Lecture 1

Introduction of Automation

Automation has a variety of applications in manufacturing such as products and systems in the area of ‘manufacturing automation’. Some of these applications are as follows:

1. Computer numerical control (CNC) machines
2. Tool monitoring systems
3. Advanced manufacturing systems
   - Flexible manufacturing system (FMS)
   - Computer integrated manufacturing (CIM)
4. Industrial robots
5. Automatic inspection systems: machine vision systems
6. Automatic packaging systems

Computer numerical control (CNC) machines

CNC machine is the best and basic example of application of Mechatronics in manufacturing automation. Efficient operation of conventional machine tools such as Lathes, milling machines, drilling machine is dependent on operator skill and training. Also a lot of time is consumed in workpart setting, tool setting and controlling the process parameters viz. feed, speed, depth of cut. Thus conventional machining is slow and expensive to meet the challenges of frequently changing product/part shape and size.
Computer numerical control (CNC) machines are now widely used in small to large scale industries. CNC machine tools are integral part of Computer Aided Manufacturing (CAM) or Computer Integrated Manufacturing (CIM) system. CNC means operating a machine tool by a series of coded instructions consisting of numbers, letters of the alphabets, and symbols which the machine control unit (MCU) can understand. These instructions are converted into electrical pulses of current which the machine's motors and controls follow to carry out machining operations on a workpiece. Numbers, letters, and symbols are the coded instructions which refer to specific distances, positions, functions or motions which the machine tool can understand.

CNC automatically guides the axial movements of machine tools with the help of computers. The auxiliary operations such as coolant on-off, tool change, door open-close are automated with the help of micro-controllers. Modern machine tools are now equipped with friction-less drives such as re-circulating ball screw drives, Linear motors etc. The detail study of various elements of such a Mechatronics based system is the primary aim of this course and these are described at length in the next modules.

**Tool monitoring systems**

Uninterrupted machining is one of the challenges in front manufacturers to meet the production goals and customer satisfaction in terms of product quality. Tool wear is a critical factor which affects the productivity of a machining operation. Complete automation of a machining process realizes when there is a successful prediction of tool (wear) state during the course of machining operation. Mechatronics based cutting tool-wear condition monitoring system is an integral part of automated tool rooms and unmanned factories. These systems predict the tool wear and give alarms to the system operator to prevent any damage to the machine tool and workpiece. Therefore it is essential to know how the mechatronics is helping in monitoring the tool wear. Tool wear can be observed in a variety of ways. These can be classified in two groups (Table 1.2).

<table>
<thead>
<tr>
<th>Direct methods</th>
<th>Indirect methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical resistance</td>
<td>Torque and power</td>
</tr>
<tr>
<td>Optical measurements</td>
<td>Temperature</td>
</tr>
<tr>
<td>Machining hours</td>
<td>Vibration &amp; acoustic emission</td>
</tr>
<tr>
<td>Contact sensing</td>
<td>Cutting forces &amp; strain measurements</td>
</tr>
</tbody>
</table>

Direct methods deal with the application of various sensing and measurement instruments such as micro-scope, machine/camera vision; radioactive techniques to measure the tool wear. The used or worn-out cutting tools will be taken to the metrology or inspection section of the tool room or shop floor where they will be examined by using one of direct methods. Therefore they are called as offline tool monitoring system. A schematic of tool edge grinding or replacement scheme based on the measurement carried out using offline tool monitoring system.
Flexible Manufacturing System

Nowadays customers are demanding a wide variety of products. To satisfy this demand, the manufacturers’ “production” concept has moved away from “mass” to small “batch” type of production. Batch production offers more flexibility in product manufacturing. To cater this need, Flexible Manufacturing Systems (FMS) have been evolved.

FMS combines microelectronics and mechanical engineering to bring the economies of the scale to batch work. A central online computer controls the machine tools, other work stations, and the transfer of components and tooling. The computer also provides monitoring and information control. This combination of flexibility and overall control makes possible the production of a wide range of products in small numbers.
Lecture 2

Flexible Manufacturing Systems

FMS is a manufacturing cell or system consisting of one or more CNC machines, connected by automated material handling system, pick-and-place robots and all operated under the control of a central computer. It also has auxiliary sub-systems like component load/unload station, automatic tool handling system, tool pre-setter, component measuring station, wash station etc. Figure 2.1 shows a typical arrangement of FMS system and its constituents. Each of these will have further elements depending upon the requirement as given below,

A. Workstations
   - CNC machine tools
   - Assembly equipment
   - Measuring Equipment

B. Material handling Equipment
   - Load unload stations (Palletizing)
     - Robotics
     - Automated Guided Vehicles (AGVs)
     - Automated Storage and retrieval Systems (AS/RS)

C. Tool systems
   - Tool setting stations
     • Tool transport systems

D. Control system
   - Monitoring equipments
     - Networks

It can be noticed that the FMS is shown with two machining centers viz. milling center and turning center. Besides it has the load/unload stations, AS/RS for part and raw material storage, and a wire guided AGV for transporting the parts between various elements of the FMS. This system is fully automatic means it has automatic tool changing (ATC) and automatic pallet changing (APC) facilities. The central computer controls the overall operation and coordination amongst the various constituents of the FMS system.

