interpret CNC coding systems

7.0 Write NC programs

8.0 Plan process for NC operations

(Machine tool advanced skills, 1996, p. 21-22)

Secretary's Commission on Achieving Necessary Skills Course Competencies. (SCANS)

Systems: Understands complex inter-relationships

A. Understands Systems - knows how social, organizational, and technological systems work and operates effectively with them.

Technology: Works with a variety of technologies

B. Applies Technology to Tasks - understands overall intent and proper procedures for setup and operation of equipment.

(What work requires of schools, 1991, p. 12)

MATHEMATICS Grades 8-12

Geometry

1.0 Students demonstrate understanding by identifying and giving examples of undefined terms, axioms, theorems, and reasoning (Mathematics content standards for California public schools, 1997, p. 51).

Lesson: Teacher Section

Before the students start this lesson they should have been taught how to designate feed and speeds for cutting aluminum.

During the presentation of manual programming students will need a list of all of the G and M codes usually provided in the instructions for the machine. Some machine controllers use slightly different codes so it is a good idea to give the students a copy of the G-code lists for the particular machine being presented. If presenting the Dyna EM 3116 Computer Numerical Controlled knee mill as suggested in Chapter four, the students should be given the entire chapter six of the machine manual (Dyna 4M Machine Control and program manual, p. 79-121). This chapter of the Dyna machine manual provides a detailed description of how each G and M code is used on the machine.

It is suggested that the teacher present the topic of Manual programming using manual methods using the following steps:

- a. Present to the students the part that will be programmed during this assignment. Have the students refer to the handout for a drawing. This part is a simple part containing a contour with an arc.
- b. Next, explain the difference between the number zero and the letter "O" and when each is used. The students should also be given a brief presentation of the importance of placing a decimal point (.) after each whole number point positions.

- c. Present how a typical program is started. Most programs begin with the following:

Program	Notes
%	Most programs start with a single percent sign.
N100 O136;	Each line that follows the percent sign should contain line numbers in sequential order. O136 gives the name of the program for machine use. The semi-colon is the end of block code.

- d. Demonstrate correct use of human notes within the code.

N102 (contour, 5-25-01, 9:46);	This line provides a note for the human telling the name of the part, date and time. As for the Dyna controller human notes should be given in parenthesis.
N104 (Make 20 parts);	Some companies may require the programmer communicate to the operator how many parts to make.

- e. Demonstrate how to set machine preparatory functions. The preparatory functions provide codes that reset the machine in case the machine was setup differently during the previous usage. Now is also a good time to present to the students the difference between modal and non-modal commands. A modal command is a command that stays on until turned off by another command with a similar function. A non-modal command is instantaneous.

N106 G20;	Set the machine in inch or metric mode. G20 sets the machine in inch mode.
N108 G17 G40 G49 G50 G54 G80 G90;	G17 is the X-Y plane selection command. This command makes the machine work in the X-Y plane when creating arcs and circles. G40 Cancels diameter compensation within the machine. G49 Cancels tool height compensation. G50 Cancels translated cycles. (Cycles that either move or mirrors parts). G54 Selects a work coordinate system as the current programming coordinate system. G80 Cancels drilling cycles. G90 Set the machine in absolute mode.

- f. Demonstrate correct use of the tool change command.

N110 (1/2 flat end mill – tool 1);	Tells the operator of the machine what tool to put into the machine.
N112 T1M6;	T1M6 tells the machine what tool to install.

- g. At this point have the students refer to the drawing and review with them how to designate point positions on a blueprint.

- h. Next, give the first machine movement in order to move to the point position for starting the cut. Also demonstrate the difference between rapid movements (G0) and feedrate movements (G1).

N114 G0 X0. Y0.;	Makes the machine move rapidly to 0,0 or the origin of the part. Keep in mind that the cutter is still above the part.
------------------	--

- i. Demonstrate the correct use of cutter height compensation commands.

N116 G43 H1;	Forces the machine to look at its tool table for the height of tool number one.
--------------	---

- j. Show the students how to turn on the spindle and coolant using m-codes and move the machine to positive .1 inches above the part.

N118 M3 M8 S2800;	M3 Turns on spindle in the forward direction at a spindle speed of 2800 RPM.
N120 Z.1;	Rapidly moves the tool .1 inches above the part.

- k. Move the cutter down slowly at a feedrate of 6 inches per minute into the part to start cutting the part.

