LECTURE #4
Computers & related hardware in the factory floor

Computers in The Factory Floor

- Numerical control
- NC machines
- Computerized numerical control
- Direct numerical control
- Distributed numerical control
- Robot manipulators
- Robot programming
- Automatic Guided Vehicles
- Process control & PLC
Computers in The Factory Floor

dedicated to one type of function.

- Material removal (NC, CNC, DNC)
- Joining & Assembly (Robot manipulators)
- Materials Handling (AGV)
- Process Control (PLC)
- Automatic Inspection (CMM)
NC
Numerical Control

1950 - 1970
- Programs had to be walked to NC controls, generally on paper tape.
- NC controls had paper tape readers precisely for this purpose.
- Many companies were still punching programs on paper tape well into the 1980s, more than twenty-five years after its elimination in the computer industry.
1980 - 1990

- transferring NC programs between a host computer and the control.
- DNC offered machine tool links using rugged proprietary terminals and networks.
- The host software would be responsible for tracking and authorising NC program modifications.
- Depending on program size, for the first time operators had the opportunity to modify programs at the DNC terminal.
- No time was lost due to broken tapes, and if the software was correctly used, an operator running incorrect or out of date programs became a thing of the past.
- Older controls frequently had no port capable of receiving programs such as an RS232 / RS422 connector. In these cases, a device known as a Behind The Reader (BTR) card was used.

1990 - today

- Customers began migrating away from expensive minicomputer and workstation based CAD/CAM toward more cost-effective PC-based solutions.
- Users began to demand more from their DNC systems than secure upload/download and editing. However, the task can still be a challenge based on the CNC Control wiring requirements, parameters and NC program format.
- To remain competitive, therefore, DNC companies moved their offerings upmarket into DNC Networking, Shop Floor Control, Manufacturing Execution Systems.
- DNC systems aim to give operators at the machine an integrated view of all the information (both textual and graphical)
- DNC systems are frequently directly integrated with corporate CAD/CAM, ERP and Process Planning systems.
Movement axes of machines

- **2-axis motion**
  - along two axis simultaneously in a plane
  - Lathes, punch presses, flame, plasma and cloth cutting machines
  - electronic component insertion, drilling machines

- **3-axis motion (x,y,z)**
  - Generally along three principal directions simultaneously
  - Milling, boring, drilling, coordinate measuring machines

- **4-axis motion**
  - Involve three linear and one rotary axis or perhaps two x-y motions
  - E.g. some lathes fitted with supplementary milling heads

- **5-axis motion**
  - Involve three linear (x,y,z) with rotation about two axis (normally x & y)
  - Generally milling machines

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**Numerical Control ?**

- actions are controlled by the direct insertion of **numerical data** at some point.
- alphanumeric code called “Part Program”
- automatically interpret at least some portion of the data
Schematic illustration of NC

NC is a method of controlling the movements of machine tools (M/T) by directly inserting coded instructions in the form of numerical data (numbers and letters) into the system.

Types of NC Machines & Applications

Milling machines

Lathes (rotational parts)

Flame cutting & Plasma arc machine

EDM (complex cutting)

Laser cutting

Punches (plate, sheet metal)

NC insertion machine

Industrial robots
Operation of Traditional NC machines

- Contains no local intelligence
- Program fed (punched paper tape)
- Part programming is done remote
- Feeding into machine control unit – MCU
- MCU reads every single block of instruction and operation takes place

Applications

The early NC machine were simple drilling machines. NC machine centers are available in two configurations

- Milling, drilling on the top face & end milling of profiles
- Drilling, face & end milling of cuboid components

![Diagram showing NC machine configurations]
Applications

Turning of cylindrical components can be achieved using NC lathes.

