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ΑΝΟΙΚΤΑ ακαδημαϊκά μαθήματα ΠΠ

# Αριθμητικός Έλεγχος Εργαλειομηχανών

## Ενότητα 1: Εισαγωγή

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# COMPUTER NUMERICAL CONTROL OF MACHINE TOOLS


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# Preface

The present edition of these lecture notes includes the historical evolution, the theory, applications and a number of new developments in the world of Computer Numerical Control (CNC).

A number of my associates in our Laboratory for Manufacturing System and Automation (LMS), in the University of Patras, have been involved with the preparation of these lecture notes; ***G. Dimitrakopoulos***, ***M. Doukas*** and ***S. Zygomalas*** contributed substantially to the content preparation, to the editing and proof reading and to the necessary literature research. I would like to thank all of them.

Dimitris Mourtzis

Patras, Greece, April 2013

# Section 1:
# An Introduction to Numerical Control Machinery

# Objectives of Section 1

At the end of this class you will be able to:

- Evaluate which of your manufacturing processes are good candidates for automation
- Understand the levels of automation that can be achieved
- Discuss the productivity gains you can achieve through automation
- Devise an automation plan
- Describe the types of automation available in CAM Systems
- Understand how a database can be used to store machining knowledge

# Objectives of Section 1

- Describe the difference between direct and distributive Numerical Control (NC)
- Describe four ways that programs can be entered into a computer numerical controller
- Explain two tape code formats in use with CNC machinery
- Give the major objectives of Numerical Control
- Describe the difference between a numerical control tape machine and a Computer Numerical Control (CNC) machine

# Class Summary

Do you need to **boost your productivity** and avoid costly human errors?

Find out how you can **standardize your manufacturing processes and develop an automation plan** to fit the needs of your business now and in the future

# Why Automate?

# Why Automate?

## Benefits of automation

- Save time
- Reduce human error
- Make processes more efficient
- Eliminate redundancies and wasted effort
- Implement process improvements faster
- Use skilled employees for more valuable tasks
- Avoid disruptions when new employees are hired or longtime employees retire

# Why Automate?

## Reality Check

- **Don't automate just because:**
  - It seems like a good idea
  - You heard from a salesman that you'll save a ton of money
  - Everyone else/competitors/the guy next door is doing it
  - You want to lay off workers

- **Automation takes time and resources**
- **Do your homework before you decide**
- **People don't want you to automate them out of a job**

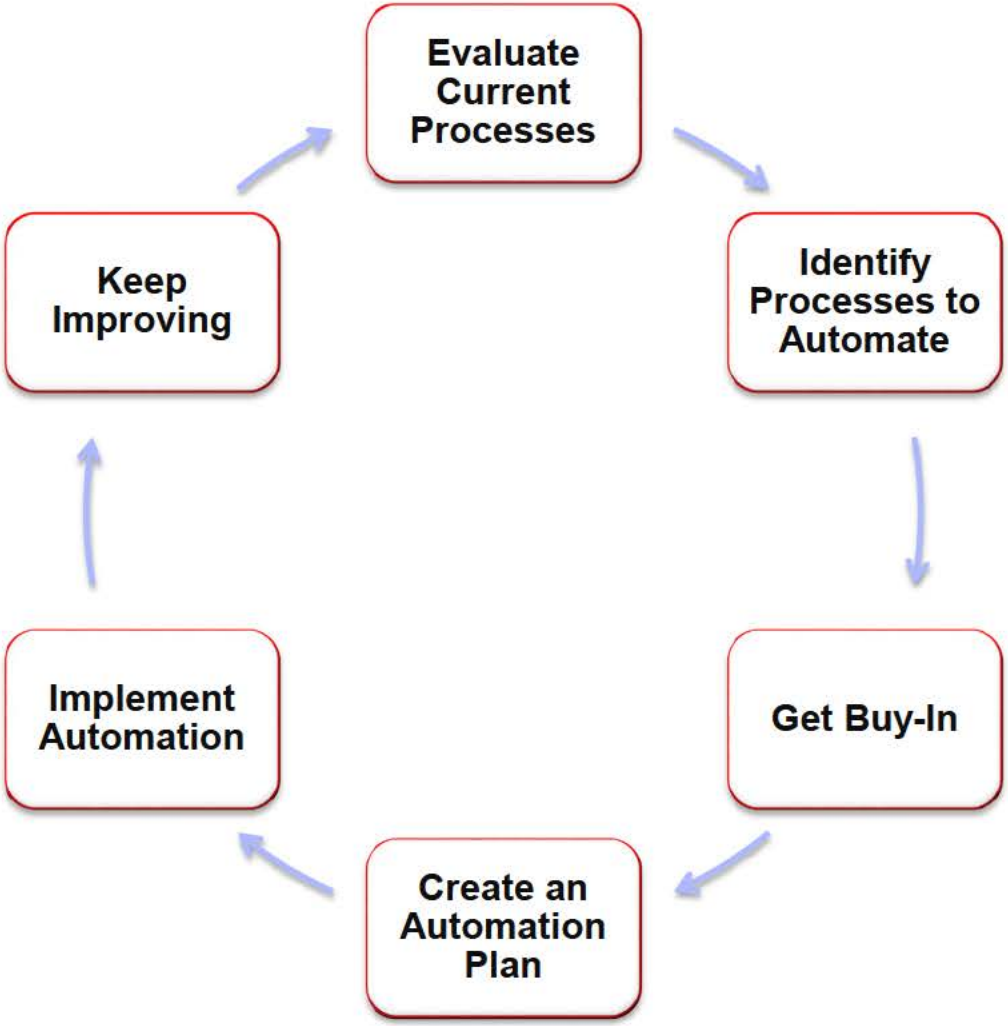
# Why Automate?