N122 G1 Z-.25 F6.;	Move the tool -.25 deep at a feedrate and 6 inches per minute.
--------------------	--

- l. Show the students how to make the next two cuts at feedrate.

N124 Y2. F12.;	Move the tool 2 inches forward.
N126 X1.;	Move the tool to the left until it gets to the beginning of the arc.

- m. At this point the students should complete the next assignment about how to create an arc within a tool path. Come back to this lesson after presenting the circular interpolation lesson.

- n. As detailed in the circular interpolation lesson an arc is made using either the G2 command or the G3 command depending on the arcs direction. G2 command creates a clockwise arc or circle and the G3 command creates a counter-clockwise arc or circle. In the case of this part the arc will be created using the G3 command.

N128 G3 X2. Y1. R1.;	The G3 command requires the end point of the arc (X2. Y1.) and the radius of the arc R1.
----------------------	--

- o. Finish the first contour by performing the last two cuts.

N130 G1 Y0.;	Move the tool backwards to Y0.
N132 X0.	Move the tool the origin of the part.

- p. Move down another $\frac{1}{4}$ inch and perform the contour again to finish the first two cuts of the part.

N134 Z-.5 F6.;	Move the tool down to -.5 in the Z direction.
N136 Y2. F12.	
N138 X1.;	
N140 G3 X2. Y1. R1.;	
N142 G1 Y0.;	
N144 X0.;	
N146 G0 Z1.;	Moves the tool up 1 inch above the part.
N148 M5 M9;	Turns off spindle and coolant.
N150 M30;	Indicates program end.
%	The program should end with two percent signs.
%	

CNC

Manual Programming

By Paul A. Van Hulle & Wayne Sutter

Absolute Programming

When you have finished this assignment
please have your instructor sign this sheet
in your signoff workbook.

Student Name:

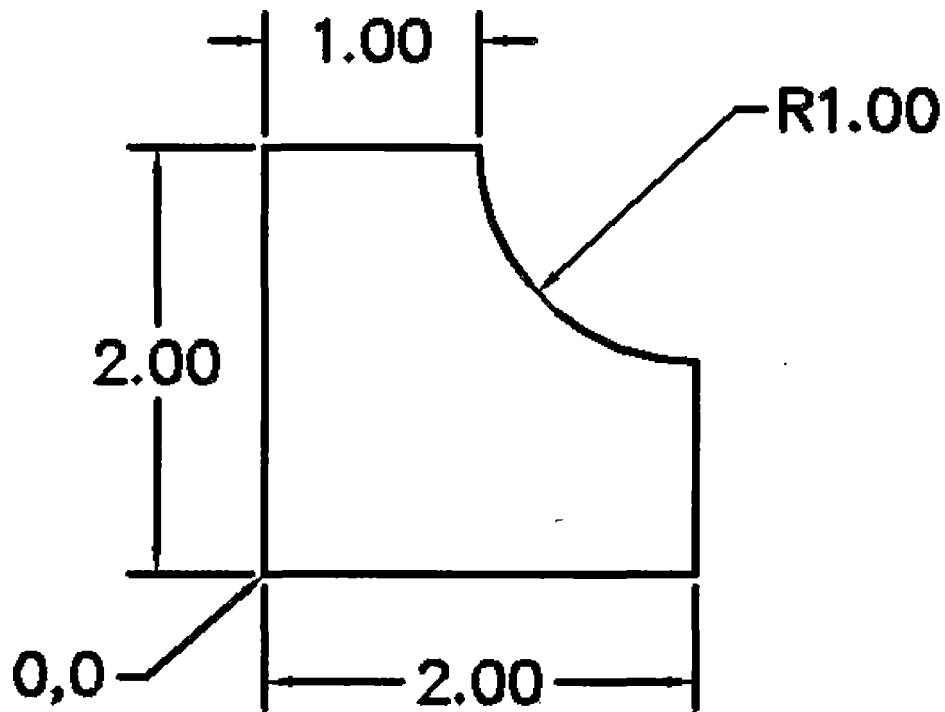
Instructor's signature

Competency achieved Yes or No: _____

Absolute Programming

During this assignment you will be writing a CNC Program using absolute programming methods. The drawing provided (on the next page) includes all necessary instructions and dimensions.

Please submit your finished code as (1) printed copy, Remember the helpful steps of generating the setup codes first and then creating a geometry table giving the coordinates of each point required to create the desired program. Identify each point using a, b, c, d,... as necessary and then determine the desired direction and path and create the necessary code.