Figure 2.1 A FMS Setup
The characteristic features of an FMS system are as follows:

1. FMS solves the mid-variety and mid-volume production problems for which neither the high production rate transfer lines nor the highly flexible stand-alone CNC machines are suitable.
2. Several types of a defined mix can be processed simultaneously.
3. Tool change-over time is negligible.
4. Part handling from machine to machine is easier and faster due to employment of computer controlled material handling system.

Benefits of an FMS
- Flexibility to change part variety
- Higher productivity
- Higher machine utilization
- Less rejections
- High product quality
- Reduced work-in-process and inventory
- Better control over production
- Just-in-time manufacturing
- Minimally manned operation
- Easier to expand

Computer Integrated Manufacturing (CIM)

A number of activities and operations viz. designing, analyzing, testing, manufacturing, packaging, quality control, etc. are involved in the life cycle of a product or a system. Application of principles of automation to each of these activities enhances the productivity only at the individual level. These are termed as ‘islands of automation’. Integrating all these islands of automation into a single system enhances the overall productivity. Such a system is called as “Computer Integrated Manufacturing (CIM)”.

The Society of Manufacturing Engineers (SME) defined CIM as ‘CIM is the integration of the total manufacturing enterprise through the use of integrated systems and data communications coupled with new managerial philosophies that improve organizational and personal efficiency’.

CIM basically involves the integration of advanced technologies such as computer aided design (CAD), computer aided manufacturing (CAM), computer numerical control (CNC), robots, automated material handling systems, etc. Today CIM has moved a step ahead by including and integrating the business improvement activities such as customer satisfaction, total quality and continuous improvement. These activities are now managed by computers. Business and marketing teams continuously feed the customer feedback to the design and production teams by using the networking systems. Based on the customer requirements, design and manufacturing teams can immediately improve the existing product design or can develop an entirely new product. Thus, the use of computers and automation technologies made the manufacturing industry capable to provide rapid response to the changing needs of customers.
Industrial robots are general-purpose, re-programmable machines which respond to the sensory signals received from the system environment. Based on these signals, robots carry out programmed work or activity. They also take simple independent decisions and communicate/interact with the other machines and the central computer. Robots are widely employed in the following applications in manufacturing:

A. Parts handling: it involves various activities such as:
   - Recognizing, sorting/separating the parts
   - Picking and placing parts at desired locations
   - Palletizing and de-palletizing
   - Loading and unloading of the parts on required machines

B. Parts processing: this may involves many manufacturing operations such as:
   - Routing
   - Drilling
   - Riveting
   - Arc welding
   - Grinding
   - Flame cutting
   - Deburring
   - Spray painting
   - Coating
   - Sand blasting
   - Dip coating
   - Gluing
   - Polishing
   - Heat treatment

C. Product building: this involves development and building of various products such as:
   - Electrical motors
   - Car bodies
   - Solenoids
   - Circuit boards and operations like
     - Bolting
     - Riveting
     - Spot welding
     - Seam welding
     - Inserting
     - Nailing
     - Fitting
     - Adhesive bonding
     - Inspection
Further detail discussion on various aspects of industrial robots such as its configuration, building blocks, sensors, and languages has been carried out in the last module of this course.

**Automatic quality control and inspection systems**

Supply of a good quality product or a system to the market is the basic aim of the manufacturing industry. The product should satisfy the needs of the customers and it must be reliable. To achieve this important product-parameter during a short lead time is really a challenge to the manufacturing industry. This can be achieved by building up the ‘quality’ right from the product design stage; and maintaining the standards during the ‘production stages’ till the product-delivery to the market.

A number of sensors and systems have been developed that can monitor quality continuously with or without the assistance of the operator. These technologies include various sensors and data acquisition systems, machine vision systems, metrology instruments such as co-ordinate measuring machine (CMM), optical profilometers, digital calipers and screw gauges etc. Now days the quality control activities are being carried out right from the design stage of product development. Various physics based simulation software is used to predict the performance of the product or the system to be developed. In the manufacture of products such as spacecrafts or airplanes, all the components are being critically monitored by using the digital imaging systems throughout their development.
Lecture 4

Robot Control Systems

To perform as per the program instructions, the joint movements of an industrial robot must accurately be controlled. Micro-processor-based controllers are used to control the robots. Different types of control that are being used in robotics are given as follows.

