Automation and Advanced Manufacturing

Basic Mechanical Engineering
MIE 1071

Department of Mechanical and Industrial Engineering.

Automation and its elements

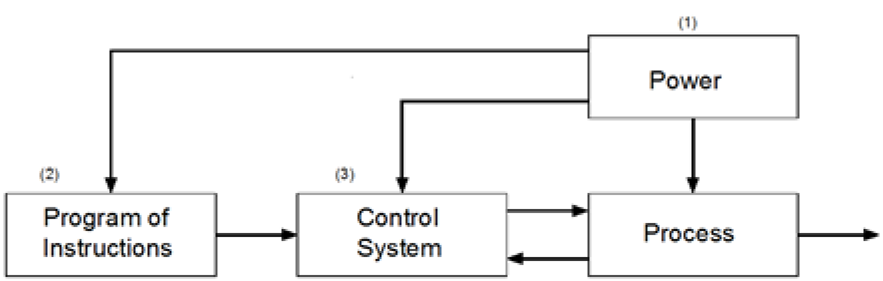
Automation can be defined as a technology concerned with the application of mechanical, electronic, and computer based systems to operate and control production. This technology includes

- Automatic machine tools to process parts
- Automatic assembly machines
- Industrial robots
- Automatic material handling and storage systems
- Automatic inspection systems for quality control
- Feedback control and computer process control
- Computer systems for planning, data collection, and decision making to support manufacturing activities

To automate a process, power is required, both to drive the process itself and to operate the program and control system.

An automated system consists of three basic elements:

1. Power to accomplish the process and operate the system
2. A program of instructions to direct the process,
3. A control system to actuate the instructions



Elements of an Automated System

Reasons for Automating

1. *To increase labour productivity.*
2. *To reduce labour cost.*
3. *To mitigate the effects of labour shortages.*

4. *To reduce or eliminate routine manual and clerical tasks.*
5. *To improve worker safety.*
6. *To improve product quality.*
7. *To reduce manufacturing lead time.*
8. *To accomplish processes that cannot be done manually.*

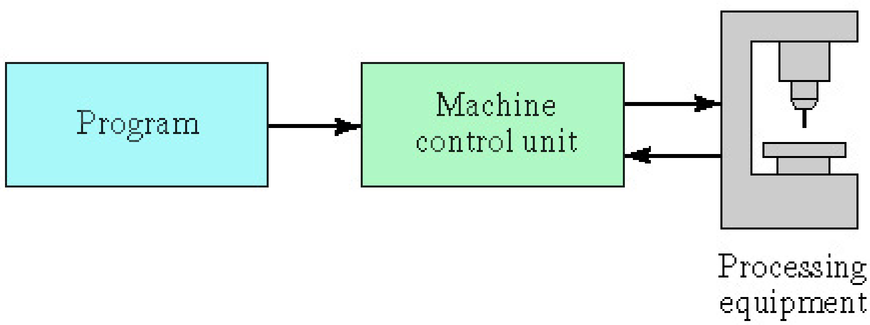
NC machines

It is a form of programmable automation, in which the process is controlled by numbers, letters and symbols.

Components of NC machines

A numerical control system consists of the following three basic components:

1. Program of instructions
2. Machine control unit
3. Processing equipment



Program of instructions:

- The program of instructions is the detailed step-by-step commands that direct the processing equipment.
- Commands refer to positions of a machine tool spindle with respect to the worktable on which part is fixture.
- Instructions include spindle speeds, cutting tools, feed rate, etc.

- The program is coded on a suitable medium for submission to the machine control unit.
- The most common medium in use has been 1-in wide punched tape.
- Magnetic disks, floppy disks, SD cards have replaced the punched tape.

Machine control unit (MCU)

MCU consists of the electronics and control hardware that read and interpret the program of instruction and convert it into mechanical actions of the machine tool or other processing equipment

Processing equipment

- The processing equipment is a component that performs useful work.
- Examples of this component include NC machine that perform machining operations.
- The processing equipment consists of the work-table and spindle as well as motors and controls needed to drive them.