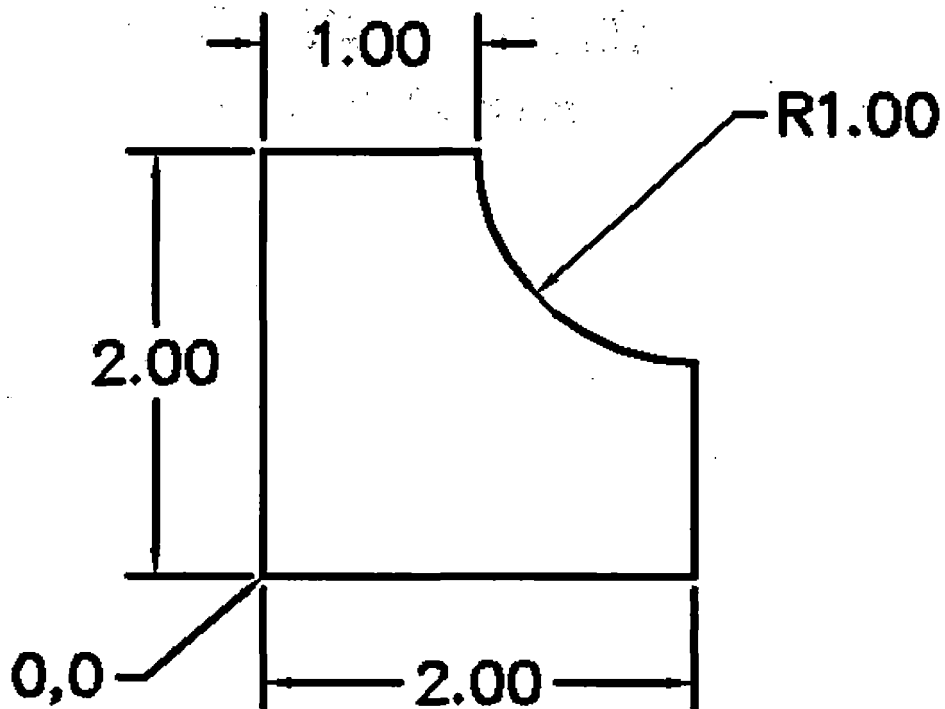


Create A
Coordinate Table

Label all points needed for
programming. Each point where a
direction change or code transition
occurs must have a point labeled.

- A. _____
- B. _____
- C. _____
- D. _____
- E. _____
- F. _____

Part is in "first quadrant"



CNC

Absolute programming

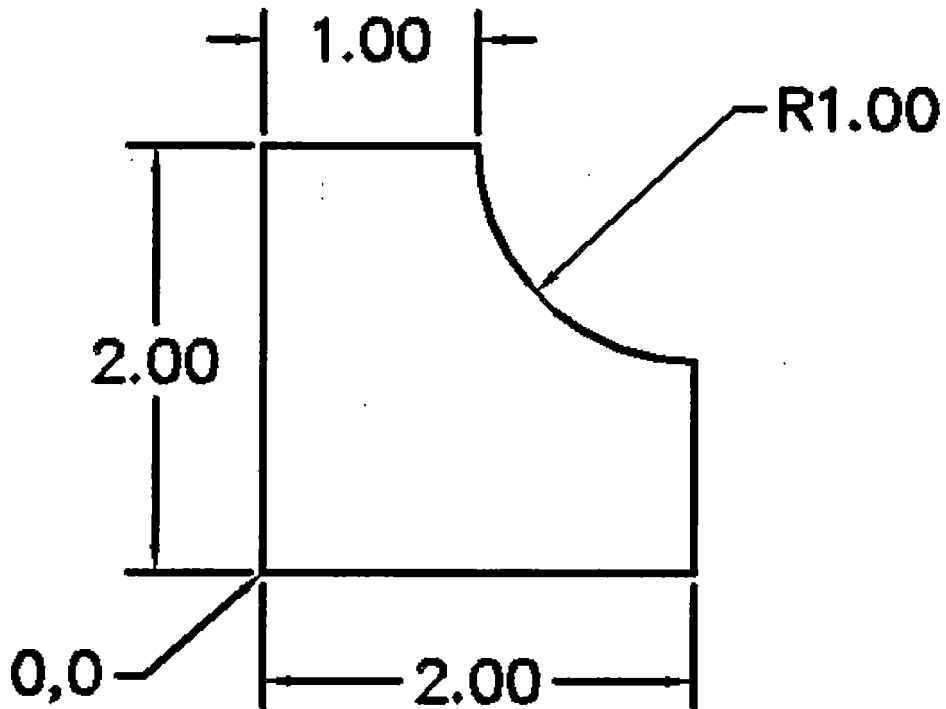
Without CAM software, write a CNC program using a 1/2" 2 flute flat end mill. Perform 2 depth cuts of 1/2 depth. Machine the material as if it were aluminum 6061 alloy. You will need to apply feed and speed concepts as instructed.