(a) **Limited Sequence Control**
   It is an elementary control type. It is used for simple motion cycles, such as pick-and-place operations. It is implemented by fixing limits or mechanical stops for each joint and sequencing the movement of joints to accomplish operation. Feedback loops may be used to inform the controller that the action has been performed, so that the program can move to the next step. Precision of such control system is less. It is generally used in pneumatically driven robots.

(b) **Playback with Point-to-Point Control**
   Playback control uses a controller with memory to record motion sequences in a work cycle, as well as associated locations and other parameters, and then plays back the work cycle during program execution. Point-to-point control means individual robot positions are recorded in the memory. These positions include both mechanical stops for each joint, and the set of values that represent locations in the range of each joint. Feedback control is used to confirm that the individual joints achieve the specified locations in the program.

(c) **Playback with Continuous Path Control**
   Continuous path control refers to a control system capable of continuous simultaneous control of two or more axes. The following advantages are noted with this type of playback control: greater storage capacity—the number of locations that can be stored is greater than in point-to-point; and interpolation calculations may be used, especially linear and circular interpolations.

(d) **Intelligent Control**
   An intelligent robot exhibits behavior that makes it seem to be intelligent. For example, it may have capacity to interact with its ambient surroundings; decision-making capability; ability to communicate with humans; ability to carry out computational analysis during the work cycle; and responsiveness to advanced sensor inputs. They may also possess the playback facilities. However it requires a high level of computer control, and an advanced programming language to input the decision-making logic and other ‘intelligence’ into the memory.

**End Effectors**

An end effector is usually attached to the robot’s wrist, and it allows the robot to accomplish a specific task. This means that end effectors are generally custom-engineered and fabricated for each different operation. There are two general categories of end effectors viz. grippers and tools.

Grippers grasp and manipulate the objects during the work cycle. Typically objects that grasped are the work parts which need to be loaded or unloaded from one station to another. Grippers may be custom-designed to suit the physical specifications of work parts. Various end-effectors, grippers are summarized in Table 7.6.1.
<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical gripper</td>
<td>Two or more fingers which are actuated by robot controller to open and close on a workpart.</td>
</tr>
<tr>
<td>Vacuum gripper</td>
<td>Suction cups are used to hold flat objects.</td>
</tr>
<tr>
<td>Magnetized devices</td>
<td>Based on the principle of magnetism. These are used for holding ferrous workparts.</td>
</tr>
<tr>
<td>Adhesive devices</td>
<td>By deploying adhesive substances, these are used to hold flexible materials, such as fabric.</td>
</tr>
<tr>
<td>Simple mechanical</td>
<td>Hooks and scoops.</td>
</tr>
<tr>
<td>devices</td>
<td></td>
</tr>
<tr>
<td>Dual grippers</td>
<td>It is a mechanical gripper with two gripping devices in one end-effector. It is used for machine loading and unloading. It reduces cycle time per part by gripping two workparts at the same time.</td>
</tr>
<tr>
<td>Interchangeable</td>
<td>Mechanical gripper with an arrangement to have modular fingers to accommodate different sizes workpart.</td>
</tr>
<tr>
<td>fingers</td>
<td></td>
</tr>
<tr>
<td>Sensory feedback</td>
<td>Mechanical gripper with sensory feedback capabilities in the fingers to aid locating the workpart; and to determine correct grip force to apply (for fragile workparts).</td>
</tr>
<tr>
<td>fingers</td>
<td></td>
</tr>
<tr>
<td>Multiple fingered</td>
<td>Mechanical gripper as per the general anatomy of human hand.</td>
</tr>
<tr>
<td>grippers</td>
<td></td>
</tr>
<tr>
<td>Standard grippers</td>
<td>Mechanical grippers that are commercially available, thus reducing the need to custom-design a gripper for separate robot applications.</td>
</tr>
</tbody>
</table>

The robot end effector may also use tools. Tools are used to perform processing operations on the workpart. Typically the robot uses the tool relative to a stationary or slowly-moving object. For example, spot welding, arc welding, and spray painting robots use a tool for processing the respective operation. Tools also can be mounted at robotic manipulator spindle to carry out machining work such as drilling, routing, grinding, etc.
**Sensors in Robotics**

There are generally two categories of sensors used in robotics. These are sensors for internal purposes and for external purposes. Internal sensors are used to monitor and control the various joints of the robot. They form a feedback control loop with the robot controller. Examples of internal sensors include potentiometers and optical encoders, while tachometers of various types are deployed to control the speed of the robot arm.