Problems with Conventional NC

The problems arise in the conventional NC system are the following:

Part Programming Mistakes

- While preparing a punched tape, part programming mistakes are common.
- Mistakes can be either syntax or numerical errors, and needs three or more passes before the NC tape is correct.
- Achieving optimum sequence of processing steps is another problem especially with manual part programming

Punched Tape

- Paper tape is fragile and is susceptibility to wear and tear making it an unreliable NC component for repeated use on the shop floor.
- Durable tape materials like Mylar and aluminium help overcome this problem but are expensive.

Tape Reader

- Tape reader is known to be the least reliable hardware components of the machine.
- When a breakdown occurs on a NC machine, the maintenance personnel usually begin their search for the problem with tape reader.

Controller

- The conventional NC controller unit id hard-wired.
- This means that its control features cannot be easily altered to incorporate improvements into the unit.

Management information

- The conventional NC system cannot provide timely information on operational performance to management.
- Information may include piece counts, machine breakdowns and tool changes

Non-optimal speeds and feeds

- The function of conventional NC is to control the position of the tool relative to the work.
- There is no attempt to optimize the speeds and feeds during machining process.
- The part programmer must plan the cutting conditions conservatively which reduces productivity.

CNC Machine

Computer Numerical Control machine (CNC machine) is an NC system using a dedicated microcomputer as the machine control unit.

Thus the large hard-wired MCUs have of conventional NC have been replaced by control units based on digital computer. Hard-wired MCUs were replaced by minicomputers which were later replaced by microcomputers. Present day CNC machines are all controlled by microcomputers.

Features of CNC Control system

1. Programming and operating features
    - More than one program can be stored
    - Multiple program entry options – using computer, edit mode/MDI mode
    - Program editing at machine site
    - Offset adjustment for tool radius and length is easy
    - Adaptive control – optimizes the speed and feed during machining
    - Re-computation of axis position – using different work offset values
    - Use of canned cycle – built in routines which move the tool in predefined way, thereby reducing the length of the program. E.g.: in a VMC G81 is the canned cycle for drilling
2. Machine tool control
    - Linear interpolation
    - Circular interpolation
    - Helical interpolation
3. Diagnostic feature
    - Control start up diagnostics – checks health of CPU, I/O devices, servo controls, etc.
    - Malfunction and failure analysis – to detect the reason for malfunction done by a PLC program
    - Tool life monitoring – expected life of tool is entered. Upon reaching the expected life, a warning signal is given to take necessary actions
    - Preventive maintenance notice – low level of hydraulic oil, coolant and lubricant
    - Programming diagnostic – tool path simulation is possible, cycle time calculations are possible.

Advantages and Disadvantages of CNC machines

1. Reduced non-productive time
    - Less number of job setup as multiple operations can be done on a single machine
    - Less job setup time due to simplified fixtures

- Less tool change time
- Tool positioning time is reduced

2. Simplified fixture

   Requires simpler fixture because the positioning is done by the program rather than the fixture or jig. Some of the fixtures used on CNC systems are as follows:

   - Machine vice (machining centre)
   - Hydraulic chuck (turning centre)
   - Grid plate and grid box
   - Strap clamps, tee bolts and nuts

3. Reduced manufacturing lead time
4. Greater manufacturing flexibility
   - CNC adapts better to changes in jobs and production schedules.
5. Improved quality control – due to less rejections and lesser inspection
6. Complex geometries are possible
7. Reduced inventory
8. Engineering changes can be easily accommodated
9. Less floor space requirement

Disadvantages of CNC system

1. Higher initial investment
2. Higher maintenance cost
3. Skilled programmers are needed

Introduction to Robotics

An industrial robot is a general purpose, programmable machine which processes certain anthropomorphic characteristics. The robot can be programmed to perform some useful task. It will repeat that motion pattern again and again until reprogrammed to perform some other task. Hence robot can be used for a variety of different industrial operation like machine loading & unloading, spot welding, spray painting, etc.

Application of Robots

1. Material transfer and handling
2. Machine loading and unloading
3. Welding
4. Spray coating
5. Processing operations
6. Assembly
7. Inspection

Following are the various applications within these seven categories

MATERIAL TRANSFER & HANDLING

Material transfer applications are those in which the robot is used to move workparts from one location to another. In some cases it may also be re-orientation of parts.