## Good Reasons to Automate

- Improve **quality** and **customer satisfaction**
- **Produce** more with the same equipment / people
- Respond **faster** to market changes
- **Expand** business into new markets

# Why Automate?

## Automation Lifecycle



# Evaluate your current processes

# Evaluate your current processes

## ● The Big Picture

- **WALK THROUGH** the entire process, from the time an order comes in until the order ships
- Do not just look, get out and literally walk through each step
- Observe and ask questions
- If you can, walk through other manufacturing facilities
- Invite people who don't know your processes to walk through your facility

# Identify processes to automate

# Identify processes to automate

## Good Candidates for Automation

- Tasks that can be repeated
- Tasks that are similar
- Tasks that are important
- Tasks where human error can be eliminated
- Tasks with known variables

# Identify processes to automate

## Ask Yourself

- Are there repetitive tasks people are having problems with?
- Where do we lose the most time?
- Where do we make the most mistakes?
- How far does each product travel before it makes it out the door?

# Identify processes to automate

- **Seek and Destroy Broken Processes**

- **Complacency** is your enemy! “Because we have always done it this way” is NO EXCUSE

- Do not automate anything that should not be done in the first place!

- Use the lean mantra “Eliminate waste”

# Identify processes to automate

## Improve Processes Before Automating

- **Consistency** is your friend! It lets you know what to expect
- Standardize the **tools, materials, processes** you already have
- Study which processes work well and see if you can apply those principles elsewhere
- Make processes **flexible** so you can adapt to changes in the future

# Identify processes to automate

## ● What can you standardize?

- Cutting tools
- Fixtures and mounting
- Stock sizes (?)
- Machining operation defaults
- Machining processes
- Lot sizes (?)

# Identify processes to automate

- **Classify by Urgency and Importance**

  - **Identify good candidates by classifying tasks into 4 zones**

| | Urgent | Not Urgent |
|---|---|---|
| **Important** | **Zone 1:** Important tasks that pop up suddenly and must be completed quickly - There is no time to automate. | **Zone 2:** Important tasks that are done on a regular basis - **Ideal candidates for automation** |
| **Not Important** | **Zone 3:** These tasks must get done quickly but are not important enough to be worth the time spent on automation | **Zone 4:** Never automate a task that is both unimportant and not urgent |

# Think Like the Manager

## ● Get Support from Upper Management

- **Management is looking for a return on investment (ROI)**
- **Here is how it works:**

- Standardization
- Consistency
- Automation
- Cheaper/Faster
- More Profit for the Company
- You Look Like a GENIUS

# Think Like the Manager

## Compare Benefits to Costs

- You need to demonstrate the value of automation
- How are you going to save the company time and money?
- Talk hard numbers to break through resistance to the time and money spent on automation

    - We can increase throughput by X pieces per day/month
    - We can decrease scrap and rework by X amount
    - We can improve on-time deliveries by X days
    - We can eliminate back orders and get paid faster
    - We can get a new product on the market X days faster

# Think Like the Manager

## Use Benchmarks to Get the Numbers

- **Get the actual costs of a current process**
  - Hourly labor rate/machine time/tools for a process that is a realistic reflection of work done on a regular basis
  - Rework/scrap caused by human error
  - Inspection time to catch human error
  - Wasted time on non-value-added work or, worse, waiting around
- **Calculate the estimated costs of an automated process**
  - Hourly labor rate/machine time/tools for the exact same process after it's automated
  - Rework, inspection, waste after automation
- **Multiply savings to show annual payback**
  - A few minutes every day can really add up
  - Compare the annual savings to the cost of software/equipment/training needed to implement automation

# Think Like the Manager

## Build Your Proof

- Show your lists of bottlenecks, quality issues, late shipments, lost opportunities, …
- Show your benchmark tests
- Offer different scenarios to overcome budget resistance
  - New equipment/software versus updating existing equipment/software
  - Automating a handful of processes versus all processes
  - Pilot program versus a company-wide rollout

# Devise an automation plan

# Devise an automation plan

## Start Out Right

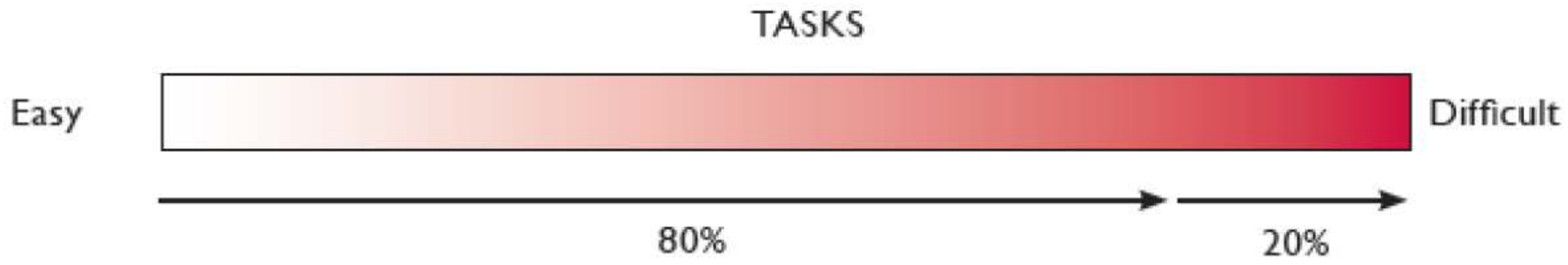
- **Choose the right project**
  - If possible, use a new project as a logical time to implement newer better processes
  - Choose a project with the biggest payback
  - Choose a project with the least risk

- **Get employees involved early**
  - Your employees and their knowledge are your most important assets
  - Get input from all levels
  - Communicate
  - Set goals
  - Show the benefits

# Devise an automation plan

## The 80/20 Rule

- 80% of tasks identified for automation will require about 20% of your time
- The last 20% of tasks will take up to 80% of your time
- Use the 80/20 rule to decide whether that last 10-20% is worth the time involved to automate



# Devise an automation plan

## Best Practices are Stupid (sometimes)

- If you use the same industry practices as everyone else, what makes you different or better?
- Copying the competition does not get you ahead
- Stand out from the crowd, create your own best practices
- Look outside your industry for ideas

  - What can you learn from a racing pit crew?
  - What can you learn from a fast-food restaurant?
  - What can you learn from Netflix or Amazon?