External sensors are external to the robot itself, and are used when we wish to control the operations of the robot. External sensors are simple devices, such as limit switches that determine whether a part has been positioned properly, or whether a part is ready to be picked up from an unloading bay.

Various sensors used in robotics are outlined in Table 4.2.

<table>
<thead>
<tr>
<th>Sensor Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tactile sensors</td>
<td>Used to determine whether contact is made between sensor and another object</td>
</tr>
<tr>
<td></td>
<td>Touch sensors: indicates the contact</td>
</tr>
<tr>
<td></td>
<td>Force sensors: indicates the magnitude of force with the object</td>
</tr>
<tr>
<td>Proximity sensors</td>
<td>Used to determine how close an object is to the sensor. Also called a range sensor.</td>
</tr>
<tr>
<td>Optical sensors</td>
<td>Photocells and other photometric devices that are used to detect the presence or absence of objects. Often used in conjunction with proximity sensors.</td>
</tr>
<tr>
<td>Machine vision</td>
<td>Used in robotics for inspection, parts identification, guidance, etc.</td>
</tr>
<tr>
<td>Others</td>
<td>Measurement of temperature, fluid pressure, fluid flow, electrical voltage, current, and other physical properties.</td>
</tr>
</tbody>
</table>
Figure shows a diagram which depicts an overview of applications of robots in manufacturing. The general characteristics of industrial work situations that tend to promote the substitution of robots for human labor.

Table 5.1: Characteristics of situations where robots may substitute for humans

<table>
<thead>
<tr>
<th>Situation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazardous work environment for humans</td>
<td>In situations where the work environment is unsafe, unhealthy, uncomfortable, or otherwise unpleasant for humans, robot application may be considered.</td>
</tr>
<tr>
<td>Repetitive work cycle</td>
<td>If the sequence of elements in the work cycle is the same, and the elements consist of relatively simple motions, robots usually perform the work with greater consistency and repeatability than humans.</td>
</tr>
<tr>
<td>Difficult handling for humans</td>
<td>If the task requires the use of heavy or difficult-to-handle parts or tools for humans, robots may be able to perform the operation more efficiently.</td>
</tr>
<tr>
<td>Multi-shift operation</td>
<td>A robot can replace two or three workers at a time in second or third shifts, thus they can provide a faster financial payback.</td>
</tr>
<tr>
<td>Infrequent changeovers</td>
<td>Robots’ use is justified for long production runs where there are infrequent changeovers, as opposed to batch or job shop production where changeovers are more frequent.</td>
</tr>
<tr>
<td>Part position and orientation are</td>
<td>Robots generally don’t have vision capabilities, which means parts must be precisely placed and oriented for</td>
</tr>
</tbody>
</table>
established in the work cell successful robotic operations.

Material Handling Applications

Robots are mainly used in three types of applications: material handling; processing operations; and assembly and inspection. In material handling, robots move parts between various locations by means of a gripper type end effector. Material handling activity can be subdivided into material transfer and machine loading and/or unloading. These are described in Table 7.6.4.

Table 5.2: Material handling applications

<table>
<thead>
<tr>
<th>Application</th>
<th>Description</th>
</tr>
</thead>
</table>
| Material transfer            | • Main purpose is to pick up parts at one location and place them at a new location. Part re-orientation may be accomplished during the transfer. The most basic application is a pick-and-place procedure, by a low-technology robot (often pneumatic), using only up to 4 joints.  
• More complex is palletizing, where robots retrieve objects from one location, and deposit them on a pallet in a specific area of the pallet, thus the deposit location is slightly different for each object transferred. The robot must be able to compute the correct deposit location via powered lead-through method, or by dimensional analysis.  
• Other applications of material transfer include depalletizing, stacking, and insertion operations. |
| Machine loading and/or unloading | • Primary aim is to transfer parts into or out-of a production machine.  
• There are three classes to consider:  
  o machine loading—which the robot loads the machine  
  o machine unloading—which the robot unloads the machine  
  o machine loading and unloading—which the robot performs both actions  
• Used in die casting, plastic molding, metal machining operations, forging, press-working, and heat treating operations. |
Processing Operations

In processing operations, the robot performs some processing activities such as grinding, milling, etc. on the workpart. The end effector is equipped with the specialized tool required for the respective process. The tool is moved relative to the surface of the workpart. Table 5.3 outlines the examples of various processing operations that deploy robots.