Do not compensate for tool diameter. Program for center of tool to travel on the contour and profile.

Name the file "1" followed by your first initial and last name.

Example "1jsmith.xls"

Absolute Programming Lesson: Answers



Create A
Coordinate Table

Label all points needed for
programming. Each point where a
direction change or code transition
occurs must have a point labeled.

- A. 0,0
- B. 0,2
- C. 1,2
- D. 2,1
- E. 2,0
- F. 0,0

Part is in "first quadrant"

CIRCULAR INTERPOLATION FOR MILLING IN THE X-Y AXIS

Overview

Grade Level: College

Time: Two Hours

Subjects: Math, Geometry

Objectives:

At the conclusion of these activities the student will be able to:

- Specify g-codes for programming circles for contours and pockets.
- Describe the difference between G02 (Clockwise) and G03 (counter-clockwise).
- Demonstrate use of Radius or R's for specifying circle coordinates and dimensions.
- Demonstrate use of circular interpolation on the CNC machine using Manual data input.

Introduction

CIRCULAR INTERPOLATION is the ability for any two axes of either a CNC milling machine or lathe to work together in generating a programmed arc of any degree up to 360 degrees.

Handbook Resources and Content Validation

When creating a contour understanding how to make a milling machine move circularly is vital to understand how to program a machine. Many textbooks dedicate a section to teaching how to make the machine move circularly. The following textbooks contain a section on circular interpolation:

- *CNC machining handbook* (Madison, 1996, p. 128-136).
- *CNC mill master* (Ward, 1995, p. 12-17).
- *Computer numerical control: Operation and programming (2nd ed.)* (Curran, 2001, p. 45-48, 253-260).
- *Machinery's handbook* (Oberg, 2000, p. 1254-1256).
- *Programming of CNC machines (2nd ed.)* (Evans, 2001, p. 104-108, 214-222).

Standards

WORKPLACE STANDARDS

Computer Aided Manufacturing and Advanced Computer Numerical Control Technical Workplace Competencies

C. Apply Mathematical Concepts

10.0 Apply Cartesian coordinate system to machining.

E. Program CNC machines and EDM

2.0 Identify and describe machine operation nomenclature.

3.0 Identify and describe essentials of CNC systems

4.0 Identify and describe types of CNC hardware and software

5.0 Identify and describe machine axes and coordinate systems.

6.0 Describe and interpret CNC coding systems

7.0 Write NC programs

8.0 Plan process for NC operations

(Machine tool advanced skills, 1996, p. 21-22)

Secretary's Commission on Achieving Necessary Skills Course Competencies. (SCANS)

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Technology: Works with a variety of technologies

B. Applies Technology to Tasks - understands overall intent and proper procedures for setup and operation of equipment.

(What work requires of schools, 1991, p. 12)

CALIFORNIA CONTENT STANDARDS

MATHEMATICS Grades 8-12

Geometry

1.0 Students demonstrate understanding by identifying and giving examples of undefined terms, axioms, theorems, and reasoning (Mathematics content standards for California public schools, 1997, p. 51).

Lesson: Teacher Section

It is suggested that the teacher present the topic of Circular interpolation using the following steps:

- a. It is suggested that the topic of circular interpolation be presented after the students start the first hand programming assignment. The first hand programming assignment requires the students to define a contour with one arc.
- b. When presenting the topic of circular interpolation the teacher should first instruct the students on the difference between clockwise (G2) and counter-clockwise (G3) arcs.
- c. The teacher should next present what it means for the arc to end at a certain point. The arc command requires the programmer to specify the endpoint of the arc.
- d. Next, the teacher should now explain how to find a radius on the drawing and how to specify that radius within the G2 or G3 command.
- e. Students should now be given many examples through guided practice.