# Devise an automation plan

## Look at All the Solutions

- Your problem may be in manufacturing but the solution could be somewhere else

**Where?**

- Designers and engineers
- Purchasing
- Customer specs, revisions, and delivery schedules
- Suppliers

**Who else?**

- If the solution is somewhere else, get those people involved
- If you do not ask, they can not help you
- If not, how can you work around the problem?

# Devise an automation plan

## ● Prioritize

- Now that you know WHAT needs to be automated, you have to figure out HOW to make it happen

- Prioritize in a way that:

**Saves the company the most time/money**

**Gets you the best value**

# Devise an automation plan

## ● Plan for the Unexpected

- **Do not expect things to go perfectly the first time**
- Do expect to **make multiple revisions** to your plan and allow time for changes / improvements
- Do have a **backup plan** in case of delays because you can not get equipment or resources at the scheduled time
- Do have a **plan for changes in deadlines**, especially if the deadline is moved up

# Implement your plan

# Implement your plan

## How CAM Can Help

- CAM KnowledgeBase for storage of your standards in a central database
- Expressions for automatically calculating machining values
- Visual Basic programs for automatically performing functions in CAM
- Custom cycles and custom settings for your specific machining requirements

# Implement your plan

## ● CAM Knowledgebase – Centralize Your Shop Floor Data

- **A central database that stores your standardized cutting tools, materials, speeds/feeds, machining preferences, machining processes**
  - Items in the database are available to anyone using CAM
  - Update your standards in one central location
  - Use security to prevent accidental updates or deletions
  - Transfer data between separate manufacturing locations
- **SQL database that stores:**
  - Cutting tool definitions
  - Speed and feed standards
  - Machining and cutting tool defaults
  - Families of parts
  - Machining processes

# Implement your plan

- **CAM Knowledgebase – Choose Your Level of Automation**

- **Easy**
  - Set up and store cutting tool definitions
  - Set up and store feeds/speeds, material classes/conditions
  - Set up and store machining preferences
- **Intermediate**
  - Set up and store part types and feature types unique to your business
  - Modify the standard machining processes to your own best practices
- **Advanced**
  - Automatically recognize features, associate machining processes, and apply those processes for complete tool path in minutes

# Implement your plan

## Expressions and the Expression Builder

- Short mathematical or VB commands entered directly into a field on a technology page

- Always start with = sign, then type the expression (=feature.depth/2)

## Levels of automation

- **Easy**: Type expressions to calculate values used on a regular basis or to pick cutting tools based on the size of the feature

- **Intermediate**: Expression Builder gives you access to lists of ESPRIT variables, functions, and modules to build more complex expressions

- **Advanced**: Create your own rules with VB code

# Implement your plan

## The Post Mortem

- A critical step you do not want to skip
- Get everyone together for a final review at the end of the project
  - What went well?
  - What went wrong?
  - What could we have done better?
  - How do the results compare with our benchmark tests?
  - How can we do things better in the future?

- This is a team effort
- Focus on constructive feedback and advice
- Do not let this degenerate into a gripe session

# Keep Improving

# Keep Improving

## Leverage Your Success

- Keep the **momentum** going!
- Never stop looking for processes to improve
- Always say **“We can do things better”**
- **Evaluate** your processes on a regular basis to keep them on track

# Numerical Control (NC)

- Numerical Control (NC) helps solve the problem of making Manufacturing Systems (MFG) more flexible

**"A Numerical Control machine is a machine positioned automatically along a pre-programmed path by means of coded instructions"**

- **Manual Part Programming**: Manual programming of the machines
- **Computer Aided Programming (CAP)**: Programming done by a computer
- **Manual Data Input (MDI)**: A manual program is entered into the machine's controller via its own keyboard

# Numerical Control (NC)

- Computer is used as the Control Unit (CU) of the modern Numerical Control machinery
- Computer replaced the Tape Reader found on earlier NC machines
- Program is loaded into and executed from the machine's computer

- Computer Numerical Control (CNC) machines are the NC machines of today

- **FOCUS on**: MDI programming of CNC machinery

# NUMERICAL CONTROL DEFINITION, ITS CONCEPTS AND ADVANTAGES

- Numerical control (NC) has been used in industry ***for more than 40 years***
- NC is a method of automatically operating a manufacturing machine based on a code ***of letters, numbers, and special characters***
- *A complete set of coded instructions for executing an operation is* ***called a program***
- The program is translated into corresponding ***electrical signals for input to motors that run the machine***
- Numerical controlled machines can be programmed manually
- If a computer is used to create a program, the process is known as ***computer-aided programming***
- The approach we take is in the form of ***Manual Programming***