<table>
<thead>
<tr>
<th>Process</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spot Welding</td>
<td>Metal joining process in which two sheet metal parts are fused together at localized points of contact by the deployment of two electrodes that squeeze the metal together and apply an electric current. The electrodes constitute the spot welding gun, which is the end effector tool of the welding robot.</td>
</tr>
<tr>
<td>Arc Welding</td>
<td>Metal joining process that utilizes a continuous rather than contact welding point process, in the same way as above. Again the end effector is the electrodes used to achieve the welding arc. The robot must use continuous path control, and a jointed arm robot consisting of six joints is frequently used.</td>
</tr>
<tr>
<td>Spray Coating</td>
<td>Spray coating directs a spray gun at the object to be coated. Paint or some other fluid flows through the nozzle of the spray gun, which is the end effector, and is dispersed and applied over the surface of the object. Again the robot must use continuous path control, and is typically programmed using manual lead-through. Jointed arm robots seem to be the most common anatomy for this application.</td>
</tr>
<tr>
<td>Other applications</td>
<td>Other applications include: drilling, routing, and other machining processes; grinding, wire brushing, and similar operations; waterjet cutting; and laser cutting.</td>
</tr>
</tbody>
</table>
Lecture 6

Robot programming

A robot program is a path in the space that to be followed by the manipulator, combined with peripheral actions that support the work cycle. To program a robot, specific commands are entered into the robot’s controller memory, and these actions may be performed in a number of ways. Limited sequence robot programming is carried out when limit switches and mechanical stops are set to control the end-points of its motions. A sequencing device controls the occurrence of motions, which in turn controls the movement of the joints that completes the motion cycle.

Lead-through programming

For industrial robots with digital computers as controllers, three programming methods can be distinguished. These are lead-through programming; computer-like robot programming languages; and off-line programming. Lead-through methodologies, and associated programming methods, are outlined in Table 6.1.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
</table>
| Lead-through programming | • Task is ‘taught’ to the robot by manually moving the manipulator through the required motion cycle, and simultaneously entering the program into the controller memory for playback.  
• Two methods are used for teaching: powered lead-through; and manual lead-through. |
| Motion               | To overcome the difficulties of co-coordinating individual programming with lead-through programming, two mechanical methods can be used: the world-co-ordinate system—whereby the origin and axes are defined relative to the robot base; and the tool-co-ordinate system—whereby the alignment of the axis system is defined relative to the orientation of the wrist faceplate.  
• These methods are typically used with Cartesian co-ordinate robots, and not for robots with rotational joints.  
• Robotic types with rotational joints rely on interpolation processes to gain straight line motion.  
• Two types of interpolation processes are used: straight line interpolation—where the control computer calculates the necessary points in space that the manipulator must move through to connect two points; and joint interpolation—where joints are moved simultaneously at their own constant speed such that all joints start/stop at the same time. |
Lecture 8

CNC programming

These are computer-like languages which use on-line/off-line methods of programming. The advantages of textual programming over its lead-through counterpart include:

1. The use of enhanced sensor capabilities, including the use of analogue and digital inputs
2. Improved output capabilities for controlling external equipment
3. Extended program logic, beyond lead-through capabilities
4. Advanced computation and data processing capabilities
5. Communications with other computer systems