CNC

Manual Programming

By Paul A. Van Hulle

Circular Interpolation

When you have finished this assignment
please have your instructor sign this sheet
in your signoff workbook.

Student Name:

Instructor's signature

Competency achieved Yes or No: _____

Circular Interpolation for Milling in the X-Y axis

CIRCULAR INTERPOLATION is the ability for any two axes of either a CNC milling machine or lathe to work together in generating a programmed arc of any degree up to 360 degrees.

Every block of X-Y CIRCULAR INTERPOLATION must contain the following:

#1. The arc is to be cut in what **direction**?

or G2 (Clockwise direction)
 G3 (Counterclockwise direction)

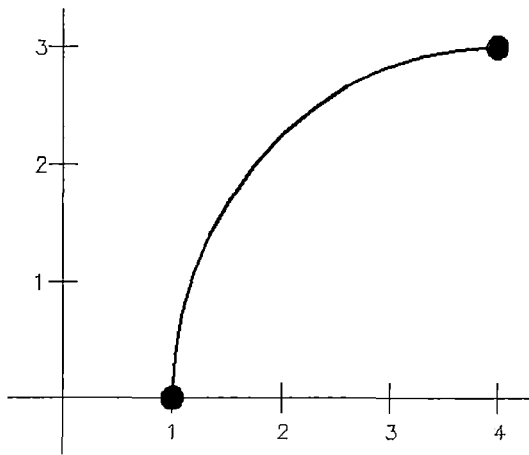
#2. The arc is to end at what coordinates?