# The History of NC

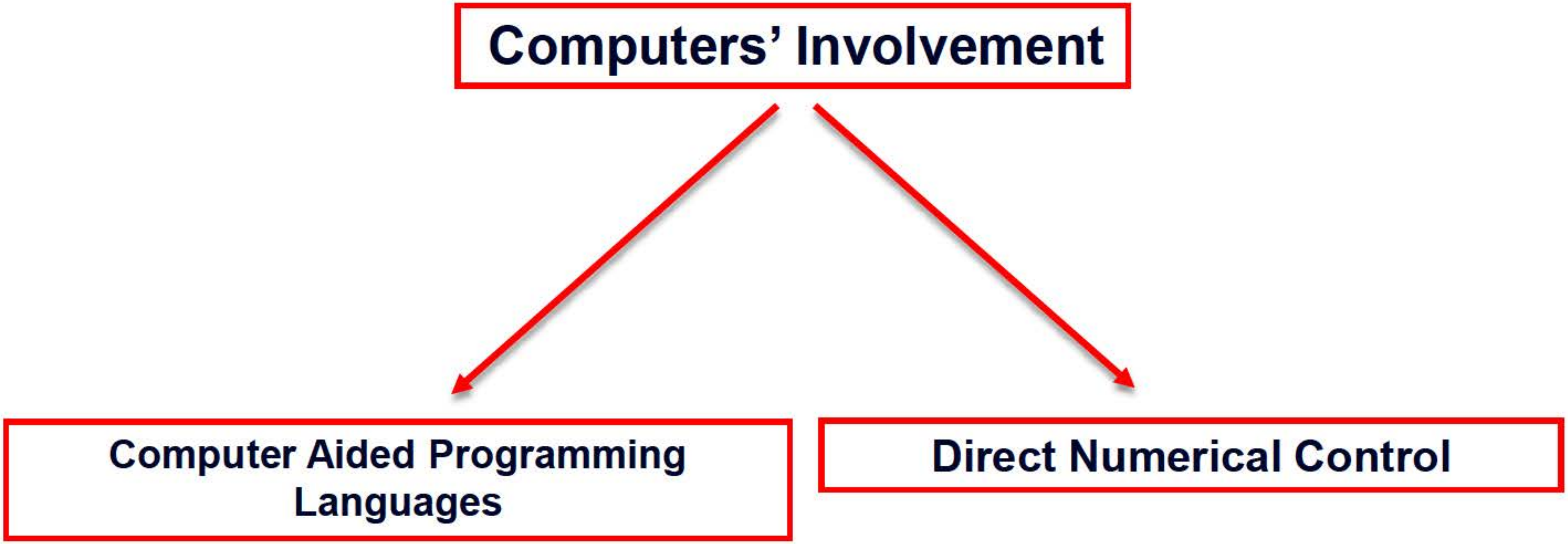
- **1947**: J. Parsons (Parsons Corporation) began experimenting for using 3-axis curvature data to control machine tool motion for the production of aircraft components
- **1949**: Parsons awarded a US Air Force contract to build the first NC machine
- **1951**: MIT was involved in the project
- **1952**: NC achieved when MIT demonstrated that simultaneous 3-axis movements were possible using a laboratory-build controller and a Cincinnati HYDROTEL vertical spindle
- **1955**: after refinements NC become available to industry
- **1959**: MIT announces Automatic Programmed Tools (APT) programming language

# The History of NC

- **1960:** Direct Numerical Control (DNC) - Eliminates paper tape punch programs and allows programmers to send files directly to machine tools
- **1968:** Kearney & Trecker machine tool builders market first machining center
- **1970's**: CNC machine tools & DNC
- **1980's**: Graphics based CAM systems introduced - Unix and PC based systems available
- **1990's**: Price drop in CNC technology
- **1997**: PC Windows/NT based "Open Modular Architecture Control (OMAC)" systems introduced to replace "firmware" controllers

# The History of NC

- Early NC machines run off punched cards and **tape**
- Due to the time and effort for editing and changing tapes **Computers** where introduced for programming



# The History of NC

## Computer Aided Programming Languages:

- Allow the development of an NC program using a set of universal "pidgin English" commands
- Computer translate commands into machine codes
- Machine codes are punched into the tapes

## Direct Numerical Control:

- A computer is used as a *partial or complete controller* of one or more NC machines