Table: G code for Milling and Turning Operations

<table>
<thead>
<tr>
<th>G00</th>
<th>Rapid Linear Positioning</th>
<th>G55</th>
<th>Work Coordinate System 2 Selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>G01</td>
<td>Linear Feed Interpolation</td>
<td>G56</td>
<td>Work Coordinate System 3 Selection</td>
</tr>
<tr>
<td>G02</td>
<td>CW Circular Interpolation</td>
<td>G57</td>
<td>Work Coordinate System 4 Selection</td>
</tr>
<tr>
<td>G03</td>
<td>CCW Circular Interpolation</td>
<td>G58</td>
<td>Work Coordinate System 5 Selection</td>
</tr>
<tr>
<td>G04</td>
<td>Dwell</td>
<td>G59</td>
<td>Work Coordinate System 6 Selection</td>
</tr>
<tr>
<td>G07</td>
<td>Imaginary Axis Designation</td>
<td>G60</td>
<td>Single Direction Positioning</td>
</tr>
<tr>
<td>G09</td>
<td>Exact Stop</td>
<td>G61</td>
<td>Exact Stop Mode</td>
</tr>
<tr>
<td>G10</td>
<td>Offset Value Setting</td>
<td>G64</td>
<td>Cutting Mode</td>
</tr>
<tr>
<td>G17</td>
<td>XY Plane Selection</td>
<td>G65</td>
<td>Custom Macro Simple Call</td>
</tr>
<tr>
<td>G18</td>
<td>ZX Plane Selection</td>
<td>G66</td>
<td>Custom Macro Modal Call</td>
</tr>
<tr>
<td>G19</td>
<td>YZ plane Selection</td>
<td>G67</td>
<td>Custom Macro Modal Call Cancel</td>
</tr>
<tr>
<td>G20</td>
<td>Input In Inches</td>
<td>G68</td>
<td>Coordinate System Rotation On</td>
</tr>
<tr>
<td>G21</td>
<td>Input In Millimeters</td>
<td>G69</td>
<td>Coordinate System Rotation Off</td>
</tr>
<tr>
<td>G22</td>
<td>Stored Stroke Limit On</td>
<td>G73</td>
<td>Peck Drilling Cycle</td>
</tr>
<tr>
<td>G23</td>
<td>Stored Stroke Limit Off</td>
<td>G74</td>
<td>Counter Tapping Cycle</td>
</tr>
<tr>
<td>G27</td>
<td>Reference Point Return Check</td>
<td>G76</td>
<td>Fine Boring</td>
</tr>
<tr>
<td>G28</td>
<td>Return To Reference Point</td>
<td>G80</td>
<td>Canned Cycle Cancel</td>
</tr>
<tr>
<td>G29</td>
<td>Return From Reference Point</td>
<td>G81</td>
<td>Drilling Cycle, Spot Boring</td>
</tr>
<tr>
<td>G30</td>
<td>Return To 2nd, 3rd and 4th Ref. Point</td>
<td>G82</td>
<td>Drilling Cycle, Counter Boring</td>
</tr>
<tr>
<td>G31</td>
<td>Skip Cutting</td>
<td>G83</td>
<td>Peck Drilling Cycle</td>
</tr>
<tr>
<td>G33</td>
<td>Thread Cutting</td>
<td>G84</td>
<td>Tapping Cycle</td>
</tr>
<tr>
<td>G40</td>
<td>Cutter Compensation Cancel</td>
<td>G85</td>
<td>Boring Cycle</td>
</tr>
<tr>
<td>G41</td>
<td>Cutter Compensation Left</td>
<td>G86</td>
<td>Boring Cycle</td>
</tr>
<tr>
<td>G42</td>
<td>Cutter Compensation Right</td>
<td>G87</td>
<td>Back Boring Cycle</td>
</tr>
<tr>
<td>G43</td>
<td>Tool Length Compensation + Direction</td>
<td>G88</td>
<td>Boring Cycle</td>
</tr>
<tr>
<td>G44</td>
<td>Tool Length Compensation - Direction</td>
<td>G89</td>
<td>Boring Cycle</td>
</tr>
<tr>
<td>G45</td>
<td>Tool Offset Increase</td>
<td>G90</td>
<td>Absolute Programming</td>
</tr>
<tr>
<td>G46</td>
<td>Tool Offset Double</td>
<td>G91</td>
<td>Incremental Programming</td>
</tr>
<tr>
<td>G47</td>
<td>Tool Offset Double Increase</td>
<td>G92</td>
<td>Programming Of Absolute Zero</td>
</tr>
<tr>
<td>G48</td>
<td>Tool Offset Double Decrease</td>
<td>G94</td>
<td>Feed Per Minute</td>
</tr>
<tr>
<td>G49</td>
<td>Tool Length Compensation Cancel</td>
<td>G95</td>
<td>Feed Per Revolution</td>
</tr>
<tr>
<td>G50</td>
<td>Scaling Off</td>
<td>G96</td>
<td>Constant Surface Speed Control</td>
</tr>
<tr>
<td>G51</td>
<td>Scaling On</td>
<td>G97</td>
<td>Constant Surface Speed Control</td>
</tr>
<tr>
<td>G52</td>
<td>Local Coordinate System Setting</td>
<td>G98</td>
<td>Return To Initial Point In Canned Cycles</td>
</tr>
<tr>
<td>G54</td>
<td>Work Coordinate System 1 Selection</td>
<td>G99</td>
<td>Return To R Point In Canned Cycles</td>
</tr>
</tbody>
</table>
Table: M code for Milling operations