NC Machining Centres

Machining centres typically include:

- automatic tool changer
- automatic work part positioning
- pallet shuttle
- multiple spindles
Program of Instructions

Step-by-step instructions telling the machine what to do

Instructions are contained on a medium

- punched tape
- magnetic tape
- punched cards
- 35-mm motion picture camera
**Punched card** (Hollerith card / IBM Card)

- Used in unit record machines
- Primary medium for input
- Off-line data entry

- Piece of stiff paper
- Contains digital information
- Presence / absence of holes

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**Magnetic Tape**

- Used for **data storage** for over 50 years.
- Packaged in cartridges and cassettes.

- Storing large amounts of data,
- Less expensive than disk or other data storage options.
- Been used with large computer systems.

Sun StorageTek T10000B 1TB
The MCU is made up of a Data Processing Unit (DPU) and a Control-Loops Unit (CLU).

Basics of motion control

- The actuator = servo-motor
- The control system = closed loop feedback
- Feedback provider = encoder

Two types of encoder configurations
Control of NC Machines

servo-controlled motors (the most common motor)

Encoder ~ Table Leadscrew A/C Motor

Servo Controller

Counter Comparator

input (converted from analog to digital value)

cnc

Computerized Numerical Control
Computerized Numerical Control

First appearance was in the 1970s.

CNC machines are computer based and can be stored the program in the internal memory and executed from there.

Each machine with its own computer.

Configuration of CNC System

CNC uses programmed instructions to drive the machine tool.
**Advantages of CNC System**

- Reduces time for delivery of part
- Reduces scrap rate of material
- Reduces tooling costs
- Reduces layout time
- Increases machine and tool life
- Reduces storage problems
- Less setup time
- Reduces actual machining time
- Allows rapid design changes in part
- Less jigs and fixtures are needed

**Advantages of CNC**

- Easier to program;
- Easy storage of existing programs;
- Easy to change a program
- Avoids human errors
- Safer to operate
- Complex geometry is produced as cheaply as simple ones
- Usually generates closer tolerances than manual machines
Types of CNC Machines

Based on Motion Type:
Point-to-Point or Continuous path

Based on Control Loops:
Open loop or Closed loop

Based on Power Supply:
Electric or Hydraulic or Pneumatic

Based on Positioning System
Incremental or Absolute

Basic CNC Principles

- Using a vertical mill machining center as an example, there are typically three linear axes of motion.
- Each is given an alphabetic designation or address.
- The machine table motion side to side is called the “X” axis.
- Table movement in and out is the “Y” axis, while head movement up and down the column is the “Z” axis.
Basic CNC Principles
-Coordinate Systems-

Servo mechanism

Servo drivers are:
- Tolerant to tool cutting forces
- Insensitive to load mass inertias (stiffness)
- Insensitive to running friction forces
- Linear to a high degree
Basic CNC Principles

All computer controlled machines are able to accurately and repeatedly control motion in various directions. Each of these directions of motion is called an axis. Depending on the machine type there are commonly two to five axes.

Additionally, a CNC axis may be either a linear axis in which movement is in a straight line, or a rotary axis with motion following a circular path.

Basic CNC Principles

If a rotary table is added to the machine table, then the fourth axis is designated the “b” axis.
How CNC Works

• Controlled by G and M codes.
• These are number values and co-ordinates.
• Each number or code is assigned to a particular operation.
• Typed in manually to CAD by machine operators.
• G&M codes are automatically generated by the computer software.

Features of CNC Machinery

• The tool or material moves.
• Tools can operate in 1-5 axes.
• Larger machines have a machine control unit (MCU) which manages operations.
• Movement is controlled by a motors (actuators).
• Feedback is provided by sensors (transducers)
• Tool magazines are used to change tools automatically.
Tools

- Most are made from high speed steel (HSS), tungsten carbide or ceramics.
- Tools are designed to direct waste away from the material.
- Some tools need coolant such as oil to protect the tool and work.