# The History of NC

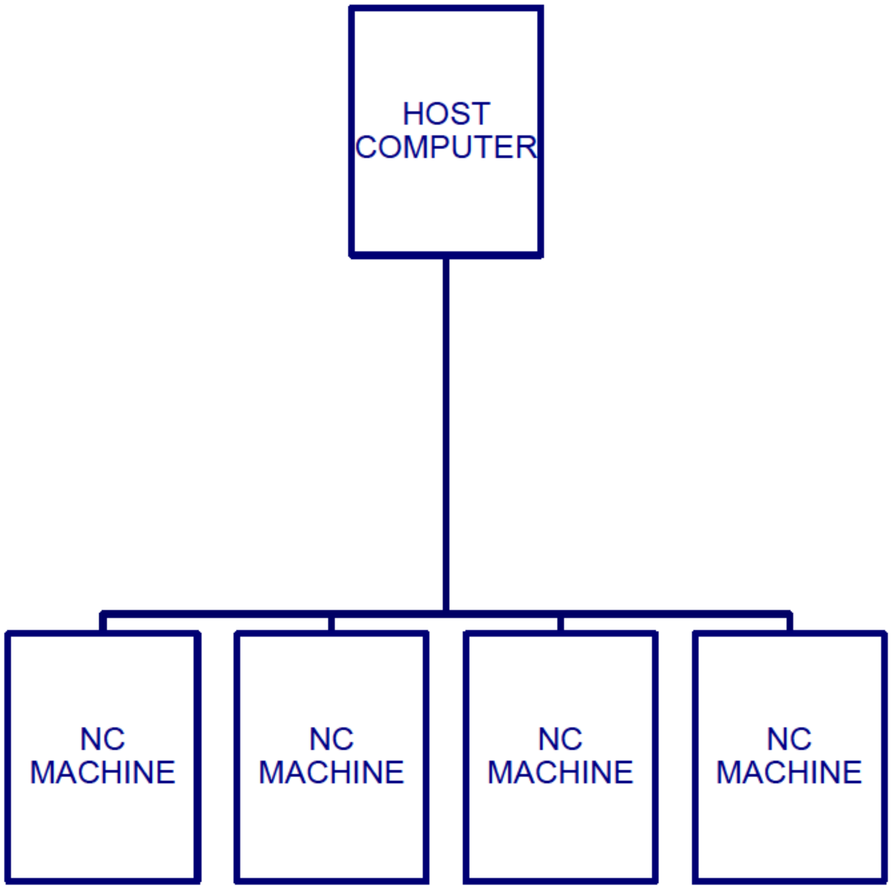



**FIGURE 1 Direct Numerical Control**

**Direct Numerical Control (DNC):**

- Expensive mainframe or mini-computers were required in the past
- Due to cost the use of DNC was limited to large companies
- Powerful PCs given rise to affordable PC-based DNC systems
- Most of PC-based DNC systems running on MS Windows OS

# The History of NC

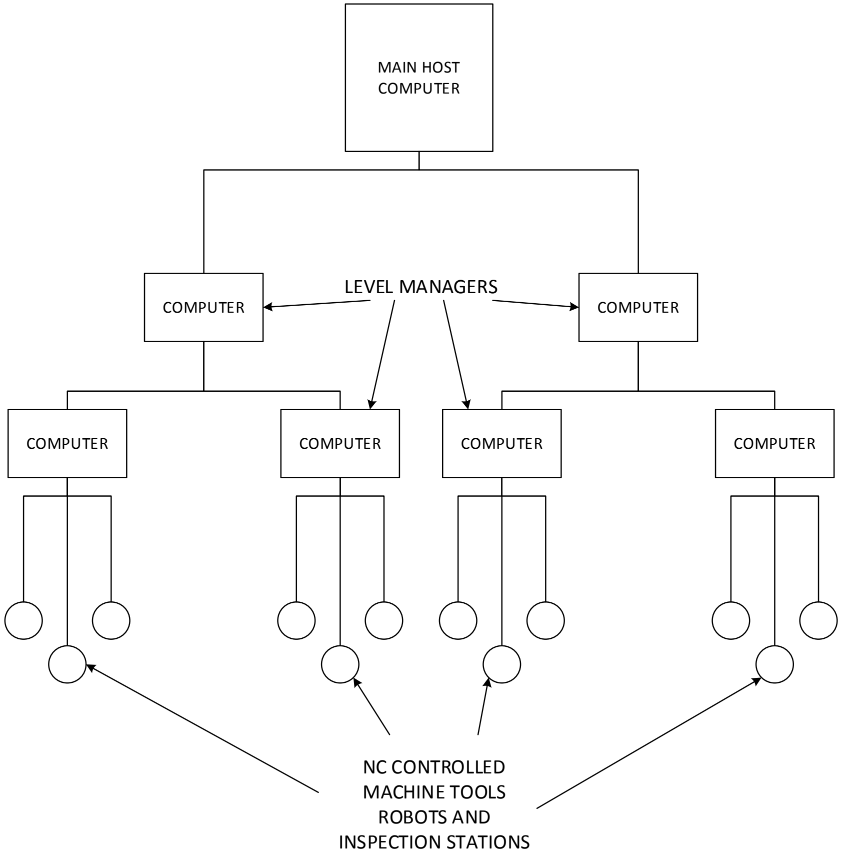



**FIGURE 2 Distributed Numerical Control**

**Distributed Numerical Control (DNC):**

- A network of computers is used to coordinate the operation of a number of CNC machines
- Ultimately an **entire factory** can be coordinated in this manner
- Alternative System 1: NC program is transferred in its entirety from a host computer directly to machines controller
- Alternative System 2: NC program is transferred from a mainframe or a host computer to a PC on the Shop Floor, stored and used when needed → transferred to machine controller

# Numerical control systems' components:

- ***Tape punch:*** converts written instructions into a corresponding hole pattern
- The hole pattern is punched into tape, which passes through this device

FIGURE 3 Five-hole and eight-hole punched [redacted]

[redacted]

## NUMERICAL CONTROL DEFINITION, ITS CONCEPTS AND ADVANTAGES

- Much older units used a **typewriter device** called a **Flexowriter**
- Later devices included a **microcomputer coupled with a tape punch unit**
- ***Tape reader:*** reads the hole pattern on the tape and converts the pattern to a corresponding electrical signal code
- ***Controller:*** receives the electrical signal code from the tape reader and subsequently causes the NC machine to respond
- **NC machine*:***
  - **responds to programmed signals** from the controller
  - Accordingly, **executes the required motions to manufacture a part** (spindle rotation on/off, table and or spindle movement along programmed axis directions, etc.)