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>M00</td>
<td>Program Stop</td>
</tr>
<tr>
<td>M01</td>
<td>Optional Stop</td>
</tr>
<tr>
<td>M02</td>
<td>End of Program</td>
</tr>
<tr>
<td>M03</td>
<td>Spindle On CW</td>
</tr>
<tr>
<td>M04</td>
<td>Spindle On CCW</td>
</tr>
<tr>
<td>M05</td>
<td>Spindle Stop</td>
</tr>
<tr>
<td>M06</td>
<td>Tool Change</td>
</tr>
<tr>
<td>M07</td>
<td>Mist Coolant On</td>
</tr>
<tr>
<td>M08</td>
<td>Flood Coolant On</td>
</tr>
<tr>
<td>M09</td>
<td>Coolant Off</td>
</tr>
<tr>
<td>M19</td>
<td>Spindle Orientation On</td>
</tr>
<tr>
<td>M20</td>
<td>Spindle Orientation Off</td>
</tr>
<tr>
<td>M21</td>
<td>Tool Magazine Right</td>
</tr>
<tr>
<td>M22</td>
<td>Tool Magazine Left</td>
</tr>
<tr>
<td>M23</td>
<td>Tool Magazine Up</td>
</tr>
<tr>
<td>M24</td>
<td>Tool Magazine Down</td>
</tr>
<tr>
<td>M25</td>
<td>Tool Clamp</td>
</tr>
<tr>
<td>M26</td>
<td>Tool Unclamp</td>
</tr>
<tr>
<td>M27</td>
<td>Clutch Neutral On</td>
</tr>
<tr>
<td>M28</td>
<td>Clutch Neutral Off</td>
</tr>
<tr>
<td>M98</td>
<td>Call Sub Program</td>
</tr>
<tr>
<td>M99</td>
<td>End Sub Program</td>
</tr>
</tbody>
</table>
Figure 8.1 shows the final profile to be generated on a bar stock by using a CNC turning center.

![Figure 8.1: A component to be turned.](image)

After studying the required part geometry and features, the main program can be written as follows.

| Block 1 |  
|---------|---
| 2 | O0004  
| 3 | N10 G21  
| 4 | N20 G40 G90  
| 5 | N30 G54 X... Z...  
| 6 | N40 T0100 M42  
| 7 | N50 G96 S450 M03  
| 8 | N60 G00 G41 X72 Z0 T0101 M08  
| 9 | N70 G01 X0  
| 10 | N80 G00 Z5  
| 11 | N90 G42 X72  
| 12 | N100 G71 U1 R3  
| 13 | N110 G71 P120 Q190 U1 W1 F0.05  
| 14 | N120 G00 X0  
| 15 | N130 G01 Z0  
| 16 | N140 G03 X20 Z-20  
| 17 | N150 G01 Z-45  
| 18 | N160 X40 Z-80  
| 19 | N170 Z-105  
| 20 | N180 G02 X70 Z-120  
| 21 | N190 G01 X75  
| 22 | N200 G00 X100 Z20  
| 23 | N210 G70 P120 Q190 F0.03  
| 24 | N220 G00 G40 X100 Z20 T0100  
| 25 | N230 M09  
| 26 | N240 M30  
| 27 | %
Let us now see the meaning and significance of each block of the program.

**Block 1 to 4:** Preparatory functions and commands.

**Block 5:** In CNC turning, only two axes viz. X and Z are used. X axis is along the radius of work part, whereas Z axis is along the length of the work part. Figure 7.4.2 shows the axes system used in CNC turning centers. The program zero will be set by using G54 command. The program zero is assumed to be located at the tip of work contour as shown in Figure 8.1.

![Axes system used in CNC turning center](image)

**Figure 8.2:** Axes system used in CNC turning center

**Block 6:** In turning programming the Tool is designated by an alphabet ‘T’ and four numerals. Out of the four numerals, first two indicates the tool number and the last signifies the wear offset number. In this block the tool number 1 is selected.

**First block:**
- \( U \) = Depth of roughing cut
- \( R \) = Amount of retract from each cut

**Second block:**
- \( P \) = First block number of finishing contour
- \( Q \) = Last block number of finishing contour
- \( U \) = Stock amount for finishing on the X-axis diameter
- \( W \) = Stock left for finishing on the Z-axis
- \( F \) = Cutting feed-rate (in/rev or m/min) between P block and Q block
- \( S \) = Spindle speed (ft/min or m/min) between P block and Q block
Lecture 9

PID controllers

Introduction

Control systems for manufacturing systems can be categorized into two types. First is the sequential control where all the operations are carried out in a sequence to automate the mechanical system(s). Automated vehicle assembly line is an example of such control system. Such operations are controlled by Programmable Logic Controller (PLCs) which we have already studied in previous lecture.

In the other type of the control system, precise control over output of system is to be obtained. Therefore a continuous monitoring of such system is essential. For example there is a necessity to continuously monitor and control the fuel tank used in a Boiler based power plant. This type of control is also called modulating control. Feedback systems and Proportional-integral-derivative (PID) controllers are employed in these systems.

In general a closed loop system has several input variables and several output variables. However one or two dominant input variables are considered in designing the control system. Output variables are measured by using suitable transducer system and the feedback is sent to the controller for comparison. A block diagram of closed loop system is shown figure 9.1.

![Block Diagram of Closed Loop System](image)

Figure 9.1: A closed loop control system
There are various types of closed loop control systems being used in mechatronics. These are listed as follows.