X _____ Y _____

Or

#3. The radius of the arc

R _____

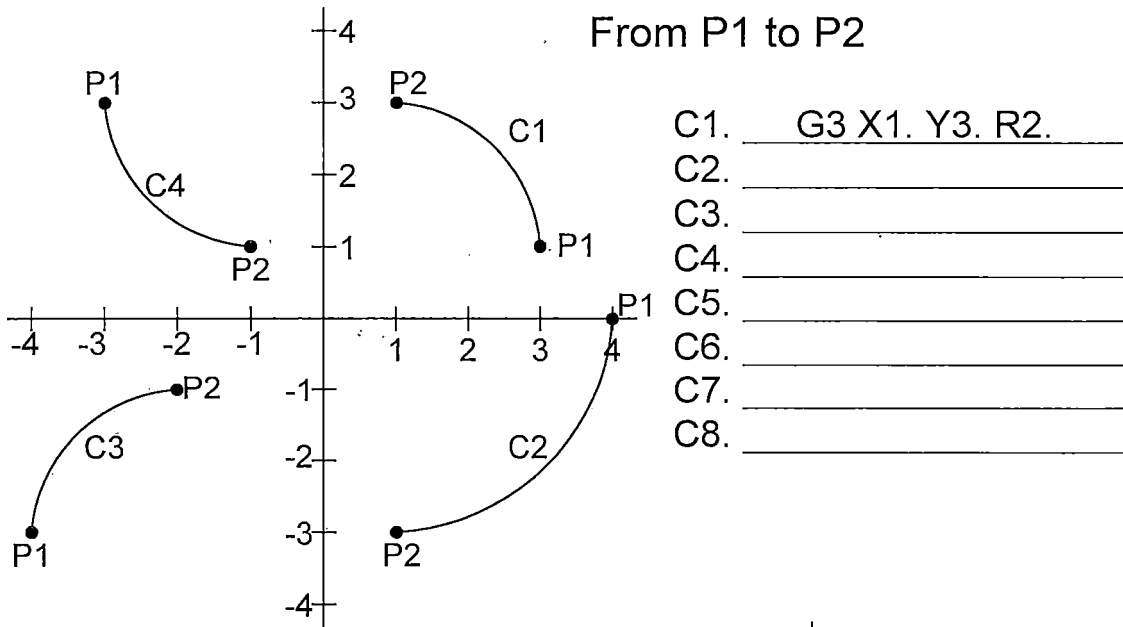


Radius of arc C3 from P1 to P2
G3 X1. Y0 R3

Circular Interpolation Lesson: Answers

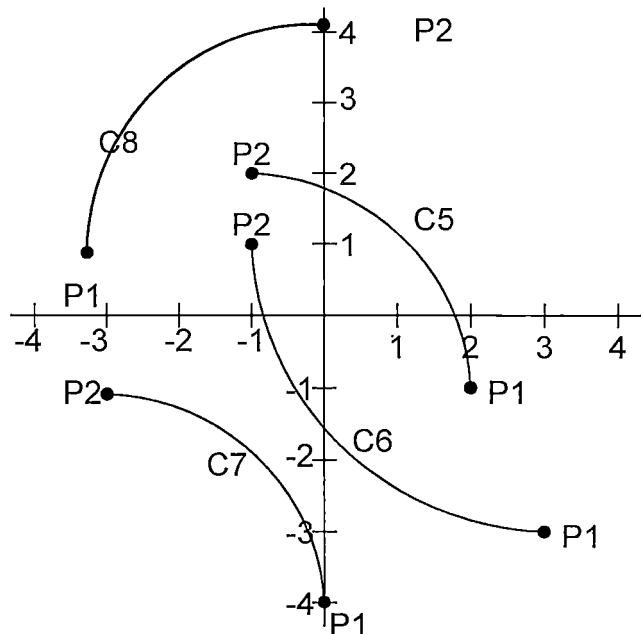
90 Degree Arcs Using R's.

Write the correct NC block for each of the following arcs. G90 is in effect.
Use R's, not I's and J's.



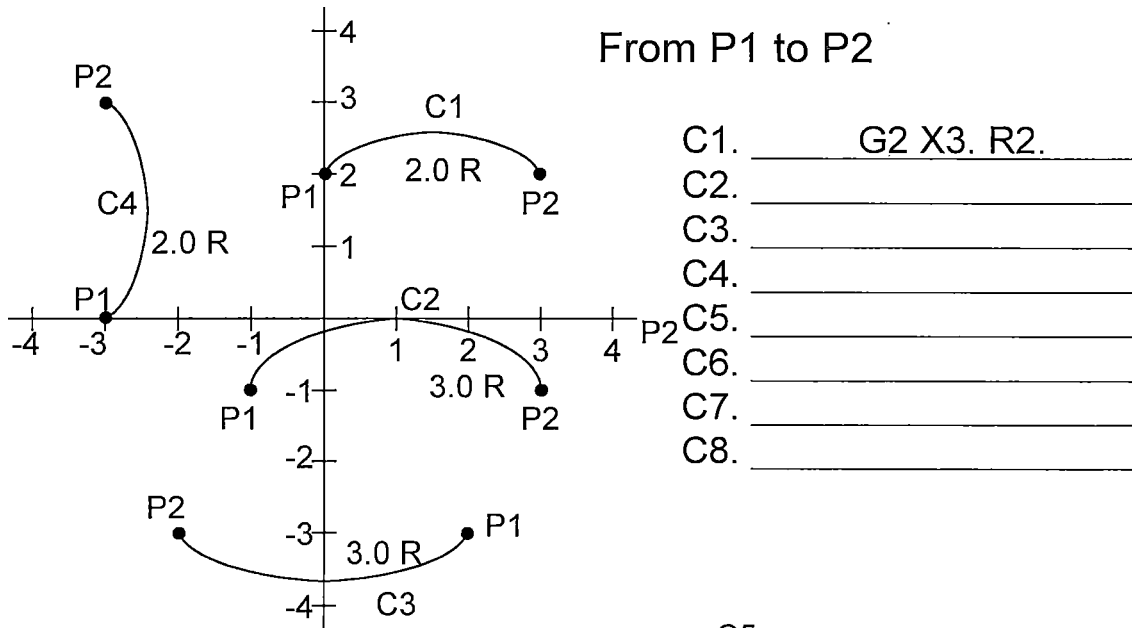
From P2 to P1

C1. _____
 C2. _____
 C3. _____
 C4. _____
 C5. _____
 C6. _____
 C7. _____
 C8. _____



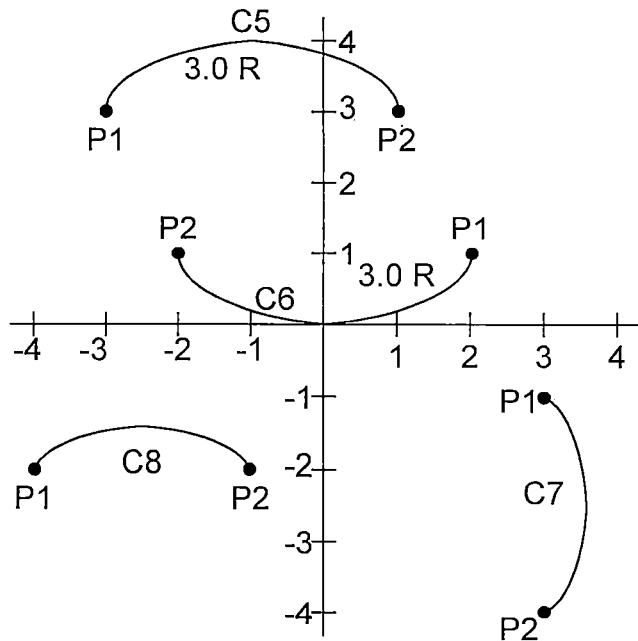
45 Degree Arcs Using R's.