Examples of material transfer robot operations

- Pick & place operation
- Palletizing & depalletizing operation
- Stacking operation
- Handling radioactive materials

Advantages

1. Heavy, complicated and delicate jobs can be easily handled
2. Worker is free from repetitive tasks
3. Reduces material transfer idle time

MACHINE LOADING AND UNLOADING

Machine loading applications are material handling operations in which the robot is required to supply a production machine with raw parts and/or to unload finished parts from the machine. In some cases the, the robot holds the part in position during processing Production operations in which robots have been successfully applied to perform the machine loading and unloading function are:

- Die casting (unloading)
- Injection moulding (unloading)

- Hot forging (holding)
- Upset forging (holding)
- Stamping press operation (holding)
- Machining operations such as turning and milling (loading and unloading)

Advantages

1. Human labour is relieved form hot and unsafe environment as in die-castings, forgings
2. Reduces machine loading and unloading time
3. Increases productivity

WELDING

The welding processes are a very important application area for industrial robots. The applications logically divide into two basic categories, spot welding and arc welding.

Spot welding is a process in which metal parts are fused together at localized points by passing a large electric current through the two parts at the point of contact. The process is implemented by means of electrodes which take the form of tongs, mounted on a large robot's wrist as the end effector.

Several types of arc welding processes can be accomplished by industrial robots, like gas metal arc welding or MIG welding and as tungsten arc welding or TIG welding

Advantages:

1. Higher productivity
2. Improved safety and quality of work
3. Greater quality of product

SPRAY COATING

Automobile and appliances industries require the application of some form of paint. Usually human workers apply this form of paint, the most common method is spray painting, which has many health hazards like fumes, mist, noise, fire hazard and possible cancer danger. For these reasons, specialized industrial robots are being used more and more frequently to perform spray painting.

Advantages:

1. Safety of operations from hazardous environment
2. Lower energy consumption
3. Less coating material usage
4. Higher productivity

PROCESSING OPERATIONS

This is a miscellaneous category in which the robot is used to perform some manufacturing process other than welding, spray painting, assembly and inspection operation. Just as welding and spray painting, the processing operation is performed by a specialized tool attached to the robot's wrist as its end effector.

Operations like drilling, boring, reboring, grinding, milling, riveting, polishing, deburring, etc.

Advantages:

1. Increased productivity
2. Reduced machining time

ASSEMBLY

Assembly operations are seen an area with big potential for robot applications, especially the batch type assembly operations. The reason for this is based on economics and the technological capabilities. Operations include parts mating, parts joining, adhesive works, crimping, etc.

Advantages

1. Higher productivity
2. Reduced rejected parts
3. Fast operations
4. Less wastage of materials

INSPECTION

Traditionally inspection function has been a very labour intensive activity. The activity is slow, tedious, and boring, and is usually performed by human beings on a sampling basis rather than by 100% inspection. Errors form an integral part of sampling inspection and 100% inspection by humans is not feasible. Use of robots overcomes both the above problems. Robots may use gauges or mechanical probes, optical sensors to perform dimensional checking.

Six Degrees of Freedom

The purpose of the robot is to perform a useful task. To accomplish the task, an end effector is attached to the end of the robots arm. The robot arm must be capable of moving the end effector through a sequence of motions. These basic motions are called as degrees of freedom. There are six basic motions, or degrees of freedom. The six basic motions consist of three arm and body motions and three wrist motions as shown in fig below.

Arm and body motions

1. Vertical traverse

Up and down motions of the arm, caused by pivoting the entire arm about a horizontal axis or moving the arm along a vertical slide

2. Radial traverse

Extension and retraction of the arm (in and out movement)

3. Rotational traverse

Rotation about the vertical axis (right or left swivel of the robot arm)