CNC machine block diagram

- Magnetic tape or Disk
- Paper tape punch
- Limit switches, coolant, spindle
- CNC controller with keypad and display
- Machine tool
- Axis drive x,y,z,a,b,w spindle speed
- User interface
Controller

ROM: contains the firmware and control of the machine tool
RAM: is the internal memory into which the part programs are stored.
Controller: provides a single to the motor driving the table.
DAC: digital to analogue convertor (convert the rotary motion of the motor into the desired linear motion)

Operator’s console

Power Amp
Motor
Table/slide
Speed/position measure
Feedback of speed & position

DNC
Direct Numerical Control
Direct Numeric Control (DNC)

Is a method where a single computer controls many numerical control machine tools.

These machine tools may or may not be of a similar nature.

Common manufacturing term for networking CNC machine tools.
DNC
Distributed Numerical Control

DNC changed its form when CNC technology arrived in 1970’s.

While all the machines are connected to a central Server (Main Computer), individual computers are attached to each machine.
Advantages of Modern DNC

- Design changes are immediate
- NC programs may be edited immediately
- Used to support FMS
- Increase efficiency of individual machine
- Simplifies GT, CAPP and other CIM concepts
- More shop efficiency than stand alone machines

Distributed Numerical Control

DNC defines a means of central storage and distribution of CNC part programs rather than central control of the machines.

CIM host database of preprocessed part program

Local area network (LAN)

CNC controller

CNC controller

CNC controller

CNC controller

Place in CIM
Distributed Numerical Control

Central Computer

Communication Lines

Bulk Storage Media
For NC Programs

NC PART PROGRAMMING
NC Part Programming

Writing instructions for the machine parts movements and tool position control.

It specifies the sequence of processing steps on a numerical control machine.

Methods

1. Manual Part Programming
2. Computer Assisted
3. Manual Data Input
4. NC Programming using CAD/CAM
5. Computer – automated Part Programming
Manual Part Programming

- The programmer prepares the NC code using the low-level machine language \( (G-M \text{ Codes}) \).
- It can be used for both point-to-point and contouring jobs.
- It is most suited for point-to-point machining operations such as drilling.
- It can also be used for simple contouring jobs, such as milling and turning when only two axes are involved.

NC Part Programming

- Contains all geometric, dimensional and material specifications
- Generate tool path for machining
- Tool Path Libraries
- Dynamic manufacturing databases
- Standard Libraries
Common tool path libraries

- Profile milling
- Milling a pocket
- Surface contouring
- Point-to-operations

Optimization of cutting parameters

- Tool path
- Depth of cut vs number of passes
- Spindle speed vs feed
- Material removal rate (MRR)
- Cutting Efficiency vs Economy
- Tool Life
Robot Manipulators

Robota (Czechoslovakian word) means servitude or forced worker.

The most common devices used for handling components materials in automatic manufacturing processes.
Robotics Timeline

- 1922 Czech author Karel Capek wrote a story called Rossum’s Universal Robots and introduced the word “Rabota” (meaning worker)
- 1954 George Devol developed the first programmable Robot.
- 1955 Denavit and Hartenberg developed the homogenous transformation matrices
- 1962 Unimation was formed, first industrial Robots appeared.
- 1973 Cincinnati Milacron introduced the T3 model robot, which became very popular in industry.
- 1990 Cincinnati Milacron was acquired by ABB

Robot Classification

The following is the classification of Robots according to the Robotics Institute of America

- **Variable-Sequence Robot**: A device that performs the successive stages of a task according to a predetermined method easy to modify
- **Playback Robot**: A human operator performs the task manually by leading the Robot
- **Numerical Control Robot**: The operator supplies the movement program rather than teaching it the task manually.
- **Intelligent Robot**: A robot with the means to understand its environment and the ability to successfully complete a task despite changes to the environment.
Current Robot application areas

Automatic assembly
Assembly accounts for approximately 33% of the applications of the world robot stock

Picking materials

Component feeders

Welding (with torch)
Nearly 25% of all industrial robots are used in different welding applications

Adhesive joining (with gun)