Write the correct NC block for each of the following arcs. G90 is in effect.
Use R's, not I's and J's.



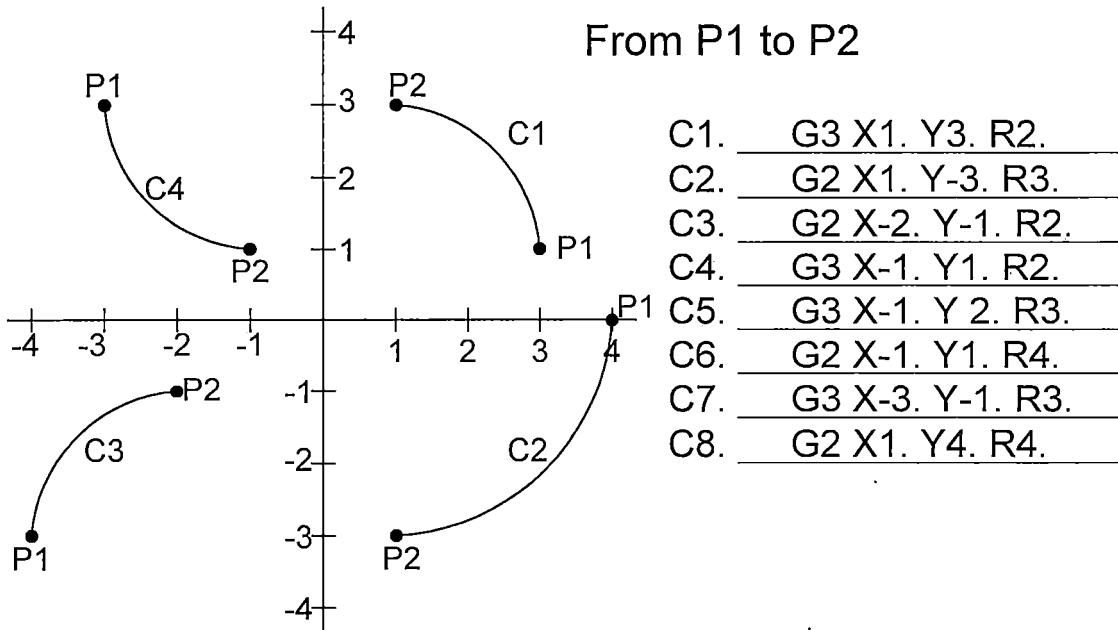
From P2 to P1

C1. _____
 C2. _____
 C3. _____
 C4. _____
 C5. _____
 C6. _____
 C7. _____
 C8. _____



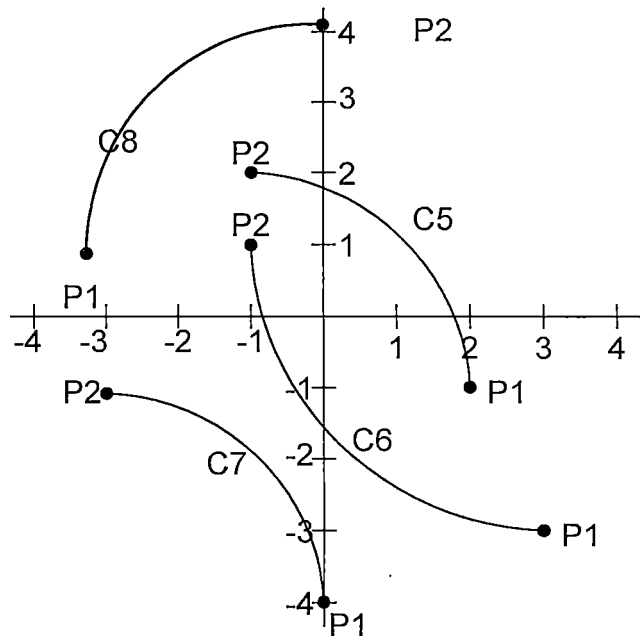
90 Degree Arcs using R's. Answers

Write the correct NC block for each of the following arcs. G90 is in effect.
Use R's, not I's and J's.