Wrist motions

4. Wrist swivel

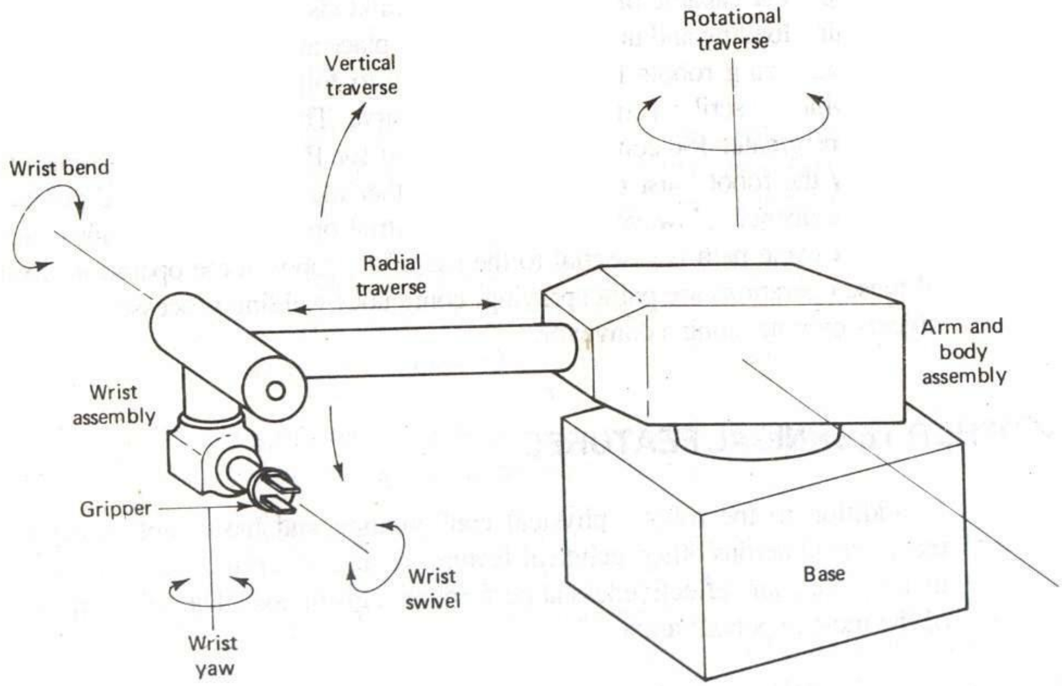
Rotation of the wrist

5. Wrist bend

Up or down movement of the wrist, which also involves a rotational movement

6. Wrist yaw

Right or left swivel of the wrist



Typical six degrees of freedom in robot motion.

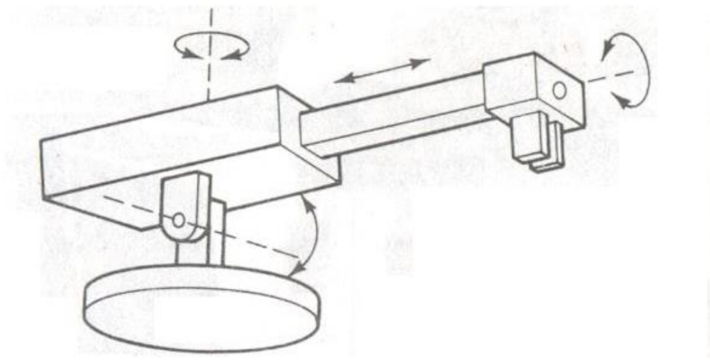
Configuration of a Robot

Industrial robots come in a variety of shape and sizes. They are capable of various arm manipulations and they possess different motion systems. Almost all present day industrial robots have one of the following four configurations:

1. Polar coordinate configuration
2. Cylindrical coordinate configuration
3. Jointed arm configuration
4. Cartesian coordinate configuration

Polar coordinate configuration

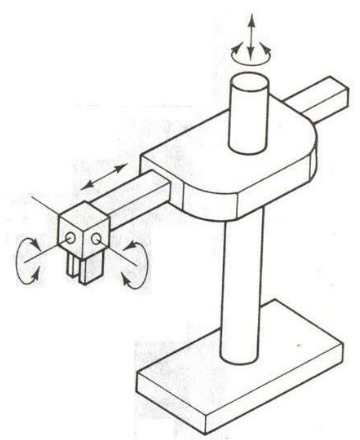
This configuration is also known as spherical coordinate configuration because the workspace within which it can move its arm is a partial sphere. As shown in fig below, the robot has a rotary base and a pivot that can be used to raise and lower a telescopic arm.



Polar coordinate configuration

Cylindrical coordinate configuration

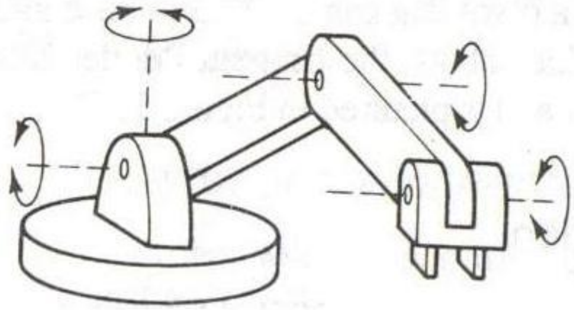
In this configuration, the robot body is a vertical column that swivels about a vertical axis. The arm consists of several orthogonal slides which allow the arm to be moved up or down and in or out with respect to the body. This is shown in fig below.