# DEFINITION OF CNC AND ITS COMPONENTS

- A **computer numerical control** (**CNC**) machine is an NC machine with the **added feature of an on-board computer**
- The **on-board computer** is often referred to as the Machine Control Unit or **MCU**
- **Control units** for NC machines are usually **hard wired**. This means that all machine ***functions are controlled by the physical electronic elements*** that are built into the controller
- The on-board computer, on the other hand, **is "soft" wired**

# DEFINITION OF CNC AND ITS COMPONENTS

- Thus, the **machine functions are encoded into the computer** at the time of manufacture

- They **will not be erased** when the CNC machine is **turned off**. Computer memory that holds such information is known as **ROM** or read-only memory

- The **MCU** usually has an alphanumeric keyboard for **direct or manual data input** (**MDI**) of part programs. Such programs are stored in **RAM** or the random-access memory portion of the computer

# DEFINITION OF CNC AND ITS COMPONENTS

- They can be **played back**, **edited**, and **processed** by the control. All programs residing in **RAM**, however, **are lost** when the CNC machine is **turned off**

- These programs can be **saved on auxiliary storage devices** such as punched tape, magnetic tape, or magnetic disk

- Newer **MCU** units have **graphics screens that can display** not only the CNC program but the **cutter paths** generated and any errors in the program

# DEFINITION OF CNC AND ITS COMPONENTS

- **Machine control unit**
  - **generates**, **stores**, and **processes** CNC programs
  - also **contains the machine motion controller** in the form of an executive software program

**FIGURE 5 STEP-NC interface on a CNC**

- **NC machine**
  - **responds to programmed signals** from the machine control unit and manufactures the part

# CNC Machines

- A CNC machine has **more programmable features** than older NC tape machinery

- A CNC machine may be used as stand-alone unit in a network of machines – Flexible Machining Centers or Machining Cells

- CNC machines are **easier to program** by **more than one method:**

    - On board computer keyboard
    - Tape reader / electronic connector to transfer a program to CNC machine

# CNC Machines

## A CNC machine is a soft-wired controller

- Once the CNC program is **loaded** into the computer's memory **no HW is required to transfer the NC codes to the controller**

- The controller uses a **permanent resident program** – **EXECUTIVE PROGRAM** – to **process the codes into electrical pulses** to control the machine

- **EXECUTIVE Program** is called "**executive software**" or "**executive firmware**"
  - **EXECUTIVE program** resides in **ROM** (**R**ead **O**nly **M**emory)
  - NC code resides in **RAM** (**R**andom **A**ccess **M**emory)

**Firmware:** Routines of SW including low-level instructions stored in ROM only for reading

# CNC Machines

## ROM (Read Only Memory)

- Is an **electronic chip** which can be accessed by a computer but not altered (erased or written) without special equipment
- The **EXECUTIVE** program **can not be erased**
- The **EXECUTIVE** program **is always active** when machine is on

## RAM (Random Access Memory)

- **RAM** can be altered by the computer
- NC code is written into **RAM** by keyboard or other outside source
- The content of **RAM** is lost when the controller is turned off
    - **Battery backup system** is used for **saving the program in the event of power loss**
    - **CMOS** (**C**omplementary **M**etal–**O**xide–**S**emiconductor) memory special type of **RAM** which **retains the information content in the case of power loss**

# SPECIAL REQUIREMENTS FOR UTILIZING CNC

**Computer numerical control machines can dramatically boost productivity. The CNC manager, however, can only ensure such gains by first addressing several critical issues**

1. Sufficient **capital** must be **allocated for purchasing quality CNC equipment**
2. CNC equipment must be **maintained** on a regular basis. This can be accomplished by obtaining a full-service contract or by hiring an in-house technician
3. **Personnel** must be thoroughly **trained** in the setup and operation of CNC machines
4. Careful **production planning** must be studied. This is because the hourly cost of operating a CNC machine is usually higher than that for conventional machines

# FINANCIAL REWARDS OF CNC INVESTMENT

**Investors are encouraged to look to the CNC machine tool as a production solution with the following savings benefits**

1. **Savings** in **direct labor**
2. One CNC machine's output is **commonly equivalent** to several conventional machines
2. **Savings** in **operator training** expenses
3. **Savings** in **shop supervisory** costs
4. **Savings** due to tighter, more **predictable production scheduling**
5. **Savings** in real estate since fewer CNC machines are needed
6. **Savings** in **power consumption** since CNC machines produce parts with a minimum of motor idle time
7. **Savings** from **improved cost estimation** and **pricing**

# FINANCIAL REWARDS OF CNC INVESTMENT

8. **Savings** due to the **elimination of construction of precision jigs**, and the **reduced need for special fixtures**. Maintenance and storage costs of these items are also reduced

9. **Savings** in **tool engineering/design and documentation**. The CNC's machining capability eliminates the need for special form tools, special boring bars, special thread cutters, etc.

10. **Reduced inspection time** due to the CNC machine's **ability to produce parts with superior accuracy and repeatability**. In many cases, only spot checking of critical areas is necessary without loss of machine time

# FINANCIAL REWARDS OF CNC INVESTMENT

## *Using Payback Period to Estimate Investment Efficiency*

The **Payback Period calculation** **estimates the number of years required to recover the net cost of the CNC machine tool**

$$\text{Payback Period} = \frac{\text{Net cost of CNC} - \text{Net cost of CNC} \times \text{Tax Credit}}{\text{Savings} - \text{Savings} \times \text{Tax Rate} + \text{Yearly Depreciation of CNC} \times \text{Tax Rate}}$$

## *Using ROI to Estimate Investment Efficiency*

The **ROI calculation** predicts what **percent of the net cost of the CNC will be recovered each year**. The **ROI calculation** accounts for the useful life of the CNC machine tool

$$\text{ROI} = \frac{\text{Average Yearly Savings} - \text{Net cost of CNC/ Years of life}}{\text{Net cost of CNC}}$$

# EXAMPLE 1 -1

- Given the investment figures in Table 1-1 for implementing a new CNC machine tool, **determine the payback period** and the **annual return** on investment. The CNC is conservatively estimated to have a useful life of 12 years.