Painting (with spray)
Types of robot configurations

- Cartesian Robot
- Cylindrical Robot
- SCARA Robot
- Polar Robot
Robot Components

the mechanical unit,
   (mechanical linkage and joints,
    guides, actuators (linear or rotary),
    control valves, and sensors)

power source,
   (pneumatic, hydraulic, or electrical)

Controller,
   (measures the position of the end
    effector using trigonometrical
    functions. The controller’s task to
    perform real-time control is
demanding)
tooling

Robot Programming

• Typically performed using one of the following
  • On line
    • teach pendant
    • lead through programming
  • Off line
    • robot programming languages
    • task level programming
Three methods of programming are carried out:

- Taught path programming
- Languages (VAL, VAL II)
- CADCAM
Robot Programming

Taught Path Programming (Leadthrough)
It involves physically moving the robot to position the end-effector and recording the position in memory.
The robot makes simple point-to-point movements.

Robot Programming

Robot controller language
It is similar manner to computer languages.
VAL combines taught path programming with a written or textual language control.
(straight line interpolation)
VAL II includes many enhancements over 1st generation.
(sensor control, better input/output facilities)
Variable Assembly Language

VAL is a computer-based control system and language design for industrial robots.

VAL language is clear, concise and generally self-explanatory instruction set.

**VAL I Generation**
- Adoptable mainly for Unimation Robots
- Designed with simple syntax
- It is capable of illustrating the robot functions very easily

Variable Assembly Language

Information regarding the operating system environment and the multiprocessor architecture (LSI-11) under which VAL II is implemented should be developed in the laboratory.

There are two frames used: (1) the world frame, and the (2) tool frame.

**VAL II Generation**
- Motion control
- Advanced sensor capabilities
- Limited intelligence
- Communication and data processing
Robot Programming

CADCAM
CADCAM systems for robots have been devised where the programmer designs a computer model of the robot. Software uses interactive graphics and the model can be animated on the screen. It generates the robot program in its own language.

II Generation Languages

AML - A manufacturing language

RAIL – high level robot language based on PASCAL

MCL – controlling two major tasks such as the manipulation and vision system
AGV
Automated Guided Vehicle

Automated Guided Vehicles

It is used to provide automated means of transporting materials and components from stores to other processes.

It is a driverless vehicle programmed to convey materials or work progress through a predefined route.

1st AGV system appeared in 1958.
The Control of AGV

Passive methods: optical tracking
  (reflective tape)
Active methods: guidwires, dead reckoning
  infra-red beams, gyroscope,
  pattern recognition
  (on-board vision system)

It is concerned with the whole AGV system which incorporates all AGVs.
It is a part of the CIM facility for the factory.
Continuous communication is possible with inductive techniques (guidewire, radio transmitter)

PLC
Programmable Logic Control
Programmable Logic Controllers (PLC)

The design and operation of assembly systems were based on the use of logic and electrically operated systems were designed using ladder logic. PLCs are used in areas where sequencing / coordinating the activities of several machines working together.

Programmable Logic Controllers (PLC)

It was first conceived in 1968. The principle of the PLC was initially to enable the same logic definition methods to be used. PLCs have been design such that their means of programming is identical to the design tools used for hard-wired logic.
The PLC processes the inputs and switches the outputs according to the control program in a cyclic fashion.

This cycle is known as a *scan* and it is the parameter known as the *scan time* (the period of time taken to read all the inputs).

Inputs and outputs from PLC vary in voltage levels.

**TTL**: transistor-transistor logic

**PIA**: peripheral interface adaptor

**Conversion**
Programming PLCs

Programming a PLC is relatively simple - many of today’s PLC programming software is icon driven - meaning you drag and drop graphical pictures of the switches and sensors and put them in a flow chart type of organization.

**Ladder logic** is the most commonly used programming language for PLCs and used a concept of switches as inputs set high / low sensors.  
*(Grafceet program)*