Cylindrical coordinate configuration

Jointed arm configuration

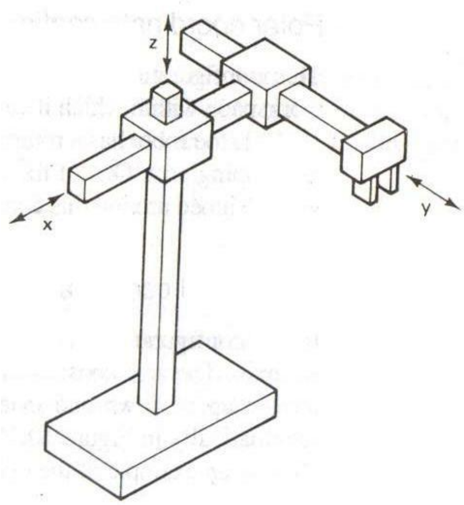
The jointed arm configuration is similar in appearance to the human arm, as shown in fig below. The arm consists of several straight members connected by joints which are analogous to the human shoulder, elbow, and wrist. The robot arm is mounted to a base which can be rotated to provide the robot with the capacity to work within a quasi-spherical space.



Jointed arm configuration

Cartesian coordinate configuration

A robot which is constructed around this configuration consists of three orthogonal slides, as shown below. The three slides are parallel to the x, y, and z axes of the cartesian coordinate system.



By appropriate movements of these slides, the robot is capable of moving its arm to any point within its three-dimensional rectangular shaped workspace

Introduction to Additive Manufacturing

Additive manufacturing is the formalized term for what used to be called rapid prototyping and what is popularly called 3D Printing. Referred to in short as AM, the basic principle of this technology is that a model, initially generated using a three-dimensional Computer-Aided Design (3D CAD) system, can be fabricated directly without the need for process planning. Although this is not in reality as simple as it first sounds, AM technology certainly significantly simplifies the process of producing complex 3D objects directly from CAD data. Other manufacturing processes require a careful and detailed analysis of the part geometry to determine things like the order in which different features can be fabricated, what tools and processes must be used, and what additional fixtures may be required to complete the part. In contrast, AM needs only some basic dimensional details and a small amount of understanding as to how the AM machine works and the materials that are used to build the part. The key to how AM works is that parts are made by adding material in layers; each layer is a thin cross-section of the part derived from the original CAD data. Obviously in the physical world, each layer must have a finite thickness to it and so the resulting part will be an approximation of the original data. The thinner each layer is, the closer the final part will be to the original. All commercialized AM machines to date use a layer-based approach, and the major ways that they differ are in the materials that can be used, how the layers are created, and how the layers are bonded to each other. Such differences will determine factors like the accuracy of the final part plus its material properties and mechanical properties. They will also determine factors like how quickly the part can be made, how much post-processing is required, the size of the AM machine used, and the overall cost of the machine and process.

Steps involved in Additive Manufacturing

AM involves a number of steps that move from the virtual CAD description to the physical resultant part. Different products will involve AM in different ways and to different degrees. Small, relatively simple products may only make use of AM for visualization models, while larger, more complex products with greater engineering content may involve AM during numerous stages and iterations throughout the development process. Furthermore, early stages of the product development process may only require rough parts, with AM being used because of the speed at which they can be fabricated. At later stages of the process, parts may require careful cleaning and post-processing (including sanding, surface preparation, and painting) before they are used, with AM being useful here because of the complexity of form that can be created without having to consider tooling.

Step 1: CAD

All AM parts must start from a software model that fully describes the external geometry. This can involve the use of almost any professional CAD solid modeling software, but the output must be a 3D solid or surface representation. Reverse engineering equipment (e.g., laser and optical scanning) can also be used to create this representation.