Table 1-1

| Initial Investment (€) | One-time savings in tooling (€) | Net Cost of CNC (€) | Average yearly savings (€) | Tax Credit (10%) | Tax Rate (46%) | Yearly depreciation of CNC (€) |
|---|---|---|---|---|---|---|
| 130.250 | 35.000 | 95.250 | 63.100 | 0.1 | 0.46 | 10.900 |

$$\text{Payback Period} = \frac{95{,}250 - 95{,}250 \times 0.1}{63{,}100 - 63{,}100 \times 0.46 + 10{,}900 \times 0.46}$$

Payback Period = 2.19 years

- This calculation estimates that the net cost of the CNC will be recovered in 2.19 years

$$\text{ROI} = \frac{63{,}100 - 95{,}250\ /12}{95{,}250}$$

ROI = .57

- This calculation estimates that the investor can expect **57%** of the net cost of the CNC or **(.57 x € 95,250) = € 54,293** to be recovered each year if the CNC machine's useful life is 12 years

# Input Media

## Input Media for the NC code into the Controller

- Are used to electronically or mechanically store the NC programs
- An NC program is read from the input medium when it is loaded into the machine
- Old NC machinery could **only read programs from punched tape** or DNC
- CNC machines may process **multiple means** of program input

## Punched Tape

- The oldest medium for program storage
- Made from **paper** or **Mylar plastic** (stronger than paper)
- The NC program code is **entered into the tape** by tape puncher in a **form of a series of holes** representing the NC codes
- A **tape reader** by electrical, optical or mechanical means ***senses the holes and transfers the coded information into the machine computer***
- The NC code is entered into **CAM** or Word Processor program and punched into tape

# Input Media

## Magnetic Tape

- Early experiments were not successful due to machine shop environment
- **High quality tapes of today can be used** with reasonable care in handling
- The most commonly used format is **¼ - inch computer cassette tape**
- Standards for tape format and coding have been developed by the Electronics Industries Association (EIA)

## Floppy Diskette

- Popularized by the use of PCs in NC programming
- The NC program is **transferred** into the CNC control by means of a **portable diskette drive** attached to the communication port of the CNC machine
- The most common used port is **RS232** (serial communication port)
- Floppy diskettes are **cheaper** than other program storage options

# Binary Numbers

**How controller processes information?**

- It is important in learning to program CNC machinery
- Computers and Computer- Controlled machinery **do not deal** in Arabic symbols or numbers
- All of the internal processing is done by calculating or comparing **binary** numbers
- **Binary** numbers contain only two digits: ZERO (0) and ONE (1)
- Within CNC controller:
    - Each **binary digit "1"** may represent a **"positive charge"** or
    - A **binary digit "0"** may represent a **"negative charge"** or
    - A **"1"** may be the **"ON"** or
    - A **"0"** may be the **"OFF"**
- The CNC program code in **binary** form must be loaded into the computer
- Programming formats and languages ***allow the NC code to be written using alphabetic characters*** / base-ten decimal numbers

# Binary Numbers

| ARABIC | BINARY | ARABIC | BINARY |
|---|---|---|---|
| 0 | 0 | 18 | 10010 |
| 1 | 1 | 19 | 10011 |
| 2 | 10 | 20 | 10100 |
| 3 | 11 | 21 | 10101 |
| 4 | 100 | 22 | 10110 |
| 5 | 101 | 23 | 10111 |
| 6 | 110 | 24 | 11000 |
| 7 | 111 | 25 | 11001 |
| 8 | 1000 | 26 | 11010 |
| 9 | 1001 | 27 | 11011 |
| 10 | 1010 | 28 | 11100 |
| 11 | 1011 | 29 | 11101 |
| 12 | 1100 | 30 | 11110 |
| 13 | 1101 | 31 | 11111 |
| 14 | 1110 | 32 | 100000 |
| 15 | 1111 | 64 | 1000000 |
| 16 | 10000 | 128 | 10000000 |
| 17 | 10001 | | |

**FIGURE 6 The Binary System**

- When the **NC program** is punched or recorded on tape or other storage media the information is **translated to binary form**

# Tape Formats

## General

- Toady **punched tape is not often used** for NC program storage
- Formats used in NC programming are still referred as **Tape Formats**
- Computer files containing the NC programs are referred as "**tape files**", "**punch files**" or "**tape image files**"
- Old machinery is still used in machine shops

## RS-274 Format

- Follows **E**lectronics **I**ndustries **A**ssociation (EIA) standard
- Program information is contained in program lines called "**Blocks**"
- "**Blocks**" are punched into the tape in one or two tape code standards
- **RS-274** is a "**variable block coding**" format
- The information contained in a block may be arranged in any order

# Tape Formats

## RS-244 Binary Coded Decimal (BCD)

- The **EIA RS-244** standard is one of the two tape codes used for NC tapes
- Became a standard early in the development of NC – limited punctuation
- Each **hole** represents the digit “**1**” while each **blank** the digit “**0**”
- The tape code allows alphabetic characters and base-ten numbers to be translated into the binary code the controller requires (**B**inary **C**oded **D**ecimal – BDC)

## RS-358 Format

- Government, telephone and Computer industries required tape code containing upper and lower case letters
- The existing tape coding formats were sufficient only for machining
- The standard accepted was **A**merican **S**tandard **C**ode for **I**nformation **I**nterchange (ASCII)
- **EIA RS-358** was adopted
- **EIA RS-358** is also as ISO and ASCII is a subset of the ASCII code used in other applications – Today is dominant over RS-244

# Objectives of Numerical Control

**Numerical control (NC) was developed with these goals in mind:**

- To **increase production**
- To **reduce labor costs**
- To make **production more economical**
- To do **jobs** that would be impossible or **impractical without NC**
- To **increase the accuracy** of duplicate parts