Single Input Single Output (SISO)
Multiple Input Single Output (MISO)
Multiple Input Multiple Output (MIMO)
Single Input Multiple output (SIMO)

**PID Controller for SISO systems**

PID controller is commonly used for SISO systems. Figure 3.4.2 shows the basic blocks of a SISO system. It has single input and single output. It has a controller which controls the operation of a process based on the feedback received.

![Figure 9.2: A SISO system.](image)

**Proportional Controller (P – Controller)**

The proportional controller gives an output value that is proportional to the error value
with a gain value of \( K_p \). The proportional response can be adjusted by multiplying the error by a constant \( K_p \), called the proportional gain constant.

**Integral Controller**

In an integral controller, the manipulation equals the integral of the error over time, multiplied by a gain \( K_I \).

**Differential control**

A derivative controller uses the derivative of the error instead of the integral.

After discussing various components of controller following conclusions can be drawn.

1. Proportional Controller improves system response time. It provides high
proportional gain which results into very low rise time and thus improves the response system.

2. Integral Controller makes the system steady with error approaches zero. But Integral controller may increase instability of a system and may cause oscillations. However in Proportional system provides very low value of Integral gain resulting in very low amount of oscillations.

3. Derivative controller improves system settling time and also improves stability.
PID controllers have wide variety of applications manufacturing industry. Some of them are listed as follows.

- PID control is used in automatic car steering when it is integrated with Fuzzy Logic
- In movement detection system of modern seismometer
- In water/oil level monitoring in tanks
- Head positioning of a disk drive
- Automated inspection and quality control
- Manufacturing process control: CNC machine tools
- Chemical process control: flow control, temperature control
- Automatic control of material handling equipments
- Automatic packaging and dispatch
- To ensure safety during manufacturing operations
Lecture 10
Programmable Logic Devices

Introduction

Programmable Logic Devices (PLD) are programmable systems and are generally used in manufacturing automation to perform different control functions, according to the programs written in its memory, using low level languages of commands. There are following three types of PLDs are being employed in mechatronics systems.

1. Microprocessor
   i. It is a digital integrated circuit which carries out necessary digital functions to process the information obtained from measurement system.

2. Microcomputer
   i. It uses microprocessor as its central processing unit and contains all functions of a computer.

3. Programmable Logic Controller (PLC)
   i. It is used to control the operations of electro-mechanical devices especially in tough and hazardous industrial environments.

A typical programmable machine has basic three components as shown in Figure 5.1:

1. Processor, which processes the information collected from measurement system and takes logical decisions based on the information. Then it sends this information to actuators or output devices.

2. Memory, it stores
   a. the input data collected from sensors
   b. the programs to process the information and to take necessary decisions or actions. Program is a set of instructions written for the processor to perform a task. A group of programs is called software.
3. Input/output devices: these are used to communicate with the outside world/operator.

Figure 10.1 Components of a programmable logic device
Figure 11.1 Schematic of a CNC machine Tool

Figure 11.1 shows a schematic of a machine tool controlled by a computer. It consists of a Machine Control Unit (MCU) and machine tool itself. MCU, a computer is the brain of a CNC machine tool. It reads the part programs and controls the machine tools operations. Then it decodes the part program to provide commands and instructions to the various control loops of the machine axes of motion. The details regarding the construction and working of mechatronics based system have already been studied in last lectures.

CNC systems have a limitation. If the same NC program is used on various machine tools, then it has to be loaded separately into each machine. This is time consuming and involves repetitive tasks. For this purpose direct numerical control (DNC) system is developed. It consists of a central computer to which a group of CNC machine tools are connected via a communication network. The communication is usually carried out using a standard protocol such as TCP/IP or MAP. DNC system can be centrally monitored which is helpful when dealing with different operators, in different shifts, working on different machines.
Axes of CNC machine

In CNC machine tool, each axis of motion is equipped with a driving device to replace the handwheel of the conventional machine tool. A axis of motion is defined as an axis where relative motion between cutting tool and workpiece occurs. The primary axes of motion are referred to as the X, Y, and Z axes and form the machine tool XYZ coordinate system. Figure 11.3 shows the coordinate system and the axes of motion of a typical machine tool. Conventionally machine tools are designated by the number of axes of motion they can provide to control the tool position and orientation.
Configuration of 2-axis machine tool

If the machine tool can simultaneously control the tool along two axes, it is classified as a 2-axis machine. The tool will be parallel and independently controlled along third axis. It means that machine tool guided the cutting tool along a 2-D contour with only independent movement specified along the third axis. The Z-axis control plane is parallel to the XY plane.

References:

5. NPTEL – Mechanical – Mechatronics and Manufacturing Automation