Step 2: Conversion to STL

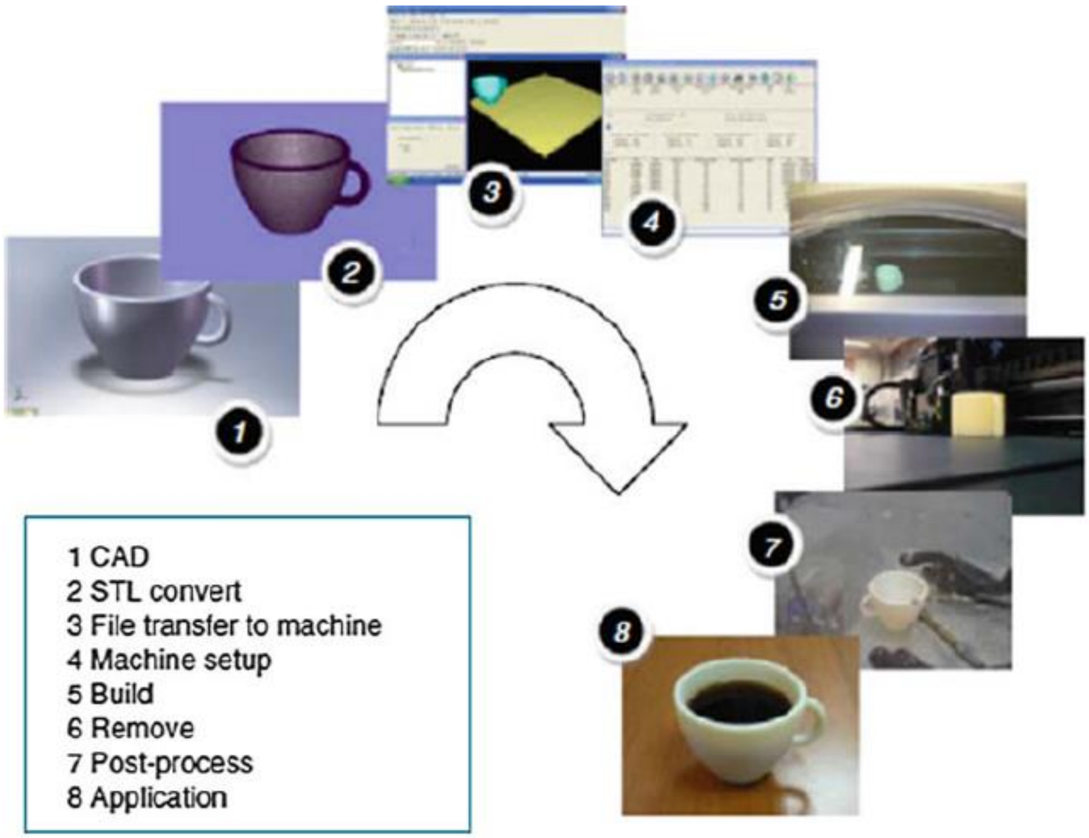
Nearly every AM machine accepts the STL file format, which has become a de facto standard, and nowadays nearly every CAD system can output such a file format. This file describes the external closed surfaces of the original CAD model and forms the basis for calculation of the slices.

Step 3: Transfer to AM Machine and STL File Manipulation

The STL file describing the part must be transferred to the AM machine. Here, there may be some general manipulation of the file so that it is the correct size, position, and orientation for building.

Step 4: Machine Setup

The AM machine must be properly set up prior to the build process. Such settings would relate to the build parameters like the material constraints, energy source, layer thickness, timings, etc.



Step 5: Build

Building the part is mainly an automated process and the machine can largely carry on without supervision. Only superficial monitoring of the machine needs to take place at this time to ensure no errors have taken place like running out of material, power or software glitches, etc.

Step 6: Removal

Once the AM machine has completed the build, the parts must be removed. This may require interaction with the machine, which may have safety interlocks to ensure for example that the operating temperatures are sufficiently low or that there are no actively moving parts.

Step 7: Post-processing

Once removed from the machine, parts may require an amount of additional cleaning up before they are ready for use. Parts may be weak at this stage or they may have supporting features that must be removed. This therefore often requires time and careful, experienced manual manipulation.

Step 8: Application

Parts may now be ready to be used. However, they may also require additional treatment before they are acceptable for use. For example, they may require priming and painting to give an acceptable surface texture and finish. Treatments may be laborious and lengthy if the finishing requirements are very demanding. They may also be required to be assembled together with other mechanical or electronic components to form a final model or product.