From P2 to P1

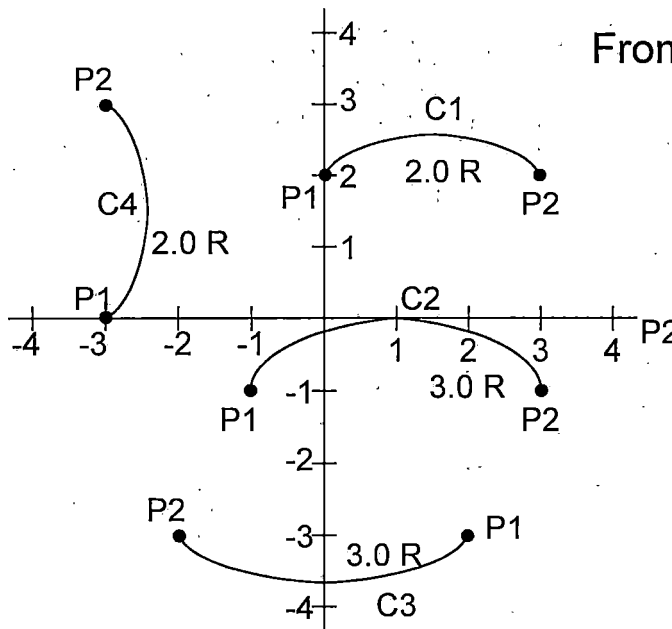
C1.	G2 X3. Y1. R2.
C2.	G3 X4. Y0. R3.
C3.	G3 X-4. Y-3. R2.
C4.	G2 X-3. Y3. R2.
C5.	G2 X2. Y-1. R3.
C6.	G3 X3. Y-3. R4.
C7.	G2 X0. Y-4. R3.
C8.	G3 X-3. Y0. R4.



45 Degree Arcs Using R's.

Answers

Write the correct NC block for each of the following arcs. G90 is in effect.
Use R's, not I's and J's

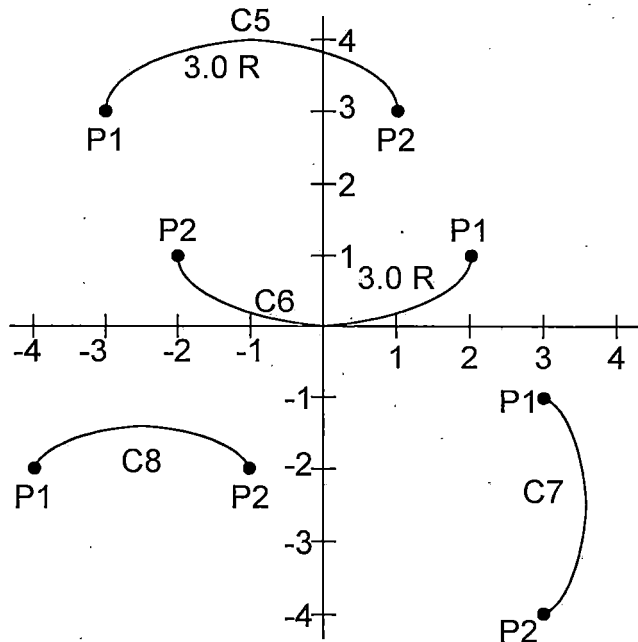


From P1 to P2

C1.	G2 X3. R2.
C2.	G2 X3. R3.
C3.	G2 X-2. R3.
C4.	G3 Y3. R2.
C5.	G2 X1. R3.
C6.	G2 X-2. R3.
C7.	G2 Y-4. R2.
C8.	G2 X-1 R2.

From P2 to P1

C1.	G3 X0. R2.
C2.	G3 X-1.R3.
C3.	G3 X2. R3.
C4.	G2 Y0. R2.
C5.	G3 X-3.R3.
C6.	G3 X2. R3.
C7.	G3 Y-1.R2.
C8.	G3 X-4. R2.



Special thanks to D. Ward from the Rands corporation for providing the idea for the assignment for 90 degree arcs using R's and 45 degree arcs using R's. (Ward, 1995).

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