**Before deciding to utilize an NC or CNC machine for a particular job the requirements and economics must be weighted against the advantages and disadvantages of the machinery**

# Objectives of Numerical Control

## Disadvantages

- Increase in **electrical maintenance**
- High **initial investment**
- Higher per-hour **operating cost** than traditional machine tools
- **Retraining** of existing personnel

**NC is a general term used for Numerical Control. CNC refers specifically to COMPUTER NUMERICAL CONTROL. CNC machines are all NC machines but not all NC machines are CNC machines**

# Applications in Industry

- Originally developed for use in **Aerospace industries**
- Widespread in manufacturing:
  - Aerospace
  - Defence
  - Automotive
  - Electronic
  - Appliance
  - Tooling industries
- Advances in microelectronics have **lowered the cost** of acquiring CNC equipment
- ***Bending, Forming, Stamping and Inspection Machines*** have been produced as NC systems

# Machining Processes

# Grinding Wheels

- **Consist of:** abrasive grains, the binding material and air gaps

➢ **Abrasive Grains** perform cutting

➢ The **bond material retains grains** in place and determine the morphology and consistency of the wheel

- Grinding wheels **Parameters**

  ➢ Grain material
  ➢ Grain size
  ➢ Bond material
  ➢ Grade
  ➢ Structure

**FIGURE 7 Grinding Wheel**

# Grinding wheels-Grain material

- **Grains** : Small, non-metallic, hard, sharp edged particles of various geometries used for material removal

**Conventional materials**

i. Natural or artificial **corundum** ($Al_2O_3$)

the most common, non-metallic high strength

II. **Silicon carbide** (SiC)

harder but not strong enough for aluminum, copper, stainless steel, cast iron and aircraft materials

**Ultra-stiff materials**

I. **Cubic Boron Nitride** (CBN)

Very hard and very expensive. Used for hardened tool metals and aircraft alloys

ii. **Diamond**

Harder and more expensive. Both natural and artificial. For hard, friable materials such as ceramics, carbides and glass

# Grinding wheels - Grains

## Grains characteristics used for grinding wheels

- High degree of hardness
- Wear resistance
- Toughness
- Friability

## Grain size

- from 8 (coarsest) to 1200 (finest)
- The **fine-grained** wheels create **better surface quality**
- The **coarse-grained** wheels allow **larger material removal rate** (MRR)
- For hard materials grinding fine-grained wheels are more suitable
- For soft materials grinding coarse-grained wheels are used

# Grinding wheels binding material

- **Bond material**

  **Holds the grains together** until they clog and become detached

- **Requirements**

  - Withstand the centrifugal forces at high temperatures
  - Withstand unexpected loads
  - Firmly hold the grains

- **Bond types**

  - Vitrified bond
  - Silicate bond
  - Rubber bond
  - Resinoid bond
  - Shellac bond
  - Metal bond

# Selecting Grinding Wheel

- General rule:

**Soft wheels for hard materials and hard wheels for soft materials**

- Grinding wheel material:

| | | |
|---|---|---|
| **Cast Iron<br>Hard Cast Iron<br>Carbide<br>Brass<br>Soft Bronze<br>Light Metals<br>Pressed Materials** | **Ordinary Steels<br>Alloy Steels<br>High Speed Steel<br>Cast Steels<br>Cohesive Bronze** | **Sharpening tools<br>by high speed steel** |
| Silicon carbide grinding wheels | Corundum grinding wheels | Ceramic bonded corundum grinding wheels |

# Honing

- For **internal cylindrical surfaces** grinding, **Abrasive sticks** arranged circumferentially are pressed by springs from the inside out

# Summary 1/2

- An **NC** machine is a machine positioned **automatically** along a **preprogrammed** path by way of coded instructions

- **DNC** involves a computer that acts as a **partial or full controller** to one or more NC machines

- **Distributive NC** is a network of computers and NC machinery coordinated to perform some task

- **CNC machines** use an on-board computer as a controller

- **Offline programming** is the programming of a part away from the computer keyboard - usually done with a micro-computer.

# Summary 2/2

- There are four ways to input programs into CNC machinery:
  - **MDI** (Manual Data Input)
  - **Punched** Tape
  - **Magnetic** Tape
  - **DNC** (Direct Numerical Control / Distributive Numerical Control)

- The **CNC** program must be loaded into the controller in binary form

- **RS-244** and **RS-358** tape codes used to place information on punched tape information being punched into the tape in binary form

- Before deciding on a NC machine for a specific job, the **advantages and disadvantages of NC** must be **weighed** in view of the primary objectives of numerical control

# Vocabulary Introduced in this section

- ASCII
- Binary coded decimal (BCD)
- Computer Aided Programming (CAP)
- Computer Numerical Control (CNC)
- Direct Numerical Control (DNC)
- Distributive numerical control
- Input media
- Manual Data Input (MDI)
- Manual part programming
- Numerical control (NC)
- Random Access Memory (RAM)
- Read-only Memory (ROM)
- Word address format

# End of Section

# Funding


- This educational material has been developed in the teaching duties of the respective educator.
- The Project "**Open Academic Courses at the University of Patras**" has funded only the reformation of the educational material.
- The Project is implemented within the context of the Operational Programme "Education and Lifelong Learning" (EdLL) and is co-funded by the European Union (European Social Fund) and national resources.

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**Figure 4:** slide 50, CC BY-SA 3.0, https://en.wikipedia.org/wiki/Punched_tape#/media/File:Papertape2.jpg

**Figure 5:** slide 55, GNU/Wikimedia, https://en.wikipedia.org/wiki/STEP-NC#/media/File:STEP-NC_control_scania.jpg

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